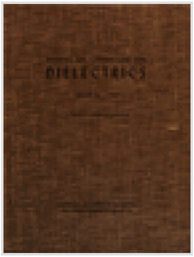

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FOREWORD

This year's edition of the Digest has been drastically changed in format but not in coverage. Instead of the continuous text of previous years, each reference is listed individually with a separate digest. The change affects all chapters except "Tables of Dielectric Constants, Dipole Moments, and Dielectric Relaxation Times," which remains unaltered from previous years.

The main purpose of the change was to reduce the amount of work required from the authors and their companies or institutions who so generously donate valuable time to creating this Digest.

Another purpose of the change was to reduce the typing and printing cost by typing the full reference once only and omitting the bibliographies at the ends of the chapters. This purpose has not been achieved because the authors have taken the opportunity of the new format to increase the amount of information for each entry. Consequently, the Digest is larger than ever. While the added information certainly is valuable, the added costs may force future editors to limit the size of the Digest by other means.

The outstanding cooperation from Mrs. Marian Miller and Mr. D. W. Thornhill in handling the typing and publishing is gratefully acknowledged. A special acknowledgment is made to Dr. D. W. Swan, Vice Chairman of the Digest Committee, who also authored the chapter on dielectric breakdown.

A. M. Sletten, Chairman
Committee on Digest of Literature
on Dielectrics

Pittsburgh, Pennsylvania
September 14, 1965

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CHAPTER VII

CHAPTER I

INSTRUMENTATION AND MEASUREMENTS

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I. Introduction

The growth of science both stimulates and requires a variety of accurate measurements. An important influence toward more careful measurements has been the increased magnitude of such efforts as space probes or modern ocean cables.

Dielectric and insulation measurements are based on dimensional gauging and electrical observations. Electromagnetic theory may then permit calculation of the material characteristics. A review of measurement of the electrical characteristics of materials therefore includes progress in sub-measurements and standards, in appropriate instrumentation, and in the electromagnetic concepts, as well as in dielectric and insulation measurements per se. The environment must also be measured and reported. Important contributions to measurement science include convenient measuring systems, new concepts, new commercial instruments and components, sophisticated use of old measuring systems, improved error analysis of systems, computer calculations that permit more detailed theory to be used, and techniques of statistics or quality control. The literature was examined with an eye for these types of advances.

With this explanation of guiding principles, we now point to the digest below. The outline of categories in the bibliography is new. The main subjects are general information, systems, electromagnetic theory, sub-measurements, and finally dielectric and insulation measurements of materials. In addition some cross references between categories are indicated. A separation based on radio frequency is partially observed but is not emphasized. Noise measurements per se were omitted, but such items as a lock-in amplifier, for low noise, may appear. Ordinary frequency measurements were omitted as being solved by commercial counters.

The length of a digest indicates mostly what information is neccessary to give the scope of a paper rather than the importance of a paper.

Laboratories

A discernable trend is the increasing number of standards laboratories and the inclusion of dielectric or insulation tests in their capabilities. The NBS Precision Measurements Seminars for the first time (in December, 1964) included sessions on standards and measurements for radio magnetic and dielectric materials. Other seminars included impedance and power standards. A review[1] gives the names of 60 electrical standards laboratories.

Reviews on Measurements and Systems

An URSI National Committee Report[1] of Commission I, Radio Measurement Methods, contains high caliber reviews on various measurements. The biannual conferences on electromagnetic measurements[3,4] contain important contributions. (Two conferences are referenced due to certain publication delays). The theory and practice of microwave measurements is covered in depth[5] including dielectric constant and breakdown.

An interesting approach to measurements is taken in a recent book[7], which attempts to set out the central features of measurement engineering as a distinct discipline. Characteristics that are common to all measurements are emphasized; it is called a unified approach to measurements[8].

Statistics

Statistical techniques should be used more[3]. A comprehensive book[19] on the analysis of test data and design of measuring schemes is available. Eisenhart has emphasized[2] the use of a "control chart," which is simply a record of repeated determinations of a property of a supposedly stable specimen, as a way of validating and investigating accurate measurements.

Advanced Sub-Measurements

Probably the most important components for accurate dielectric measurements are the accurate ratio divider at low frequencies and the accurate piston or other attenuator at rf and microwave frequencies.

The convenience and absolute accuracy of the inductive voltage divider has brought about a new generation of accurate dielectric measurements using two fluid immersion. Papers on the inductive, or ratio divider continue to appear[82,101,121-126].

A direct coaxial attenuator of high performance, equalling that of the rotating vane waveguide type, has not appeared. It is therefore customary in accurate coaxial systems to use either waveguide below-cutoff piston attenuators or highly precise power and voltage measurements. Papers on piston attenuation standards and calibration continue to appear[99,100]. An application of the piston attenuator to cavity magnetic measurements was discussed[102]. Power and voltage measurements, either of high accuracy or high relative precision, are possible[79,80,84]. In fact there are at least three insertion-loss test sets offered commercially that aim at thousandths of a db precision. In addition some coaxial attenuators are available, working on a strip-line variable directional coupler principle.

An important development is the high precision low VSWR coaxial connector. A large committee on the subject is active[3]. Two commercial connectors, one from the USA and one from Europe, are being used and have enhanced the convenience and accuracy of dielectric measurements. A so-called laboratory precision connector of still lower VSWR is in use at NBS, Boulder.

Environment

The environment, and especially the surface condition created by the environment, has a strong influence on the electrical tests of materials. A salt spray test was reported[232]. A committee on dielectric properties of materials in simulated space environments and cryogenic conditions, ASTM Committee D-9 Sub IV, was activated. A test report under space environment conditions exists[241]. The effects of oxygen, temperature, and radiation are not additive[140].

Dielectric Constant

The field of dielectric measurements was advanced in terms of accuracy and extreme environments. Dielectric standards were discussed[4], and standard specimens are now available[3]. Comparison of ϵ' measurements at three National Standards Laboratories showed good agreement[151]. There was, however, need for improvement either in the accuracy of loss measurement or the control of surface contamination as an influence on the effective dielectric loss. Accurate high temperature methods were demonstrated[179]. Standard specimens were used as transfer standards[155,156].

It seemed to us that the separation of surface conductance loss and volume loss was not receiving the attention it deserved, judging from the literature reviewed. Properties of glass surfaces[165] are, of course, well known. Surface conductance of semiconductors versus atmosphere was investigated[214].

The art of nondestructive testing is emerging more clearly as a distinct field. Dielectric tests have been used for monitoring of conditions[171,168] and detecting material inhomogeneity[177]. Breakdown also may be nondestructive[222,223]. It seems probable that nondestructive surface and volume dielectric testing will grow in importance.

An important influence arises from the push of millimeter waves and infrared waves into the intervening gap between them. Thus dielectric measurements extend into the infrared and must blend into the usual refractive index of optics. Tensor and nonlinear dielectric properties are often the main interest. The literature is extensive; our references are limited to a few examples[248-250]. Ellipsometry[242] techniques may be duplicated with microwaves[246]. Infrared techniques are discussed in a book[247]. A selected review on lasers is available[1].

The time domain reflectometer[119,120] is a rather new method of measuring impedance. It has not been investigated for dielectric measurements.

II. Reviews, Compilations, and General Considerations on Measurements

A. Reviews and Compilations

1. URSI National Committee Report, J. Research, Radio Science, NBS 68D, 523-46, 1964.
Contains 8 papers by experts in the field of radio measurements and standards: Mockler, frequency and time; Engen and Larsen, rf and microwave power; Beatty, attenuation, impedance and phase angle; Selby, pulsed and cw voltage and current; Mumford, noise; Fellers, mm waves; Bender, laser measurement of distance; White, calibration laboratories and measurement standards. Contains thorough and mature reviews of the subject with very well selected bibliographies up to mid 1963.

2. National Bureau of Standards, Misc. Publ. No. 248, 16, Aug. 1963.
Gives proceedings of the "1962 Standards Laboratory Conference." Contains some 36 papers and reports. Nine papers on NBS standards and calibration services for industry, including ϵ^* and magnetic calibrations. Four on precision and error of calibration, including a thorough review by Eisenhart. Same as J. Research, NBS 67C, 161-87, 1963. Three on corporate standards laboratories, two on comparisons between laboratories, eight on training of personnel, and five on work planning.

Note: ϵ^* is used to represent dielectric constant and loss.

3. CPEM (Conf. on Precision EM Meas.) IEEE Trans. on Instrumentation and Meas. *IM-13*, Dec. 1964.
Contains significant papers on electrical measurements. Three papers on ϵ^* measurements are individually digested below (Nos. 151, 152, and 189). Based on prepublication abstracts given in IEEE Spectrum, April 1965, the following papers are noted very briefly, giving only the name of the first author:

Crow, E. L., Statistical construction of a single standard from several standards;

Thompson, A. M., bridge methods of three terminal admittances;

Petersons, O., self balancing high voltage capacitance bridge; measures corona loss on a transmission line;

Karoli, A. R., standard cell voltage is maximum at 3°C, which is maintained with thermoelectric cooler;

Hill, J. J., calibration of dc resistance standards;

Cutkosky, R. D., audio direct reading ratio sets compare admittances with accuracies as high as 1 in 10^9;

Weill, V., performance of coaxial connectors;

Harris, I. A., hf and rf impedance standards using air spaced coaxial lines;

Beatty, R. W., errors of attenuators from connectors and adaptors;

Fossum, D. E., report of committee on precision coaxial connectors;

Weinschel, B. O., precision coaxial VSWR measurements by coupled sliding load;

Bichara, M. R. E., measures semiconductor.

4. ICPEM, International Conf. on Precision EM Meas., IRE Trans. on Instrumentation, *I-11*, 312 pages, Dec. 1962.
Contains 45 papers and 11 abstracts on precision measurements. Particularly pertinent are: Hill, precision audio current transformer; Richman, peak to dc comparator, audio; McKnight, direct reading standard voltage divider; Youden, uncertainties of calibration; Snowden, bimodal cavity; Bussey, dielectric standards measurements; Beers, voltage measurement by the Stark effect; Barlow, microwave power; Leavenworth, Hall effect power measurement; Denney, Gc pulse power; Hudson, rf peak pulse power; James, Gc attenuation standard; Clark, Gc attenuation standard; White, Gc pulse power by electric wave; Sparks, phase measurement of rf pulses.

5. Sucher, M. and Fox, J., *Handbook of Microwave Measurements*, 3rd ed. completely revised, Vol. I, II, and III (1963) Interscience (John Wiley) New York, London.
Covers all aspects of microwave measurement, plus ϵ^*, dielectric breakdown, and ferrite materials.

6. Anderson, P. C., *Dielectrics*, Reinhold Publishing Corp., New York, 1964.
This book includes a brief chapter summarizing the conventional methods of measuring ϵ^* at various frequencies.

Note: ϵ^* is used to represent dielectric constant and loss.

B. General

7. Stein, P. K., Measurement Engineering, Vol. I, Basic Principles, Stein Engineering Services Inc., Phoenix, Arizona, 1964.
A unified approach to measurements. Generalizes by considering the inputs (energies) going into a measuring device (transducer) and the output results, and considers how sub-measurements combine to form a system.

8. Stein, P. K., Instr. Soc. Amer., 19th Internat. Conf., Oct. 12-15, 1964. Preprint ISA-11.1-4-64.
An outline of the idea that one may investigate in a general way how various transducers combine to make a measuring system.

9. Fisher, F. A., Nachrtech. Z. 17, 388-92, 1964. (German).
This paper reviews general laws governing electromechanical transducers.

10. Delicath, R. C. and Abeyta, M., 19th Annual ISA Conf. Proc. 19, Pt. 1, 1964.
Describes the development of an industrial standards laboratory, the services now provided, and those which may need to be added.

11. Engineering Div., Radio Standards Lab., NBS, Boulder, Colo., IEEE Trans. on Microwave Theory and Techniques MTT-12, 480-3, 572-4, 623-4, 1964.
Announces calibration services for power, noise, and rf calorimeters, various attenuators, and field strength, and reflection coefficient, and immittance.

12. Harris, F. K., 19th Annual ISA Conf. Proc. 19, Pt. 1, 1964.
The author reviews the history and the present status of the units of electrical measurement. He discusses the differences between the formal MKSA system of units and the practical measuring system of the United States.

13. Oason, W. E., Lexicon of International and National Units, Elsevier Publishing Co., Amsterdam, 1964.
This volume indicates the meaning and value of units of measurement used in scientific and technical work throughout the world.

14. ASTM Metric Practice Guide, American Society for Testing and Materials, Philadelphia, 1964.
Conversion factors are provided for expressing the results of measurements made in units commonly employed in the United States at the present time in units of the Systeme International.

15. Remich, J. E., Ed., Electronic Precision Measurement Techniques and Experiments, Prentic Hall, Englewood Cliffs, N. J., 1964.
Discusses measurements starting from the national standards, and a description of dc, ac, and microwave electronic instruments and measurements.

16. Himmel, H., Harwood, J. J., and Harris, W. J., Jr., Eds., "Perspectives in Materials" National Academy of Sciences, Washington, D. C., 1963.
Gives a very mature review of the present knowledge or lack of it regarding electric, magnetic, optical, thermal and microscopic structure of materials, especially crystals. Especially pertinent is a chapter on instrumentation which reviews X-ray, high temperature, pressure, magnetic fields, ultrasonic frequency, intensity stress-wave environment and tests.

17. Magid, M., Electro-technology 74, 67-88, Oct. 1964.
Good survey of VHF measurements technique.

18. Gray, D. A., 19th Annual ISA Conf. Proc. 19, Pt. 1, 1964.
The author gives a simplified treatment of the PIN diode as a precision microwave component. He suggests its use as a modulator for power levelling, pulse switching, amplitude modulation, and programmable attenuator.

C. Statistics

19. Natrella, M. G., Experimental Statistics (NBS Handbook 91) Govt. Printing Office, Washington, D. C., 1963.
The statistical treatment of experimental data is covered thoroughly in 23 chapters. It is intended as a guide for ready reference in the planning and interpretation of experiments and tests. Contains many useful statistical tables.

20. Moon, W. D., IEEE Trans. Aerospace AS-2, 1161-5, 1964.
This paper reviews basic ideas concerning measurement errors and their statistical treatment. There is a short bibliography.

See also references 2, 3, 4, and 151.

III. Instrumentation

A. General

21. Morrison, C. F., Generalized Instrumentation for Research and Teaching, Washington State University, Pullman, Washington, 1964.
This report is a primer in the use of operational amplifiers to synthesize electronic instruments.

22. Bleuler, E. and Haxby, R. O., Electronic Methods, Academic Press, New York, 1964.
This is volume 2 of the Methods of Experimental Physics series. Electronic methods is a vast field which is here summarized by 28 contributing authors in 839 pages.

23. 19th Annual ISA Conference Proceedings, Vol. 19, 1964 is published in four parts by the Instrument Society of America.
Part I Standards Laboratories and Measurement Standards, Part II Physical and Mechanical Measurement Instrumentation, Part III Advances in Instrumentation, and Part IV Applications in Industry and Science. Some of the papers have been listed separately.

24. Mayo-Wells, J. F., 19th Annual ISA Conf. Proc. 19, Pt. 1, 1964.
This paper describes the Instrumentation Literature Reference File at the National Bureau of Standards and recommends its use as a means of access to NBS as a measurements information center.

25. Wilson, J. P., 19th Annual ISA Conf. Proc. 19, Pt. 1, 1964.
Discusses methods of calibrating rf signal generators. Mostly deals with calibration of output level, other calibrations being treated briefly.

26. Wolcott, H. O. and Pulsiper, L. C., 19th Annual ISA Conf. Proc. 19, Pt. 1, 1964.
Description of the design of an ac source for instrument calibration which has good amplitude stability.

27. Minnor, E., ISA Transducer Compendium, Plenum Press, New York, 1964.
Commercial performance data on 1250 different model series of transducers based on 5000 questionaires. Covers dimensions, temperature, pressure, etc.

28. Scherago, E. J., (Compiler) Science 146A, 9-114, No. 3647A, Nov., 1964.
Directory of commercial scientific instruments including bridges for capacity, conductivity and impedance, dielectric constant apparatus and dielectric measuring instruments, and all instruments for electrical measurements and environmental conditions.

29. Fellers, R. G., J. Research NBS 68D, 538-40, 1964. This is a part of the URSI National Committee Report, XIV General Assembly, Tokyo, Sept. 1963.
A Review of developments in millimeter and sub-millimeter wave measurements including some dielectric measurements.

30. Wentworth, F. L., Dozier, J. W., and Rodgers, J. D., Microwave J. 7, 69-75, No. 6, 1964.
Survey of millimeter wave harmonic generators, mixers and detectors and some results.

31. Mortenson, K. E., Microwave J. 7, 49-57, No. 5, 1964.
Surveys semiconductors for microwave switching and phase or amplitude control.

32. King, A. P., Microwave J. 7, 102-6, No. 3, 1964.
Survey article entitled "Status of Low Loss Waveguide and Components at Millimeter Wavelengths."

33. Meredith, R., Warner, F. L., Davis, W. V., and Clarke, J. L., Proc. IEE 111, 241-56, 1964.
Comprehensive treatment of mm wave radiometer for taking temperature of a plasma.

34. De Ronde, F. C., IEEE Trans. on Microwave Theory and Tech., MTT-12, 112-17, 1964.
Wall current detector in waveguide gives very broad band flat detection, though of lower sensitivity.

35. Baier, O. and Elbel, F., Ann. Phys. 13, 330-3, 1964. (German).
Polyamid belt for van de Graff machine gives short circuit current up to 12 ma.

36. Cunningham, R. G., J. Appl. Phys. 35, 2332-37, 1964.
Describes apparatus designed to measure the charge developed on a dielectric belt as it slips against a roller. Belt speed, tension, rate of slip, and angle of wrap are all adjustable.

See also reference 3.

B. Electronics

37. Herrmann, K. H. and Shonborn, W., Exper. Tech. Phys. 12, 65-9, 1964. (German).
Phase sensitive detector circuits having 1/3 cps bandwidth at 280 cps using semiconductors.

38. Faulkner, E. A. and Stannett, R. H. O., Electronic Eng. 36, 159-161, 1964.
General purpose phase sensitive vacuum tube detector without transformers.

39. Spencer, T., Electronic Eng. 36, 315-21, 1964.
Design of transistorized twin-T amplifier.

40. Butler, F., Wireless World 70, 318-21, 1964.
Construction details are given for a transistor oscillator and a tuned amplifier suitable for incorporation in an impedance measuring bridge. These units are compact, separately shielded, and battery powered.

41. Dutta Gupta, R. R., Indian J. Physics 38, 250-64, 1964.
This paper describes an integrator-type sawtooth-wave generator with adjustable feedback. It includes the equations for this and for simple sawtooth-wave generators.

42. Staudte, H. G., Nachrichtentechnik 14, 395-7, 1964. (German).
This article is a discussion of the frequency stability of transistorized Wien-bridge oscillators.

43. Shishatskii, A. V. and Zhizhin, I. P., Pribory i Tekhn. Eksperim. No. 1, 205-6, 1964. (Russian). Translation: Instr. Exptl. Tech. (USSR) 220-31, 1964.
A circuit is given for a generator of rectangular pulses up to 25 kv with a duration between 20 and 500 microseconds. A single pulse is generated each time the switch is operated.

44. Max, J. and Chevalier, H., J. Phys. 25, 90A-94A, 1964. (French).
Converts galvanometer to very sensitive voltage amplifier, $\approx 10^{-8}$ volt, of high stability.

45. Erdman, R. J. and Praglin, J., 19th Annual ISA Conf. Proc. 19, Pt. 1, 1964.
The authors discuss the design and use of an electronic dc null detector capable of detecting signals below one nanovolt with a drift of 10 nanovolts in 24 hours.

46. Dauphinee, T. M., 19th Annual ISA Conf. Proc. 19, Pt. 1, 1964.
The author treats the design of contact modulators and their application in a variety of laboratory measurements.

47. Pacak, M., Electron. Eng. 36, 550-3, 1964.
A description of an electronic voltage or current stabilizer with stability and setting precision of 0.1% or better.

48. Jones, D. L., Electron. Eng. 36, 820-3, 1964. (French).
A description of a simple spectrometer for use at audio and sub-audio frequencies.

49. Martinot, H. and Baudet, J., L'Onde Electrique 44, 1064-69, 1964. (French).
The authors describe a signal generator for dielectric measurements at very low frequencies. Both sinusoidal and triangular waveforms are developed with periods between 10 and 16000 seconds at less than .5% distortion. They also describe a low distortion amplifier with a stable zero level to raise the output of the generator to ±1500 volts.

50. Russell, R. D., Ostic, R. G., and Stacey, J. S., J. Sci. Instr. 41, 487, 1964.
A circuit is given for a simple electrometer preamplifier with noise and drift less than 10^{-14} ampere through a 10^{11} ohm input resistor.

See also references 87, 133, 134, and 208.

IV. Electromagnetic Theory and Analysis

51. Jones, D. S., The Theory of Electromagnetism, The Macmillan Co., New York, 1964.
Gives a systematic advanced development of the dynamic theory and treats methods for solving many difficult modern advanced problems.

52. Argence, E. and Kahan, Th., Theorie de Guides et Cavites Electromagnetiques, Dunod, Paris, 1964. (French).
Surveys theory, approximation methods, and applications to physical measurements.

53. East, B. B. and Westphal, W. B., Technical Report 189, Laboratory for Insulation Research, MIT, 1964.
Discusses the behavior of ϵ^* vs frequency in terms of equivalent circuits.

54. Ku, H. Y. and Ullman, F. G., J. Appl. Phys. 35, 265-67, 1964.
The effect of the potential distribution in the metal electrodes on the measured capacitance is calculated.

55. Frenkel, L., J. Res. NBS 68A, 185-8, 1964.
Deals with the general theory of measuring dielectric loss of a thin sample with a parallel plate capacitor when the sample has a non-zero surface conductivity. Airgaps between the sample faces and the electrodes are included.

56. Waldron, R. A., IEEE Trans. Microwave Theory Tech. MTT-12 (1), 123-31, 1964.
Theory and curves are given for stripline cavities that measure dielectric constant and loss between 100 Mc and 2000 Mc. See also Marconi Rev. 27, 30-42, 1964.

57. Boudouris, G., J. Phys. (Paris) 25, 119A-127A, 1964. (French).
Equations are developed for spherical TE_{101} and TM_{101} microwave cavities with a view to their use in measuring small spherical samples of dielectric or magnetic material by the cavity perturbation method.

Note: ϵ^* is used to represent dielectric constant and loss.

58. Paris, D. T., IEEE Trans. Microwave Theory Tech. MTT-12(2), 251-2, 1964. Notes necessity of using complex frequency in Horner's cavity method if loss is high, which is well known, same journal, MTT-6, 72-6, 1958.

59. Roussy, G., Ann. des Telecommunications 19, 121-4, 1964. (French). The equations for calculating ϵ^* are given for an axial rod sample in a perfect cylinder cavity resonator.

60. Gunn, M. W., Proc. IEEE 52, 185, 1964. This letter gives a transcendental equation for H_{10} mode propagation in inhomogeneously filled waveguide. It gives greater accuracy than the single-mode approximation, when measuring ϵ^* of semiconductors.

61. Holmes, D. A. and Feucht, D. L., Proc. IEEE 52, 100, 1964. This letter suggests the solution of the problem discussed by Gunn above, by means of a Rayleight-Ritz variational technique.

62. Champlin, K. S., Proc. IEEE 52, 1061-2, 1964. Reviews the comments of Holmes and Feucht and of Gunn on the work of Nag, Roy, and Chatterji on the microwave dielectric constant of semiconductors and points out two criteria for accurate measurements when a thin slab sample is placed in the center of a rectangular waveguide.

See also references 137, 192, 198, and 245.

V. Sub-measurements

A. Standards

63. Ross, G. S. and Frolen, L. J., J. Research NBS 67A, 607-14, 1963. Measurement of the dielectric constant of a partially frozen standard reference material and its correlation with the temperature is used to infer the purity of the substance. The sensitivity of this method also suggests the possibility of building a thermostat with an instability below 0.0001°C.

64. Dunn, A. F., Canadian J. Phys. 42, 53-69, 1964. This paper describes the absolute determination of capacitance by the National Research Council of Canada, including standard capacitors, bridges, the establishment of 10:1 capacitance ratios, and a primary standard of capacitance. Discusses bridges and ratio dividers.

65. Kanno, M., Canadian J. Phys. 42, 1508-21, 1964. This paper describes a transportable standard capacitor of 1 pf or less. This unit shows a stability of 1 ppm (part per million) for at least six months and 1 ppm after being dropped from a height of 10 cm. Its temperature coefficient is less than 3 ppm per degree C and its variation with voltages from 10 to 100 v is also less than 1 ppm.

Note: ϵ^* is used to represent dielectric constant and loss.

66. Aida, Y., Acta IMEKO, Vol. III, 165-78, 1964.
Theoretical and experimental research on an electrodynamic ammeter to establish an accurate absolute standard of current at high frequency.

67. Eicke, W. G., Jr., ISA Trans. 3, 93-9, 1964.
This paper summarizes the operating characteristics of temperature compensated zener diodes with references to more detailed literature. These diodes are used as standards of electro-motive force.

68. Cutkosky, R. D., IEEE Trans. Communications Electronics 70, 19-22, 1964.
This paper treats the theory of four-terminal impedance standards. The general treatment includes the four-terminal resistor at one limit and the three-terminal capacitor at another limit.

69. Sanderson, A. E., 19th Ann. ISA Conf. Proc. 19, Pt. 1, 1964.
Impedance calibrations of coaxial one and two port devices using calculable coaxial transmission lines as standards. Errors are below 0.1%.

70. Weinschel, B. O., Microwave J. 7, 47-50, 1964.
Reviews available information on the use of air filled coaxial lines as microwave impedance standards.

See also reference 71.

B. Capacitance, Inductance, and Resistance

71. Rayner, G. H. and Ford, L. H., J. Sci. Instr. 41, 149-52, 1964.
Clamped mica capacitance standards were found to increase exponentially in capacitance with a time constant of about 10 years. This aging could be hastened, and the ultimate stability improved by aging the standards at 10°C about the ambient temperature. For best stability, such standards need protection from rapid or large changes in temperature.

72. Cutkosky, R. D., J. Research NBS 68C, 305-7, 1964.
Presents a theoretical discussion of the dependence of capacitance upon electrode temperature in air dielectric capacitors and a successful design for a 5 pf capacitor which is insensitive to fast and slow temperature changes. Such compensation is best suited to capacitors of less than 10 pf.

73. Bailey, D. F., Wireless World 70, 204-7, 1964.
Construction details are given for a direct-reading capacitance meter with a linear scale. Its error is ±3% for capacitances between 300 pf and 0.1 µf. The range may be extended with some increase in error.

74. Hurst, S. L., Electron. Eng. 36, 596-99, 1964.
A simple circuit measures capacitance from .001 µf to 10 µf with digital presentation. The accuracy is ±2% and is better over smaller ranges.

75. Sauer, H. A. and Shirk, W. H., IEEE Trans. Commun. Electronics 71, 131-6, 1964.
The authors describe a dc Wheatstone bridge for the measurement of resistances greater than 10^{10} ohms. An equivalent Y is used to replace two of the bridge arms, permitting the use of precision wire-wound resistors of 1 MΩ or less in construction of the instrument.

76. Ripper, L., Acta IMEKO, Vol. III, 277-90, 1964. (German).
A system for accurate measurement of large resistance, up to 10^{16} Ω.

77. Skov, C. E. and Pearlstein, E., Rev. Sci. Instr. 35, 962-4, 1964.
A method is given for measuring deviations from Ohm's law of one part in 10^8 at impedance levels of 10^6 to 10^9 ohms.

78. Gunn, R., Rev. Sci. Instr. 35, 867-8, 1964.
A device for producing transportable free electrical charges of 0.01 to 10 esu of either sign is described. It may be used to calibrate Faraday cage electrometers and other electrostatic instruments.

See also references 3, 54, 64, and 88.

C. Voltage, Current, and Power

79. Selby, M. C., J. Research NBS 68D, 533-6, 1964.
Surveys U. S. work on measurements of rf voltage and current, including pulsed, cw, small and large quantities.

80. Engen, G. F. and Larsen, N. T., J. Research NBS 68D, 527-8, 1964.
Surveys rf and microwave power measurements work of the U. S. for 1960-63.

81. Karoli, A. R. and Nelson, R. E., 19th Ann. ISA Conf. Proc. 19, Pt. 1, 1964.
This paper suggests the maintenance of saturated standard cells at 3°C to minimize their sensitivity to residual temperature fluctuations. Tests with a thermoelectric thermostat show a voltage reference stability of 1 ppm.

82. Milleu, A., Stoica, A., and Gruia, N., Acta IMEKO Vol. III, 263-67, 1964.
Basic paper in the developing area of current ratio measurement.

83. Selby, M. C., J. Research NBS 68D, 533-8, 1964. This is a part of the URSI National Committee Report, XIV General Assembly, Tokyo, Sept. 1963.
A review of pulsed voltage and current measurements.

84. Selby, M. C., 19th Ann. ISA Conf. Proc. 19, Pt. 1, 1964.
Replacement of one of the bolometers in a series-parallel rf voltage and power measuring bridge by a resistor which is not temperature sensitive permits an increase in the accuracy of measurement. Estimates that an error of 0.1% should now be realizable at frequencies of several hundred megacycles.

85. Edgerton, A. K., 19th Ann. ISA Conf. Proc. 19, Pt. 1, 1964.
Discusses the extension of voltage measuring techniques into the frequency range 20 cps to 0.002 cps. A sine wave generator for this part of the spectrum is also described.

86. Ambrozy, A., Acta IMEKO Vol. III, 347-59, 1964.
Method for measuring voltage of very low frequency sinusoids by gated rectifiers to charge and discharge a capacitor.

87. Crovini, L. and Ruffino, G., Acta IMEKO 11, 447-62, 1964.
A high stability voltage generator with semiconductor techniques to replace standard cells of precision potentiometer.

88. Yeager, J. R. and Praglin, J., 19th Ann. ISA Conf. Proc. 19, Pt. 1, 1964.
This paper discusses the measurement of currents as small as 10^{-12} amperes, with an error of 0.25% or less, by electrometer techniques. It includes information on the calibration of high-megohm resistors and on the precautions necessary for accuracy in electrometer measurements.

89. Dimeff, J. and Lane, J. W., Rev. Sci. Instr. 35, 666-8, 1964.
Preliminary results indicate that a vibrating membrane electrometer should be capable of measuring currents below 10^{-17} amperes.

90. Aizenshtein, A. I., Pribory i Tekhnika Eksperimenta, No. 1, 132-35, 1964. (Russian). Translation: Instruments and Experimental Techniques 137-40, 1964.
A design is given for a capacitive high voltage divider and an amplifier suitable for coupling it to an oscilloscope. Its input will accept voltages as high as 110 kv and its frequency response is from 25 cps to 100 kc.

91. Hand, B. P., 19th Ann. ISA Conf. Proc. 19, Pt. 1, 1964.
An instrument is described which permits rapid comparison of the efficiency of two bolometer mounts.

92. Engen, G. F., J. Research NBS 68C, 7-24, 1964.
Reflectometer type power meter determines power to a load of arbitrary impedance.

93. Evendorff, S., 19th Ann. ISA Conf. Proc. 19, Pt. 1, 1964.
Reviews several techniques of microwave peak pulse power measurement: average power measurement, baretter integration - differentiation, notch wattmeter, crystal detector - video chopper, and sampling comparison using crystal switches.

See also references 1, 3, 4, 11, 45, 56, 57, 59, and 66.

D. High Voltage and Current

94. Witt, W., Z. Angew.Phys. 17, 369-74, 1964. (German).
50 kv dc voltage source stabilized to 1 part in 10^{8} per day by feedback to standard cell.

95. Witt, W., Z. Angew.Phys. 17, 364-9, 1964. (German).
Measures dc voltages to 24000 v to 1 part in 10^{5} by using accurately measured dry cells in series.

96. Keller, R., Rev. Sci. Instr. 35, 1057-60, 1964.
A high pulse voltage probe with a bandwidth of 300 cps to 300 Mc is described. The pulse is differentiated by a high voltage coupling capacitor, propagated along a cable and finally integrated for observation on an oscilloscope.

97. Izumi, I. and Kokubu, M., Nucl. Instr. Methods 28, 349-52, 1964.
Transistorized precision regulated high voltage supply 300-1500 v, stable to 1 part in 10^5 per °C and 1 part in 10^4 per day.

98. Kusters, N. L. and Moore, W. J. M., IEEE Internat. Convention Record 12, Pt. 8, 204-12, 1964.
Construction details of a multi-ratio compensated current comparator, covering all normally encountered ratios from 5/5 to 1200/5, are given. Its ratio accuracy for burdens up to 750 volt-amperes, is better than 5 ppm. A test set for use in calibrating current transformers up to errors of 1 per cent and 100 minutes, is also described. The set employs three conductance and three capacitance decades, with a 3-position range switch, and is direct reading.

E. Attenuation and Phase

99. Alred, C. M. and Cook, C. C., 19th Ann. ISA Conf. Proc. 19, Pt. 1, 1964.
Discusses the theory and design of a piston attenuator capable of 0.001 db linearity at an output level of one volt. In particular they discuss the mode launcher, mode filter, impedance matching network and a feedback circuit to maintain constant input current.

100. Hollway, D. L. and Kelly, F. P., Trans. IEEE PTG on Instru. and Meas. IM-13, 33-44, 1964.
Below cutoff attenuator and measuring system with accuracy of about 0.001 db.

101. Finne, C. J., Schuster, D., and Otoshi, T. Y., 19th Ann. ISA Conf. Proc. 19, Pt. 1, 1964.
Describe the use of a ratio transformer in a simple system for high precision microwave insertion loss measurements. The estimated error of the system is ±.003 db for a .5 db measurement. Relative errors may be as low as .001 db for the .5 db measurement. The system cannot be used to measure more than 20 to 30 db in one step.

102. Case, W. E., Harrington, R. D., and Schmidt, L. B., J. Research NBS 68C, 255-259, 1964.
Application of the piston attenuator to measure the transmission coefficient and Q of a cavity resonator containing a specimen.

103. Beatty, R. W., J. Research NBS 68D, 529-33, 1964.
Surveys standards for and measurement of attenuation, impedance, and phase shift based on work in the U. S. from 1960 to 1962.

104. Ebert, J. E. and Sorger, G. V., ISA Trans. 3, 280-90, 1964.
This paper is a survey of the techniques of precision microwave attenuation measurement using commercially available equipment. It includes an estimate of the errors normally encountered and references to the original literature.

105. Larson, W., 19th Ann. ISA Conf. Proc. 19, Pt. 1, 1964.
In an article on gearing errors and alignment techniques for microwave rotary vane attenuators, the author shows that errors in these attenuators may be reduced by an order of magnitude or more by a special alignment procedure. As an example, he reports reduction of the error at the 50 db setting from 0.320 db to 0.021 db.

106. Yu, Y. P., 19th Ann. ISA Conf. Proc. 19, Pt. 1, 1964.
The author explains the principles of three null methods for phase comparison, the quadrature rejection bridge, the vector difference detector, and the vector sum - difference coherent detector.

107. Mukaihata, T., 19th Ann. ISA Conf. Proc. 19, Pt. 1, 1964.
The author discusses the principles of phase measurement in the microwave spectrum. He includes a discussion of the errors to be expected when standard components are used in constructing the instrument and includes references to more detailed analyses.

108. Berger, N., Nachrichtentechnik 14, 241-4 and 14, 298-301, 1964. (German).
This is a short review of methods of measuring phase and it includes 52 references to the German language literature on the subject.

109. Epstein, W. S., J. Research NBS 68C, 223-6, 1964.
Describes a device for measuring the relative phase of two audio or low ultrasonic frequency signals. The device is easy to operate and its error is 0.1 degree or less under ordinary conditions.

110. Burton, R. W., Microwave J. 7, No. 4, 51-3, 1964.
Describes a coaxial microwave phase measuring system which is insensitive to the amplitude of the signal being measured. Theory, error analysis, and experimental results are given.

111. Cohn, S. B. and Weinhouse, N. P., Microwave J. 7, 49-56, No. 2, 1964.
An automatic microwave phase-measurement system.

See also references 1, 3, 4, and 11.

F. Impedance (Admittance)

112. Cutkosky, R. D., J. Research NBS 68C, 227-36, 1964.
Discusses the design of direct reading ratio sets for the comparison of audio-frequency admittances. One of the designs operates at a fixed frequency and has a precision of one part in 10^9 for admittances between 10^{-8} and 10^{-5} mhos.

113. Lund, P., Electronics 37, No. 1, 57-9, 1964.
The author describes a direct-reading impedance meter which gives both magnitude and phase angle. The instrument may be operated at any frequency between 25 cps and 1 Mc. It will measure an impedance with any phase angle and with a magnitude that falls between +1Ω and +1.1MΩ or between -1Ω and -110kΩ.

114. Franke, O., Nachrichtentechnik 14, 290-4, 1964. (German).
The accuracy of measuring small conductances with Thurston's coaxial comparator may be increased by varying the reactance standard to obtain a fine balance.

115. Alexander, J. W., Nederlands Elektronica en Radiogen. 29, 45-6, No. 1, 1964.
This short note claims new method for finding input and output impedance of a 4-pole.

116. Weinschel, B. O., Microwave J. 7, 47-50, 1964.
Summary of factors affecting impedance accuracy of coaxial lines used with high precision connectors.

117. Tikhomandritskaya, V. A., Izmeritel'naya Tekhnika 45-7, 1964. (Russian).
Translation: Measurement Techniques 67-8, 1964.
This paper describes a probe carriage for a coaxial slotted line. Two probes enter the line from opposite sides. This design is intended to reduce variations in coupling due to irregularities in the line.

118. Loele, H., Nachrichtentechnik 14, 251-3, 1964. (German).
A circuit is described which can indicate directly the real and imaginary parts of microwave reflection coefficient.

119. Oliver, B., Hewlett Packard J. 15, No. 6, Feb. 1964.
Time resolved reflections on a coaxial transmission line measure impedance changes. See also application note No. 62, Time Domain Reflectometry printed by the Hewlett Packard Co., 1964.

120. Long, G. D., Pulsed Reflection Measurements of Transmission Line Discontinuities, printed by Tektronix Co., 1962. Time domain reflectometer.

See also references 3, 11, 68, 69, 70, 92, and 246.

G. Ratio Dividers

121. Zapf, T. L., IMEKO Vol. III, 317-331, 1964.
The Accurate Measurement of Voltage Ratios of Inductive Voltage Dividers. Uncertainties in voltage ratio of less than 2×10^{-7} have been obtained with transformer type capacitor bridges. This provides a basis for investigation of inductive voltage dividers.

122. Binnie, A. J., J. Sci. Instr. 41, 747-50, 1964.
The author presents the simplified theory, design, construction and test results of an inductive divider for use at low audio frequencies. The accuracy was 1 part in 10^{8} . He suggests its use in a ratio bridge for comparing small capacitances.

123. Riley, J. C., 19th Ann. ISA Conf. Proc. 19, Pt. 1, 1964.
A general introduction to ac ratio measurement techniques.

124. Carrington, K., 19th Ann. ISA Conf. Proc. 19, Pt. 1, 1964.
Discussion of methods for calibrating and comparing dc ratio sets to establish confidence in their accuracy. Reference is made to National Bureau of Standards publications on these techniques.

125. Dunn, A. F., IEEE Internat. Convention Record 12, Pt. 8, 213-24, 1964.
Theory and technique of calibrating Kelvin-Varley voltage dividers is given. The method gives corrections which can be easily applied to multiple dial settings and requires half as much calibration data as older techniques.

126. Lisle, R. V. and Zapf, T. L., ISA Trans. 3, 238-42, 1964.
This paper treats the calibration of precision inductive voltage dividers by a comparison method. The precautions needed to control errors due to stray impedances, phase angle differences, etc. are included.

H. Q-Quality

127. Jones, R. N., J. Research NBS 68C, 243-48, 1964.
Discusses the calibration of Q-meters, including recent improvements in the NBS calibration service.

128. Almassy, G. and Kasa, S., Nachrichtentechnik 14, 254-8, 1964. (German).
This discussion of the determination of surface quality by precision Q measurements of microwave cavity resonators includes a description of a null method for comparing the Q of two resonators. It is capable of measuring Q variations with an error of 0.2%. (See also IRE Trans. Instrum. I-9, 171-5, 1960).

129. Swartz, J. C., Rev. Sci. Instr. 35, 1573-4, 1964.
Decay rate of low frequency (below 80 cps) oscillations is measured by transistor instrumentation. Precision of Q measurements is about 2%.

130. Burton, C. H., Lasich, W. B., Noon, J. H., and Parsons, R. W., Proc. IREE Australia 25, 389-90, 1964.
The Q of a 10 Gc cavity, was measured with an error of ±2% without using a frequency stabilized klystron or accurate microwave frequency measuring equipment. The width of the resonance was measured with a heterodyne-type signal generator. Frequency measurements were obtained by counting the frequency of the 15 Mc tunable heterodyne oscillator, taken quickly to minimize klystron drift.

See also references 3, 4, 64, 101, and 102.

I. Bridges

131. Mulhall, B. E., Philips Res. Repts. 19, 78-102, 1964.
Gives a good analysis of bridge measurements of the impedance of a coaxial sample holder for frequencies of 0.1 to 30 Mc.

132. Eckert, K., Nachrichtentechnik 14, 423-6, 1964. (German).
This is a brief presentation of the design conditions for optimum sensitivity of a Wheatstone bridge.

133. Benetiere, R., Compt. Rend. 258, 3832-4, 1964. (French).
Describes a servomechanical system for balancing a Schering Bridge. The technique is described and a block diagram given.

134. Nguyen, H. C. and Mezencev, R., Compt. Rend. 258, 2977-80, 1964. (French).
The authors show that their earlier work on the servomechanical balancing of an ideal Schering bridge can be extended to apply to a real Schering Bridge.

See also references 3, 40, 64, 147, and 166.

J. Gaging

135. Thomas, J. B. and Saudreau, B., L'Onde Electrique 44, 1308-14, 1964. (French).
Discusses the measurement of the thickness of evaporated films. For transparent films photometric methods are employed; for opaque films a piezoelectric micro-balance is used.

136. Bottom, V. E., Rev. Sci. Instr. 35, 374-6, 1964.
A dilalometer is described which has a sensitivity of 10^{-7} cm, and is self calibrating. It is suitable for measurement of dc coefficients of electrostriction, piezoelectricity, and thermal expansion.

137. Holmes, P. J., Solid State Electronics 7, 633-5, 1964.
In measuring thickness of Al_2O_3 layer by capacitive method the profile of the layer must be taken into account.

138. Cho, A. Y. H., J. Appl. Phys. 35, 2561-64, 1964.
Uses a quadrupole mass spectrometer and an electrometer to measure the mass and charge of particles whose radii lie between 0.3 and 15 microns.

K. Environment

139. Blackburn, G. F. and Caldwell, F. R., J. Research NBS 68C, 41-59, 1964.
This paper contains the National Bureau of Standards thermocouple tables for iridium-rhodium alloys vs iridium. Such thermocouples are used up to 2150°C.

140. Linnenbom, V. J., Insulation 10, No. 3, 21-6, 1964.
In this review of some recent developments in the study of radiation effects, the author emphasizes the importance of testing dielectric materials under the conditions of their intended use. He observes, for example, that the effects on some plastics of heat, oxygen, and radiation are not simply additive.

141. Seligman, L. J., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 82-4, 1965.
Describes a temperature controlled chamber for dielectric breakdown studies. It operates between -10°C and + 210°C with ±0.1° stability.

142. Semerchan, A. A. and Kuzin, N. N., Pribory i Tekhnika Eksperimenta No. 1, 194-5, 1964. (Russian). Translation: Instruments and Experimental Techniques 206-7, 1964.
A compact 60 ton hydraulic press is described. It is intended for use in a thermostat between 20 and 200°C.

143. Güttler, F., Nachrichtentechnik 14, 202-6, 1964. (German).
This paper considers climatic effects on the characteristics of cavity resonators: thermal expansion, variations in the refractive index of the air in the cavity, etc.

144. Fogel'son, I. B., Pribory i Tekhnika Eksperimenta No. 1, 227, 1964. (Russian). Translation: Instruments and Experimental Techniques 248-9, 1964. Variation of the emitter voltage in a germanium transistor is used as a measure of temperature between -183°C and +40°C. Equations are given.

145. Zaitsev, A. M., Pribory i Tekhnika Eksperimenta No. 1, 228-9, 1964. (Russian). Translation: Instruments and Experimental Techniques, 250-2, 1964.
A miniature, low inertia, glass enclosed platinum resistance thermometer is described. Its dimensions are 30 x 2 x 1 mm, its lag constant 0.2 to 0.4 sec., its initial resistance repeats within 0.002°C after nine months use between -183°C and +630°C.

146. Orlova, M. P., Astrov, D. N., and Medvedeva, L. A., Pribory i Tekhnika Eksperimenta No. 1, 230-2, 1964. (Russian). Translation: Instruments and Experimental Techniques 253-5, 1964.
This is a brief description of the design, manufacture and characteristics of a germanium resistance thermometer for the temperature range between 1.5 and 20°K.

147. Williams, A. J. and Mergner, G. C., 19th Ann. ISA Conf. Proc. 19, Pt. 1, 1964.
Describes the design and performance of an automated Mueller bridge capable of tracking a platinum resistance thermometer with precision comparable to the best performance by a human operator. As might be expected, a rather elaborate digital computer is required to achieve such a result.

148. Isaacs, A. D., Klock, F. G., Jr., Koop, C. D., Mitchell, J. D., Snyder, W. F., and Winchell, J. A., ISA Trans. 3, 366-77, 1964.
This report of the F - 6 Environmental Committee of the Instrument Society of America defines several types of standards laboratories and recommends environmental conditions which should be maintained in each.

149. Ieda, M., Kosaki, M., and Shinahara, U., Memoirs of Faculty of Engng., Nagoya Univ. 15, 117-25, 1963.
Gives measurements of dc conductivity of polyvinylchloride versus pile irradiation.

150. Gross, P. M., Gugliotta, J., Krysiak, K. F., and Gross, L. B., ISA Trans. 3, 305-12, 1964.
This paper describes the design of a thermocouple probe for use at 4500°F under oxidizing conditions (space vehicle re-entry).

See also references 16, 63, 157, 162, 163, 165, 169, 171, 172, 173, 174, 178, 179, 206, 207, 214, 221, 225, and 232.

VI. Dielectric and Insulation Measurements

A. Special Methods

151. Bussey, H. E., Gray, J. E., Bamberger, E. C., Rushton, E., Russell, G., Petley, B. W., and Morris, D., IEEE Trans. Instrumentation and Measurement IM-13, No. 4, 1964.

ϵ^* measurements made by government laboratories in Canada, England, and the United States agreed within an error of 0.8% to 0.2% depending upon the material measured. Loss tangent measurements agreed within an error of 0.0001 in many cases but larger discrepancies were found. These errors may result in part from different conditions at the three laboratories. A statistical significance test (t-test) was made.

152. Cross, L. E. and Groner, C. F., IEEE Trans. Instrumentation and Measurement, IM-13, No. 4, 1964.
An instrument is described for determining the loss of a dielectric specimen by measuring the torque developed when it is suspended in a rotating electric field. This design covers the frequency range from 0.001 cps to 80 kc.

153. Lal, H. B. and Singh, Y. D., Phys. Letters 8, 165, 1964.
Rutile capacitor made with Wood's metal electrodes and measured by vibrating reed.

154. Bur, A. J., 1964 Annual Report Conf. on Elec. Insul., NAS-NRC Publication 1238, 70-71, 1965.
Confirms by direct measurement, a Davidson-Cole dielectric dispersion curve obtained by the superposition of data taken at various temperatures.

155. Bamberger, E. C. and Dalke, J. L., 1964 Annual Report Conf. on Elec. Insul., NAS-NRC Publication 1238, 72, 1965.
A specimen holder is described for dielectric measurements at high and low temperatures. The errors associated with expansion, inductance, resistance and transmission lines are reduced by observing the difference between the readings for the unknown dielectric and for a known standard dielectric.

156. Delbos, G., J. Physik 25, 194A-98A, 1964.
Measures ϵ^* in a cavity by compensating the unknown against a standard (reference) sample.

157. Gottlieb, M. and Garbuny, M., Rev. Sci. Instr. 35, 641-42, 1964.
A 500 cps superconducting resonant circuit was evaporated on Mylar film. The loss tangent of the film was calculated from the decay time of oscillations of the circuit. The method can be used for loss tangents of the order of 10^{-4} or 10^{-5} at cryogenic temperatures.

158. Jezewski, M., Morstin, T., and Wierzbicki, M., Acta Phys. Polon. 25, 187-92, 1964.
Immersion method for ϵ^* using a special coaxial capacitor was easier and more correct than usual method.

159. Rabinovitch, M., Compt. Rend. 258, 4663-5, 1964. (French).
E, the dielectric constant of a powder measured by the von Hippel method obeys the equation $\log E = p \log \epsilon + k$ where p is the fractional volume occupied by solid matter and ϵ is the dielectric constant of the solid. ϵ is obtained by measuring versus compression (density).

Note: ϵ^* is used to represent dielectric constant and loss.

160. Pradhan, B. P. and Gupta, R. C., Dielectrics 1, 195-200, 1964.
Discusses theories of dielectric mixtures and gives experimental tests.

161. El'gard, A. M., Pribory i Tekhnika Eksperimenta No. 4, 94-7, 1963. (Russian). Translation: Instruments and Experimental Techniques 682-5, Feb. 1964.
Measurement of ϵ'' in a capacitor from heat generated.

162. Gibbs, D. F. and Hill, G. J., Phil. Mag. 9, 367-75, 1964.
Measurement of variation of ϵ^* of diamonds with pressure and theoretical analysis of results.

163. Chakravorty, D. and Cross, L. E., J. Am. Ceram. Soc. 47, 370-4, 1964.
Describes a method of making dielectric measurements under pressures up to 60 kilobars using a Bridgman opposed-anvil pressure machine for three-terminal dielectric measurements.

See also references 53, 63, and 136.

B. Low Frequency and Lumped Circuit

164. Astier, M., L'Onde Electrique 44, 85-9, 1964. (French).
Describes a bridged-T substitution instrument for measuring ϵ^* of materials at frequencies between 1 and 32 cps. Gives the practical details as well as the equations.

165. Holland, L., The Properties of Glass Surfaces, John Wiley, New York, 1964.
Pertinent here is the information on adsorption and on surface conduction and capacity due to water adsorption.

166. Pander, K., Archiv für Tech. Messen No. 335, 283-4, 1963.
Gives ϵ^* of ceramic titania from 0.5 cps to 5 Mc, and discusses especially the use of bridges from 0.5 to 50 cps.

167. Dunn, A. F., Canadian J. Phys. 42, 1489-98, 1964.
Relative permittivities have been obtained for several reference gases at an audio frequency with an accuracy comparable to that available in microwave and optical measurements. The measured permittivities of these gases, argon, carbon dioxide, nitrogen, and oxygen, may be used to calibrate other measuring equipment, cf NBS Circular 537.

168. Pais, J. C. and Griffiths, V. S., Proc. IEE 111, 1775-7, 1964.
This letter describes a sample holder for making dielectric measurements on a test tube containing polymerizing plastic. Measurements are made through the test tube with no electrodes on or in the plastic.

169. Nanassy, A. J., Canadian J. Phys. 42, 1270-81, 1964.
ϵ^* of dry birch. Describes evacuated Hartshorn Jig for 20 to 100°C.

Note: ϵ^* is used to represent dielectric constant and loss.

170. Wentworth, F. L. and Cohn, M., J. Research NBS 68D, 681-91, 1964.
ϵ^* (0.1 to 30 Mc) of arctic sea ice measured and compared with conductivity measurements.

171. Paquet, J., L'Onde Electrique 44, 940-50, 1964. (French).
The author reports a dielectric study of damp materials, and suggests the use of dielectric measurements for the determination of the moisture content of building materials in completed structures.

172. Miles, R. H. A., Electron. Eng. 36, 682-7, 1964.
Automatic equipment is described for obtaining approximate (10% to 20% error) measurements of ϵ^* of materials throughout the temperature range 20°C to 500°C at frequencies of 100 kc and 1 Mc. The capacitance range of the equipment is 1 to 1000 pf. The resistance range is 10Ω to 500 MΩ. The capacitance and resistance are not separable for high loss materials.

173. Stewart, J. W., J. Chem. Phys. 40, 3297-3306, 1964.
Describes the cryogenic dielectric measuring cell and instrumentation used in a study of the dielectric polarizability of fluid parahydrogen.

174. Brown, N. L., 1964 Annual Report Conf. on Elec. Insul., NAS-NRC Publication 1238, 36-40, 1965.
A combination of a bellows dilatometer and a three-terminal capacitor is described for simultaneous measurement of ϵ and volume of liquids at pressures up to 2000 kg/cm^2 and temperatures down to -150°C. Temperature corrections are less than .025% and pressure corrections are about 0.2% for capacitance, volume measurements being good within ±0.1%.

175. Mathes, K. N., 12th Quarterly Report, Contract NAS8-2442, 15 July, 1964, General Electric Co.
This report is devoted to the development of cables for use at cryogenic temperatures. One section discusses variations in ϵ^* of polyfluoroethylene-propylene and aromatic polyimide films with temperature. The measuring electrodes were of evaporated gold backed with silver paint.

See also references 5, 151, 152, 179, and 203.

C. Wave Methods

176. Primich, R. I. and Hayami, R. A., IEEE Trans. on Microwave Theory and Techniques MTT-12, 33-42, 1964.
Mearuements of ϵ^* in a confocal Fabry-Perot cavity.

177. Aron, C. P., Proc. IEE 111, 310-1, 1964.
Irregular tuning of a TE_{01} microwave cavity containing a disc sample and contradictory results of loss measurements in this cavity were found to indicate inhomogeneity of the dielectric sample. The inhomogeneity could be extimated well enough to identify materials which were weak under heavy electrical loading.

Note: ϵ^* is used to represent dielectric constant and loss.

178. Keller, W. C., Proc. of the OSU-RTD Symposium on Electromagnetic Windows, Vol. III, Ohio State Univ., 1964.
ϵ^* is obtained up to 1430°C by measuring the scattering of microwaves by a heated sphere about 9/16 inch in diameter. The sphere is permitted to fall freely through the measuring device. The method was tested at about 10,000 Mc for ϵ' of about 10. Loss tangent measurements could not be made below $\tan \delta = .001$.

179. Westphal, W. B., Dielectric Constant and Loss Measurements on High-Temperature Materials, Tech. Rpt. 182, Lab. for Insulation Research, MIT, Oct. 1963.
Good measurement techniques for frequencies of 10^3 to 10^{10} cps, up to 1650°C.

180. Hansen, E. F., High Frequency Characteristics of Ceramic Materials, General Electric Co., Sept. 1963. Final Report 104 p. Contract DA-36-039 AMC-00008(E), Rpt. No. 4.
Survey of microwave dielectric measurement methods for solids.

181. Hedvall, P. and Hägglund, J., Ericsson Techniques 19, 89-96, 1963.
Cavity method for measuring dielectric constant at microwave frequencies.

182. Le Petit, J. P., Proc. XII Colloque Ampere, pp. 420-2, North-Holland Publishing Co., Amsterdam, 1964. (French).
The principal dielectric constants of a biaxial dielectric (stacks of paper with oriented fibers) were measured at 10 cm wavelengths by cutting several samples which were differently oriented and measuring each by the shorted waveguide method.

183. Rowe, P. E., Luoma, E. J., and Buckley, E. F., Dielectric Properties; Data and Measurement Techniques. Emerson and Cumming Report presented at Symposium on Radar Reflectivity, Lincoln Labs., June 2, 1964.
Convenient tables were made for evaluating ϵ^* from in-guide impedance data and free space transmission data. A way of using a beam area of about one square wavelength is mentioned.

184. Burdick, G. A., Lyon, T. J., and Pippin, J. E., IEEE Trans. Instrumentation and Measurement, IM-13, No. 4, 1964.
Measurement of ϵ' as high as 1500 and loss tangents as large as 0.1 were measured with an error of the order of 5% at 35 Gc. The specimen was mounted with conducting epoxy in a waveguide shaped hole in a metal plate. The plate and the sample were then ground to the desired thickness and mounted between waveguide flanges for the microwave measurement.

185. Haase, J., Stistig, E., and Zeil, U., Z. Naturforsch. 19a, 660-1, 1964.
Measured ϵ^* of plexiglass at 36-42 Gc using interferometer.

186. Schubring, N. W., Nolta, J. P., and Dork, R. A., Rev. Sci. Instr. 35, 1517-21, 1964.
The authors describe a hysteresis loop tracing bridge which permits grounding the sample holder and conveniently compensating for the linear capacitance and dc conductance of the sample and its holder.

Note: ϵ^* is used to represent dielectric constant and loss.

187. Cummins, S. E., Rev. Sci. Instr. 35, 1372-2, 1964.
Gives a simple circuit with two mercury wetted contact relays which can be driven from 1 cps to 60 cps and will produce pulses 1 millisecond to .1 second wide for polarization reversal studies in ferroelectric crystals.

188. Dagg, I. R. and Reesor, G. E., Canad. J. Phys. 41, 1314-20, 1963.
Dielectric measurements are made on low loss liquids in the frequency range from 8.2 to 12.4 Gc with a standing-wave measuring device. The dielectric constant is obtained from measurements of the wave reflection at the air-sample interface with an estimated error of less than 2%. The loss tangent is obtained from the loss of a long waveguide filled with dielectric and terminated in a short circuit.

189. Conklin, G. E., J. Appl. Phys. 35, 3228-35, 1964.
A resonant cavity is described which yields ϵ' with an error of 0.5% in the range $\epsilon = 1$ to $\epsilon = 6$ and loss tangent with an error of 5% or less for loss tangents between 1 and 3×10^{-5} in the frequency range 50 to 60 Gc.

190. Holmes, D. A. and Feucht, D. L., IEEE Trans. Microwave Theory Tech. MTT-12 (4), 478-80, 1964.
Non-resonant stripline is used to measure semiconductor properties. The technique is apparently adaptable to dielectric constant and loss measurements between 100 and 1000 Mc.

191. Ezhik, I. I., Instruments and Experimental Tech. No. 5, 1113-6, 1964.
Sensitive measurement of changes of ϵ^* by VSWR in waveguide.

192. Fatuzzo, E. and Mason, P. R., J. Sci. Instr. 41, 694-5, 1964.
For measuring ϵ^* of liquids at microwave frequencies, the authors suggest the use of a generalized open and short circuit method. They point out that by judicious choice of the terminating impedance, one can improve the accuracy of the results without unduly complicating either the calculations or the measuring procedure.

193. Vincint, P., L'Onde Electrique 44, 61-71, 1964. (French).
Reviews the standard methods of measuring dielectric materials used in the construction of radomes.

194. Krishnaji and Mansingh, A., J. Chem. Phys. 41, 827-31, 1964.
Employs the short circuited waveguide method for measuring ϵ^* of liquids between 9.95 and 32.0 Gc. Apply clock motor drives to the standing wave probe and to the shorting plunger. Record the detected signal on a chart recorder which can be read to .005 cm for plunger position and to .001 cm for probe position.

195. Falkvik, I., Proc. IEEE 52, 203, 1964.
A cavity perturbation method for measuring small dielectric spheres is briefly described.

Note: ϵ^* is used to represent dielectric constant and loss.

196. Servant, R., Proc. XIIth Colloque Ampere, pp. 476-8, North-Holland Publishing Co., Amsterdam, 1964. (French).
The permittivity tensor of a biaxial dielectric (gypsum) is measured near 10 Gc by cutting several samples of different orientations and measuring each by the short circuited waveguide method. Although the positions of the electrical axes are initially unknown, they can be determined by plotting the measured results for several samples.

197. Salmer, G., Constant, E., and Lebrun, A., Proc. XIIth Colloque Ampere, pp. 391-7, North-Holland Publishing Co., Amersterdam, 1964. (French).
Describe technique of measuring complex permittivity in the frequency range from 1 Gc to 12 Gc. Obtain the real part of the permittivity from the reflection of a travelling wave at an air-dielectric interface and the imaginary part from the attenuation of the wave as measured by two probes separated by a length of the dielectric. Include a brief description of coaxial and waveguide equipment for these measurements.

198. Mandel, M. and Marco, C., Physica 30, 597-607, 1964.
Present a theoretical analysis of the dependence of measurement error on sample thickness for ϵ^* made in shorted coaxial transmission lines.

199. Haare, J., Z. Naturforsch. 18a, 883, 1963.
Measures ϵ^* of plexiglass at 36 and 70 Gc, get $k' = 2.6$ and 2.54, loss tan = .0091 and .0112.

200. Hoffman, H. J., Z. Phys. Chem. 224, 110-132, 1963.
Measures ϵ^* of lossy liquids by parallel (lecher) wires, 0.5 to 3 Gc, by reflection.

201. Cagan, V. and Lemaire, B., Proc. XIIth Colloque Ampere, pp. 517-24, North-Holland Publishing Co., Amsterdam, 1963. (French).
Reviews the measurement of the complex permittivity of ferrites at frequencies approaching 35 Gc. Perturbation formulae and suitable dimensions are given for circular cylindrical cavities operating in the TM_{010}, TM_{020}, and TM_{012} modes. Sample rods less than 0.8 mm in diameter were made with a square cross-section because that proved to be easier.

202. Maxwell, S. P., Marconi Review 27, 22-9, 1964.
A stripline cavity resonator technique is described which was developed to measure the dielectric and magnetic properties of ferrites in the range 300 Mc to 3000 Mc. The limiting values that can be measured with this cavity are loss tangent between 0.0001 and 0.1 and dielectric constant to 120. The error for the design given is about ±3% for dielectric constant and ±15% for loss constant. (Waldron's paper reference 56 gives the theory for this).

203. Friess, W. and Boden, Ch., Die Kurzinformation 10, 9-36, 1964. (Printed by Rhode and Schwarz Co.).
Describes dielectric measuring equipment and its use.

Note: ϵ^* is used to represent dielectric constant and loss.

204. Type 900 Precision Slotted Line, printed by General Radio Co., 1964. Section 4.4 describes ϵ^* measurements by a half wave length specimen method which is simple but exact.

205. Kugaevskii, A. F., Izmeritel'naya Tekhnika, No. 11, 44-6, 1963. (Russian). Translation: Measurement Techniques 949-52, 1963. This paper describes a coaxial resonator which may be used as a sample holder for measuring ϵ^*, permeability and magnetic loss up to 400°C. The errors range from 3% to 20% not including those due to air gaps between the sample and its holder.

See also references 4, 5, 33, 35, 151, 156, and 249.

D. Ferroelectrics

206. Ruprecht, G. and Bell, R. O., Phys. Rev. 135, A748-52, 1964. Outline microwave ϵ^* measurement of a paraelectric over a temperature range.

207. Bäumler, P., Blum, W., and Deyda, H., Z. Phys. 180, 96-104, 1964. ϵ^* of rochelle salt versus temperature using interferometer at 10^{10} cps.

208. Tambovtsev, D. A. and Novoselov, A. S., Prib. i Tekh. Eksp., No. 5, 125-7, 1963. (Russian). Translation: Instruments and Experimental Techniques, 906-8, 1963. The authors describe a two-channel amplifier with cathode follower output. It is intended to couple a pair of commercial pulse generators to a ferroelectric crystal for domain switching experiments. One channel carries positive pulses, the other negative pulses. Pulse amplitude is 200 V or less with a rise time of 0.3 microsecond.

209. Yamaguchi, S., J. Appl. Phys. 35, 2559-60, 1964. Employs an electron beam to obtain diffraction patterns which show the orientation of the internal field in barium titanate. By controlling the exposure he was able to vary the temperature of the crystal and to observe the ferroelectric transition.

210. Das, S. N., IEEE Trans. Microwave Theory Tech. MTT-12 (4), 440-5, 1964. Describes simple methods of observing nonlinear properties of ferroelectric materials at microwave frequencies.

211. Le Foch, G., Proc. XIIth Colloque Ampere, pp. 451-4, North-Holland Publishing Co., Amsterdam, 1964. (French). Measures the dissipation factor of barium titanate near its ferroelectric transition temperature by the unusual method of measuring the heating of the sample when it is subjected to an ac voltage.

212. Ahroni, A. and Sapoznikov, D., Rev. Sci. Instr. 35, 1370-1, 1964. Describe an automatic scanning device for locating piezoelectric resonances.

See also reference 184.

Note: ϵ^* is used to represent dielectric constant and loss.

E. Conductivity

213. Davies, D. K., Nature 203, 290-1, 1964.
A device is described which permits an estimate of the amount of surface charge trapped on a dielectric, and a fairly accurate measurement of the decay of this charge with time.

214. Chatterji, C. K., Roy, S. K., and Nag, B. R., Proc. IEEE 52, 873-4, 1964.
Surface conductance versus humidity is obtained from ϵ^* of semiconductor strip in waveguide.

215. Klimenko, A. G., Prib. i Tekh. Eksp., No. 5, 222-3, 1963. (Russian).
Translation: Instruments and Experimental Techniques, 991-2, 1963.
The author describes a four terminal microprobe for measuring the resistivity of a thin film. Electrolytically pointed tungsten electrodes are positioned by a grooved glass jig.

216. Watson, P. K. and Sharbaugh, A. H., Rev. Sci. Instrum. 35, 1310-3, 1964.
Initial conductivity of insulators is measured by storing charge from a μ sec voltage pulse in a capacitor.

217. Veltri, R. D., Phys. Chem. Glasses 4, 221-8, 1963.
Measures electrical resistivity of fused silica from 1000 to 2400°C.

218. Johnson, E. W. and Johnson, H. H., Rev. Sci. Inst. 35, 1510-16, 1964.
Measures surface conductivity of metal versus depth by coil and eddy currents.

219. Foster, M. D. and Marsh, K. J., J. Sci. Instr. 41, 379-81, 1964.
Describe an instrument for measuring the conductivity of aviation fuels. It is designed for tests made at the airfield yet its error is not much larger than that of the corresponding laboratory instruments. At the 95% confidence level, its error is ±0.45 picomhos per meter as compared with ±0.23 for the Lindemann electrometer method and ±0.19 for the relaxation cell method.

220. Levine, N. E. and Uman, M. A., J. Appl. Phys. 35, 2618-24, 1964.
An ionization chamber is used to measure the drift speed of electrons in various gas mixtures. Gas mixing system which admixes as little as 0.1% of the secondary gas with an uncertainty of less than 10% or 1% with an uncertainty of 1% is described.

221. Mitoff, S. P., J. Chem. Phys. 41, 2561-2, 1964.
This letter describes a modified guard-ring sample holder for high temperature electrical conductivity measurements on insulating materials. It is designed to measure bulk conductivity without the errors often introduced by gaseous or surface conduction at elevated temperatures.

See also references 3, 128, 149, and 170.

Note: ϵ^* is used to represent dielectric constant and loss.

F. Breakdown and Corona

222. Miller, H. N., *Nondestructive High Potential Testing*, Hayden Book Co., New York, 1964.

223. Bullwinkel, E. P., 1964 Annual Report Conf. on Elec. Insul., NAS-NRC Publication 1238, 101-3, 1965.
Describes a scanning electrode device for locating areas of minimum dielectric strength in kraft capacitor tissue in single or multiple layers. The device limits the power dissipated and the duration of the discharge so that the paper appears to be unharmed. As a result, these areas may be studied to determine their nature and causes.

224. Verob'ev, G. A. and Lisetskaya, M. N., Prib. i Tekh. Eksp., No. 3, 175-7, 1964. (Russian). Translation: Instruments and Experimental Techniques, No. 3, 667-9, 1964.
The authors employ the firing delay of an irradiated spark gap to clip short the pulse from a high voltage cable discharge apparatus. The resulting pulses could be made as short as 1.7 nanoseconds, and their length could be easily adjusted. They employ the device to study the development of dielectric breakdown.

225. Barney, W. H., 1964 Annual Report Conf. on Elec. Insul., NAS-NRC Publication 1238, 99-101, 1965.
Hollow electrodes are used to give a predictable point of failure in high temperature tests on glasses. Temperature can then be measured at this point.

226. Milton, O., 1964 Annual Report Conf. on Elec. Insul., NAS-NRC Publication 1238, 77-81, 1965.
Reports a series of breakdown measurements using electrodes of an unconventional shape which avoids local increase of stress and breakdown at points of unknown field strength. The results show a somewhat higher dielectric strength than the ASTM method. The dielectric samples must be moulded to a special recessed shape.

227. Curdts, E. B., Insulation Testing by DC Methods, 50 pp., Rept. of James Biddle Co., 1964.

228. Noelke, O. E., Arch. Techn. Messen 241-44, No. 346, 1964. (German).
Describes corona measurements with ac high voltage and gives historical bibliography.

229. Sudan, R. N. and Gonzalez-Perez, F., J. Appl. Phys. 35, 2269-70, 1964.
Describe the use of a field emission microscope to observe the condensation of copper vapor in aggregates capable of initiating electric breakdown in a vacuum. The copper vapor was liberated by an arc between copper electrodes.

230. Mosley, K. and Gumley, P., UK Atomic Energy Rept. 592, 1963.
Experimental safe working electric fields for ceramic at 800° to 1140°C.

231. Milton, O., 1964 Annual Report Conf. on Elec. Insul., NAS-NRC Publication 1238, 89-92, 1965.
Point electrode tests of pulse life of potting resins are confirmed by the observed performance of potted pulse transformers.

232. Ey, C. H. A. and Lambeth, P. J., Proc. IEEE 111, 991-8, 1964.
Flashover of insulator is measured in an artificial saline fog of adjustable salinity.

233. Jedynah, L., J. Appl. Phys. 35, 1727-33, 1964.
Measures influence of dielectric films on breakdown between electrodes.

234. Creed, F. C., Bull. Radio and Elec. Eng. Div., Nat. Res. Council, Canada, 14, 8-11, No. 4, 1964.
Calibrates breakdown voltage versus rise time for spherical electrodes. Useful for pulse breakdown testing.

235. Hayes, R. and Walker, G. B., Proc. IEEE 111, 600-4, 1964.
Measured breakdown (tracking) on ceramic surfaces in a microwave cavity.

236. Barrett, H. H., J. Appl. Phys. 35, 1420-5, 1964.
Recommends the use of a single steadily increasing voltage pulse in measuring breakdown of solid dielectrics. Repeated pulsing seems to fatigue his samples of strontium titanate altering their measured breakdown voltage.

237. Henry, E. N., Proc. 1964 Electronics Components Conf. (Wash., D.C.), 290-8, 1964.
Suggests a modification to the proposed IEEE test procedure for the evaluation of insulation systems for electronic power transformers. His data indicate chemical decomposition of cellulose at the proposed test temperatures. Also printed as IEEE Trans. on Component Parts CP-11, 290-8, 1964.

238. Duncan, G. I., Proc. 1964 Electronics Components Conf. (Wash., D.C.), 279-289, 1964.
Reports the proposed IEEE test procedure for the evaluation of insulation systems for electronic power transformers. Also printed as IEEE Trans. on Component Parts CP-11, 279-89, 1964.

239. Wentz, J. L., 1964 Annual Report Conf. on Elec. Insul., NAS-NRC Publication 1238, 85-8, 1965.
Mentions that an inexpensive charge storage cable system developed for exploding wire studies is suitable for obtaining pulsed dielectric strength data.

240. Heinrich, O. X., Proc. 1964 Electronics Components Conf. (Wash., D.C.), 299-316, 1964.
Reviews methods of corona testing and use for insulation evaluation. Also printed as IEEE Trans. on Component Parts CP-11, 299-316, 1964.

241. Frisco, L. J., Johns Hopkins Report NAS 8-5253, 1964.
Investigation of the behavior of dielectric materials at high field strengths in a high vacuum environment.

See also reference 3.

G. Infrared and Optical Related Work

242. Passaglia, E., Stromberg, R. R., and Kruger, J., Eds., Ellipsometry in the Measurement of Surfaces and Thin Films, (Symposium at NBS, Sept. 1963; NBS Miscel. Publ. No. 256) Govt. Printing Office, 1964.

243. Cathcart, J. V., 1964 Annual Report Conf. on Elec. Insul., NAS-NRC Publication 1238, 63-6, 1965.
Summarizes the advantages and limitations of ellipsometry and X-ray diffraction as methods for characterizing thin dielectric films. In addition to film thickness and average dielectric constant, such properties as anistropy and variation of strain with distance below the surface of the film can be studied by these methods.

244. Pliskin, W. A. and Conrad, E. E., J. Phys. (Paris) 25, 17-20, 1964.
A simple non-destructive method of measuring the refractive index and thickness of transparent films on reflective substrates has been developed. The technique involves the use of a microscope equipped with a monochromatic filter and a stage that can be rotated so that the reflected light is observed at various angles. The technique can be used for the determination of film thicknesses from several hundred angstroms up to several microns with accuracies of 0.2% on films thicker than 2μ, and tens of angstroms on thinner films.

245. Passaglia, E. and Stromberg, R. R., J. Research NBS 68A, 601-10, 1964.
Theory of ellipsometry when thin film is on a transparent substrate instead of more usual metal substrate.

246. Sardos, R., Proc. XIIth Colloque Ampere, pp. 495-7, North-Holland Publishing Co., Amsterdam, 1964. (French).
Describes a microwave polarimeter-ellipsometer with no rotary joint and only one detector. The device uses a turnstile junction with adjustable short circuits on some of its arms.

247. Szymanski, H. A., IR Theory and Practice of Infrared Spectroscopy, Plenum Press, New York, 1964.
Instruments are briefly discussed, and a bibliography is included.

248. Cleek, G. W., Consitt, F. J. P., and Lawson, W. D., Standard Procedures for Measuring and Reporting the Physical Properties of Optical Material. Printed at Royal Radar Establishment, Malvern, England, Dec. 1963. Written by a tripartite technical committee (USA, UK, and Canada).
This report briefly defines some physical properties including dielectric, and urges complete reporting of properties required to judge an optical material.

249. Potter, R. F., Reflectometer for Determining Optical Constants, NOLC Report 600, 15 May 1964. Naval Ord. Lab., Corona.
Reviews prior art briefly. Uses convenient mechanism to rotate sample while getting the ratio of reflectance with perpendicular and parallel polarization.

250. Heilmeier, G. H., Applied Optics 3, 1281-7, 1964.
Gives radio dielectric, electro-optical, and optical absorption data for a molecular crystal used in microwave modulation of light.

See also references 1 and 176.

CHAPTER II

TABLES OF DIELECTRIC CONSTANTS, DIPOLE MOMENTS, AND DIELECTRIC RELAXATION TIMES

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I. Introduction

This year's tables provide a continuation from last year's without any break in coverage. As in the past, Chemical Abstracts was the sole source of references. All papers found in the 1964 volumes were included in these tables, irrespective of their actual date of publication. Only papers dealing with dielectric measurements on pure materials were covered and ones dealing exclusively with mixtures, radiation damaged or doped materials, or resistivity measurements were excluded.

The data reported in these tables are always for the temperature closest to 25°C and, when more than one temperature was reported, this fact is represented by a footnote. Also, no estimates of accuracy are included with the data since these tables are not intended to be a critical compilation. Moreover, many papers did not give any estimates of accuracy and for those that did, the significance of such estimates could only be appreciated by a reading of the original paper. Similarly, all data reported here are given to as many significant figures as reported and no attempt has been made to indicate accuracy by rounding of the results. Only results derived from measurements reported in the original paper are given and any reported values are not included.

The tables presented are the same as last year's except that only a single table of relaxation times has been included. This year not enough data could be found to justify the inclusion of a separate table of resolved relaxation times. The tables given are:

I. Static Dielectric Constants of Pure Liquids
II. Static Dielectric Constants of Pure Solids
III. Dipole Moments

IV. Relaxation Times

V. Graphs and Tables of Dielectric Data

A supplementary bibliography appears at the end of the list of references for articles that could not be located at the library of the National Bureau of Standards and whose abstract did not give enough information to include it in the tables. A short abstract is given with each reference to indicate its probable contents. Unless otherwise indicated, all data are taken from the original articles.

The compounds listed in the tables are given in the following order:

Inorganic: The listing is alphabetical by name.

Organic: (Only C, H, O, N, S, and halogens). The listing is by empirical formula in order of carbon number, hydrogen number, and the others in alphabetical order.

Metallic and Nonmetallic Organic: The listing is by the name of the metallic or nonmetallic element and then by the rules for organic compounds.

Complexes: The same as for metallic and nonmetallic compounds.

Polymers: The same rules as for organic compounds according to monomer unit. All values are given for the polymer as a whole and no attempt was made to reduce any values to those per monomer unit.

For Table III, a cross reference by functional groups for the organic compounds is given by carbon-hydrogen numbers.

Abbreviations:

Column Headings:

Temp. - Temperature in degrees Celsius except where otherwise noted.

ϵ_0 - Static dielectric constant.

State - Physical state of the compounds.

Freq. - Measurement frequency in hertz (Hz), kilohertz (kHz), megahertz (MHz) or gigahertz (GHz).

μ - Dipole moment in Debyes (10^{-18} esu cm).

τ - Relaxation time in picoseconds (10^{-12} sec).

α - Cole-Cole parameter for the distribution of relaxation times.

Method - Method of calculation.

General Abbreviations:

f_m - the frequency for the maximum value of ϵ''.

g - Kirkwood g factor for static dielectric constants.

M - molecular weight.

N/V - moles per liter.

QV - the information was not reported in the abstract for a * reference.

RT - room temperature.

Z - the original paper should be referred to for the information.

— - the data were not given in the original paper.

* - the paper was not available at the library of the National Bureau of Standards and the data are from the abstract.

$\alpha\pi/2$ - the angular depression of the center of the circular are of the Cole-Cole distribution in the complex ϵ^* plane.

ϵ', ϵ'' - the real and imaginary components of the complex dielectric constant $\epsilon^* = \epsilon' - i\epsilon''$.

$\epsilon_{\parallel}$, $\epsilon_{\perp}$ - the static dielectric constant parallel and perpendicular to the major crystallographic axes.

ϵ_a, ϵ_b, ϵ_c - the dielectric constant along the crystallographic axes.

tan δ - the ratio ϵ''/ϵ'.

μ_a, μ_b, μ_c - the components of the dipole moment parallel to the inertial axes.

μ_o, μ_1 ... the dipole moments of the ground, 1st excited vibrational state, etc.

μ_o, μ_e - the dipole moment of the ground and 1st excited electronic state.

λ - wavelength.

ρ - resistivity.

σ - conductivity.

State:

Am - amorphous or glass (pure).

B - benzene solution.

C - carbon tetrachloride solution.

Cy - cyclohexane solution.

D - 1,4 dioxane solution.

F - film (pure).

G - gas (pure).

Hx - n-hexane solution.

L - liquid (pure).

P - polycrystalline, ceramic (pure).
S - solid, single crystal (pure).
T - toluene solution.
X - p-xylene solution.

Method of Calculation:

CC - circular arc plot of ϵ'' vs ϵ, Cole, K. S. and Cole, R. H., J. Chem. Phys. 9, 341 (1941).
CD - skewed arc plot of ϵ'' vs ϵ, Davidson, D. W. and Cole, R. H., J. Chem. Phys. 19, 1484 (1951).
D - for dipole moments, the Debye equation, Debye, P. J., Physik. Z. 13, 97 (1912), for dielectric relaxation times, semicircular arc plot of ϵ'' vs ϵ, Debye, P. J., "Polar Molecules," Chemical Catalogue (New York, 1929).
Gu - Guggenheim, E. A., Trans. Faraday Soc. 47, 573 (1951).
He - Hendestrand, G., Z. Physik. Chem. 2B, 428 (1929).
HK - Halverstadt, I. F. and Kumber, W. D., J. Am. Chem. Soc. 64, 2988 (1942).
Kr - Kirshna, K. V. G., Trans. Faraday Soc. 53, 767 (1957).
L - LeFevre, R. J. W., "Dipole Moments," 3rd ed., Methuen (London, 1953).
Os - Onsager, L., J. Am. Chem. Soc. 58, 1486 (1936).
Sm - Smith, J. W., Trans. Faraday Soc. 46, 394 (1950).
St - the Stark effect (microwave spectra).

Table I. Static Dielectric Constants of Pure Liquids

Name	Formula	Temp.	ϵ_0	Freq.	Ref.
Inorganic Compounds					
argon (gas, 1 atm)[3]	Ar	20°	$\epsilon_0 - 1 =$ 516.59×10^{-6}	1592 Hz	1
argon[3]	Ar	87.27°K	1.504	-	2
carbon dioxide (gas, 1 atm)[3]	CO_2	20°	$\epsilon_0 - 1 =$ 921.62×10^{-6}	1592 Hz	1
para-hydrogen[18]	H_2	42°K	1.26071	-	3
krypton[3]	Kr	119.80°K	1.657	-	2
nitrogen (gas, 1 atm)[3]	N_2	20°	$\epsilon_0 - 1 =$ 527.40×10^{-6}	1592 Hz	1
oxygen (gas, 1 atm)[3]	O_2	20°	$\epsilon_0 - 1 =$ 494.31×10^{-6}	1592 Hz	1
phosphoric acid	H_3PO_4	25.0°	61	4.89 to 19.32 MHz	4
sulfuric acid	H_2SO_4	20°	106	10 MHz	4
xenon[3]	Xe	165.05°K	1.874	-	2
Organic Compounds					
formamide[3]	CH_3NO	25°	108.7	-	5
methane[3]	CH_4	111.65°K	1.622	-	2
methanol[3]	CH_4O	25°	32.70	-	6
methane	CH_4	20°	3.80^9	$\lambda = .2143$ cm	7
acrylonitrile[3]	C_3H_3N	20°	33.0	-	8
1,2 - dibromoethane	$C_2H_4Br_2$	RT	4.86^2	1 MHz	9
1,2 - dichloroethane	$C_2H_4Cl_2$	25°	10.38	3 MHz	10
1,2 - dichloroethane	$C_2H_4Cl_2$	RT	10.5^2	1 MHz	9
N-methylformamide[3]	C_2H_5NO	25°	171	-	5
ethanol[3]	C_2H_6O	25°	24.55	-	6
ethanol[3,5]	C_2H_6O	25°	24.44	-	11
ethanol	C_2H_6O	20.0°	2.97^8	$\lambda = .2135$ cm	7
ethyl ether	C_2H_6O	RT	4.38^2	1 MHz	9
methyl disulfide[3]	$C_2H_6S_2$	25.0°	9.6	10 MHz	12
ethylamine[3]	C_2H_7N	0°	8.7	1 MHz	13
propionitrile[3]	C_3H_5N	20°	29.7	-	8
1,3-dichloropropane	$C_3H_6Cl_2$	25°	10.08	3 MHz	10
2,2-dichloropropane	$C_3H_6Cl_2$	25°	11.20	3 MHz	10
N,N-dimethylformamide[3]	C_3H_7NO	25°	37.2	-	5
N-methylacetamide	C_3H_7NO	30°	178.9	-	5

Table I (Continued)

Name	Formula	Temp.	ϵ_0	Freq.	Ref.
n-propanol[3]	C_3H_8O	25°	20.33	-	6
isopropanol[3]	C_3H_8O	25°	19.41	-	6
n-propylamine[3]	C_3H_9N	0°	5.90	1 MHz	13
1,4-dichlorobutane	$C_4H_8Cl_2$	25°	9.51	3 MHz	10
tetrahydrothiophene - 1,1-dioxide[3]	$C_4H_8O_2S$	30°	43.3	10 MHz	14
N-methylpropionamide[3]	C_4H_9NO	25°	163.1	-	5
n-butanol[3]	$C_4H_{10}O$	25°	17.51	-	6
isobutanol[3]	$C_4H_{10}O$	25°	17.93	-	6
sec-butanol[3]	$C_4H_{10}O$	25°	16.56	-	6
t-butanol[3]	$C_4H_{10}O$	25°	12.47	-	6
n-butylamine[3]	$C_4H_{11}N$	0	5.4	1 MHz	13
diethylamine[3]	$C_4H_{11}N$	0°	4.5	1 MHz	13
pivalonitrile[3]	C_5H_9N	20°	21.1	-	8
1,5-dichloropentane	$C_5H_{10}Cl_2$	25°	9.92	3 MHz	10
methyl methacrylate	$C_5H_{10}O_2$	27°	5.78	-	15
tetrahydrofurfuryl alcohol	$C_5H_{10}O_2$	30°	13.48	1 MHz	16
3-methyltetrahydrothiophene-1,1-dioxide[3]	$C_5H_{10}O_2S$	25°	29.4	10 MHz	14
1,5-pentanediol	$C_5H_{12}O_2$	26°	25.3	1 MHz	16
n-amylamine[3]	$C_5H_{13}N$	0°	4.6	1 MHz	13
chlorobenzene[3]	C_6H_5Cl	20°	5.71	-	17
nitrobenzene	$C_6H_5NO_2$	RT	36.4[3]	1 MHz	9
1,6-dichlorohexane	$C_6H_{12}Cl_2$	25°	8.79	3 MHz	10
n-hexyl chloride	$C_6H_{13}Cl$	25°	5.820	3 MHz	10
2-methyl-2,4-pentanediol[3]	$C_6H_{14}O_2$	30°	24.4	1 MHz	16
di-n-propylamine[3]	$C_6H_{15}N$	0°	3.73	1 MHz	13
benzonitrile[3]	C_7H_5N	20°	25.9	-	8
o-nitrotoluene	$C_7H_7NO_2$	RT	27.4[3]	1 MHz	9
m-nitrotoluene	$C_7H_7NO_2$	RT	24.3[3]	1 MHz	9
o-nitroanisole	$C_7H_7NO_3$	RT	43[3]	1 MHz	9
1,7-dichloroheptane	$C_7H_{14}Cl_2$	25°	8.34	3 MHz	10
1,8-dichlorooctane	$C_8H_{16}Cl_2$	25°	7.64	3 MHz	10
di-n-butylamine[3]	$C_8H_{19}N$	0°	3.20	1 MHz	13
2,6-dimethylbenzonitrile	C_9H_9N	100°	16.8	-	8
1,10-dichlorodecane	$C_{10}H_{20}Cl_2$	25°	6.813	3 MHz	10
2-naphthyl o-hydroxybenzoate[3]	$C_{17}H_{12}O_3$	20°	6.65	-	18

Table II. Static Dielectric Constants of Pure Solids

Name	Formula	Temp.	ϵ_0	Freq.	State	Ref.
ammonium dihydrogen phosphate	$NH_4H_2PO_4$	-	$\epsilon_{\parallel} = 15.9$ $\epsilon_{\perp} = 57.0$	1 kHz[24]	S	19
diammonium uranyl oxalate	$(NH_4)_2UO_2(C_2O_4)_2$	-	8.14	-	S	20
diammonium uranyl oxalate trihydrate	$(NH_4)_2UO_2(C_2O_4)_2 \cdot 3H_2O$	-	6.06	-	S	20
argon	Ar	83.85°K	1.599	-	S	2
bismuth titanate	$Bi_4Ti_3O_{12}$	RT	135 to 220	1 kHz	S	21
hexaminocobalt (III) Chloride	$[Co(NH_3)_6]Cl_3$	QV	7.31	1 MHz	P	22*
cuprous chloride	CuCl	-	9.8	1 kHz[24]	S	19
diamond	C	-	5.93	1 kHz	S	23
iodine[3]	I_2	RT	$\epsilon_a = 6$ $\epsilon_b = 3$ $\epsilon_c = 40$	50 kHz to 50 MHz	S	24
krypton	Kr	116.05°K	1.784	-	S	2
potassium dihydrogen phosphate	KH_2PO_4	-	$\epsilon_{\parallel} = 21.3$ $\epsilon_{\perp} = 43.3$	1 kHz[24]	S	19
potassium trithionate	$K_2S_3O_6$	20°	5.7	1.8 MHz	S	25
potassium tetrathionate	$K_2S_4O_6$	20°	5.5	1.8 MHz	S	25
potassium pentathionate monohydrate	$K_2S_5O_6 \cdot H_2O$	20°	7.8	1.8 MHz	S	25
potassium hexathionate	$K_2S_6O_6$	20°	7.8	1.8 MHz	S	25
rubidium indium sulfate	$RbIn(SO_4)_2$	-	6.85	-	S	26
rubidium indium sulfate dihydrate	$RbIn(SO_4)_2 \cdot 2H_2O$	-	6.82	-	S	26
rubidium indium sulfate tetrahydrate	$RbIn(SO_4)_2 \cdot 4H_2O$	-	6.54	-	S	26
selenium[3]	Se	25°	$\epsilon_c = 19.85$	24.029 GHz	S	27
selenium[3]	Se	25°	11.20	24.029 GHz	P	27
selenium[3]	Se	25°	6.60	24.029 GHz	Am	27
sodium chloride	NaCl	QV	5.91	1 MHz	P	22*
disodium uranyl oxalate	$Na_2UO_2(C_2O_4)_2$	-	5.18	-	S	20
disodium uranyl oxalate monohydrate	$Na_2UO_2(C_2O_4)_2 \cdot H_2O$	-	5.37	-	S	20
disodium uranyl oxalate dihydrate	$Na_2UO_2(C_2O_4)_2 \cdot 2H_2O$	-	5.35	-	S	20
disodium uranyl oxalate trihydrate	$Na_2UO_2(C_2O_4)_2 \cdot 3H_2O$	-	5.25	-	S	20
disodium uranyl oxalate tetrahydrate	$Na_2UO_2(C_2O_4)_2 \cdot 4H_2O$	-	5.25	-	S	20

Table II (Continued)

Name	Formula	Temp.	ϵ_0	Freq.	State	Ref.
disodium uranyl oxalate pentahydrate	$Na_2UO_2(C_2O_4)_2 \cdot 5H_2O$	-	5.56	-	S	20
α-tantalum pentoxide[14]	Ta_2O_5	77°K	ϵ_0 = 30 ⊥ to cleavage plane ϵ_0 = 65 || to cleavage plane	1 kHz	S	28
β-tantalum pentoxide[12]	Ta_2O_5	292°K	24	1 kHz	P	28
xenon	Xe	161.35°K	2.033	-	S	2
		Organic Compounds				
methane[3]	CH_4	89.20	1.739	-	S	2
hexamethylenetetramine	$C_6H_{12}N_4$	-	2.5	1 kHz[24]	S	19
D - camphor	$C_{10}H_{16}O$	-20°	12.4	-	S	29
13,20-dotriacontanediol[7]	$C_{32}H_{66}O_2$	20°	4.04 to 8.2	80 Hz	P	30
		Polymers				
poly (methyl methacrylate)	$(C_5H_8O_2)_n$	22 to 24°	2.54 2.55	36 GHz 42 GHz	S	31
poly (tetrachlorohexatriene)	$(C_6H_4Cl_4)_n$	20°	2.3	QV	S	32*

Cross Reference List for Dipole Type (Table III)

Aliphatic

Unsubstituted: 2-1, 4-6, 5-6, 10-12

Halides: 1-0, 1-1, 2-1, 2-3, 2-4, 3-5, 3-6, 4-8, 5-10, 6-6, 6-12, 6-13, 7-14, 8-16, 10-20

Hydroxyl Oxygen: None.

Ether Oxygen: 4-10, 7-16, 10-22, 13-28

Double Bond Oxygen: 3-6, 4-5

Carboxyl or Ester Oxygen: 3-4

Amines: 4-11, 12-27

Other N Compounds: 1-0, 2-3, 2-4, 2-5, 3-5, 3-7, 4-5, 4-7, 4-8, 4-9, 5-9, 5-10

S Compounds: None

Aromatic

Unsubstituted: 8-8, 9-8, 10-14

Halides: 6-3, 6-4, 6-5, 7-5, 8-6, 8-7, 9-9, 12-8

Hydroxyl Oxygen: 6-3, 6-4, 10-8

Ester Oxygen: 7-9, 9-12, 11-10, 18-14, 24-18, 26-22

Double Bond Oxygen: 7-5, 7-6, 8-6, 8-7, 8-8, 8-9, 9-9, 9-10, 10-12, 11-14, 12-16, 29-20

Carboxyl or Ester Oxygen: 15-13, 18-17

Amines: 7-9, 8-9, 8-10, 9-10, 10-8, 10-9, 12-10, 13-10, 14-12, 16-16, 16-18, 17-16, 21-36

Other N Compounds: 6-3, 7-5, 8-7, 8-10, 9-9, 9-10, 10-7, 10-8, 12-8, 12-10, 13-10, 13-11, 14-12, 14-13, 14-14, 15-13, 16-16, 16-18, 17-16, 18-17, 20-18, 21-36

S Compounds: 12-8, 12-10, 13-10, 14-14, 18-14, 24-18

Heterocyclic

Unsubstituted: 2-2, 3-6, 4-5, 5-5, 6-7, 9-14, 10-11

Halides: None

Hydroxyl Oxygen: None

Ester Oxygen: None

Double Bond Oxygen: None

Carboxyl or Ester Oxygen: None

Amines: None

Other N Compounds: 6-6, 7-8, 8-10, 10-10, 10-14

S Compounds: None

Table III. Dipole Moments

Name	Formula	Dipole Moment	State	Method	Ref.
		Inorganic			
lithium bromide	LiBr	$\mu_0 = 7.26797$ $\mu_1 = 7.35228$ $\mu_2 = 7.43772$	G	St^{19}	33
lithium chloride	Li^6Cl^{35}	$\mu_0 = 7.119$ $\mu_1 = 7.206$ $\mu_2 = 7.296$ $\mu_3 = 7.386$	G	St^{10}	34
nitrogen dioxide	NO_2	0.316	G	St	35
nitrogen dioxide	$^{15}N^{16}O_2$	0.294	G	St	36
nitrogen dioxide	NO_2	0.38	B	Gu	37
nitrogen dioxide	NO_2	0.29	C	Gu	37
nitrogen dioxide	NO_2	0.37	Cy	Gu	37
nitrogen dioxide	NO_2	0.41	X	Gu	37
dinitrogen tetroxide	N_2O_4	0.54	B	Gu	37
dinitrogen tetroxide	N_2O_4	0.41	C	Gu	37
dinitrogen tetroxide	N_2O_4	0.53	Cy	Gu	37
dinitrogen tetroxide	N_2O_4	0.57	X	Gu	37
sodium fluoride	NaF	$\mu_0 = 8.19$ $\mu_1 = 8.29$ $\mu_2 = 8.41$	G	St^{19}	38
Sulfur monoxide	SO	1.55	G	St	39
water	H_2O	1.86	G	D	40

Table III (Continued)

Name	Formula	Dipole Moment	State	Method	Ref.
		Organic			
trifluoronitrosomethane	CF_3NO	0.31	G	D	41
chloroform	$CHCl_3$	1.13	D	D	42
formaldehyde	CH_2O	$\mu_e = 1.48$	G	St[11]	43
acetylene-d$_1$	C_2HD	> 0	G	St	44
trifluoroethylene	C_2HF_3	$\mu_a^2 = 0.01$ $\mu_b^2 = 1.95$	G	St	45
1,2,5-thiadiazole	$C_2H_2N_2S$	1.565	G	St	46
1,1,2-trifluoroethane	$C_2H_3F_3$	$\mu^2 = 2.49$	G	St	47
acetonitrile	C_2H_3N	3.56	B	Kr	48
1,2-dichloroethane	$C_2H_4Cl_2$	1.376[23]	Hx	Os	10
1,2-dinitroethane	$C_2H_4N_2O_4$	4.4	B	D	49
N-methyl methylenimine	C_2H_5N	1.53	G	St	50
acetamide	C_2H_5NO	3.75	G	D	40
N-methylformamide	C_2H_5NO	3.82	G	D	40
vinyl formate	$C_3H_4O_2$	1.48	G	St	51
cis-1-chloropropylene	C_3H_5Cl	1.64	G	St	52
propionitrile	C_3H_5N	3.59	B	Kr	48
1,3-dichloropropane	$C_3H_6Cl_2$	2.035[23]	Hx	Os	10
2,2-dichloropropane	$C_3H_6Cl_2$	2.290[23]	Hx	Os	10
acetone	C_3H_6O	2.85	D	Z	53
propionaldehyde	C_3H_6O	2.52[16]	G	St	54
s-trioxane	$C_3H_6O_3$	2.07	G	St	55
N,N-dimethylformamide	C_3H_7NO	3.80	G	D	40
N-methylacetamide	C_3H_7NO	3.71	G	D	40
pyrrole	C_4H_5N	1.75	Cy	HK	45
pyrrole	C_4H_5N	2.15	D	HK	56
imidodiacetodinitrile	$C_4H_5N_3$	3.52	D	He	57
acetylacetylene	C_4H_5O	2.4	G	St	58
isoprene	C_4H_6	0.25	G	St	59
butyronitrile	C_4H_7N	3.63	B	Kr	48
1,4-dichlorobutane	$C_4H_8Cl_2$	2.033[23]	Hx	Os	10
ℓ-2,3-dinitroxybutane	$C_4H_8N_2O_6$	3.83	B	HK	60
meso-2,3-dinitroxybutane	$C_4H_8N_2O_6$	4.19	B	HK	60
N,N-dimethylacetamide	C_4H_9NO	3.79	G	D	40
N-methylpropionamide	C_4H_9NO	3.59	G	D	40

Table III (Continued)

Name	Formula	Dipole Moment	State	Method	Ref.
trimethyl orthoformate	$C_4H_{10}O_3$	1.66	C	L	61
isobutylamine	$C_4H_{11}N$	1.15	Cy	Z	62
isobutylamine	$C_4H_{11}N$	1.38	B	Z	62
pyridine	C_5H_5N	2.27	B	Sm[22]	63
pyridine	C_5H_5N	2.34	C	Z	53
cyclopentadiene	C_5H_6	0.34	C	L	64
pivalonitrile	C_5H_9N	3.64	B	Kr	48
1,5-dichloropentane	$C_5H_{10}Cl_2$	2.332[23]	Hx	Os	10
dℓ-erythro-2,3-dinitroxypentane	$C_5H_{10}N_2O_6$	4.09	B	HK	60
dℓ-threo-2,3-dinitroxypentane	$C_5H_{10}N_2O_6$	3.91	B	HK	60
2,6-dibromo-p-nitrophenol	$C_6H_3Br_2NO_3$	3.32	B	Z	65
2,6-dichloro-p-nitrophenol	$C_6H_3Cl_2NO_3$	3.04	B	Z	65
bromobenzene	C_6H_5Br	1.57	Cy	Z	53
chlorobenzene	C_6H_5Cl	1.72	G	D	40
α-hexachlorocyclohexane	$C_6H_6Cl_6$	2.18	B	He	66
δ-hexachlorocyclohexane	$C_6H_6Cl_6$	2.22	B	He	66
γ-hexachlorocyclohexane	$C_6H_6Cl_6$	2.82	B	He	66
nicotinamide	$C_6H_6N_2O$	3.07	B	Sm[22]	63
γ-picoline	C_6H_7N	2.60	Cy	Z	53
1,6-dichlorohexane	$C_6H_{12}Cl_2$	2.447[23]	Hx	Os	10
n-hexyl chloride	$C_6H_{13}Cl$	1.989	Hx[23]	Os	10
o-chlorobenzaldehyde	C_7H_5ClO	2.80	B	Kr	67
m-chlorobenzaldehyde	C_7H_5ClO	2.44	B	Kr	67
p-chlorobenzaldehyde	C_7H_5ClO	1.83	B	Kr	67
benzonitrile	C_7H_5N	4.08	D	He	68
o-nitrobenzaldehyde	$C_7H_5NO_3$	3.90	B	Kr	67
p-nitrobenzaldehyde	$C_7H_5NO_3$	2.15	B	Kr	67
benzaldehyde	C_7H_6O	2.75	B	Kr	67
N-methylnicotinamide	$C_7H_8N_2O$	3.42	B	Sm[22]	63
o-anisidine	C_7H_9NO	1.53	B	D	69
o-anisidine	C_7H_9NO	1.50	T	D	69
o-anisidine	C_7H_9NO	1.48	X	D	69
m-anisidine	C_7H_9NO	1.71	B	D	69
m-anisidine	C_7H_9NO	1.69	T	D	69
m-anisidine	C_7H_9NO	1.66	X	D	69
p-anisidine	C_7H_9NO	1.96	B	D	69

Table III (Continued)

Name	Formula	Dipole Moment	State	Method	Ref.
p-anisidine	C_7H_9NO	1.92	T	D	69
p-anisidine	C_7H_9NO	1.91	X	D	69
1,7-dichloroheptane	$C_7H_{14}Cl_2$	2.491^{23}	Hx	Os	10
triethyl orthoformate	$C_7H_{16}O_3$	1.67	C	L	61
2,5-dibromoacetophenone	$C_8H_6Br_2O$	2.63	B	Z	70
2,5-dichloroacetophenone	$C_8H_6Cl_2O$	2.66	B	Z	70
o-bromoacetopheone	C_8H_7BrO	3.22	B	Z	70
o-chloroacetophenone	C_8H_7ClO	3.15	B	Z	70
p-chloroacetophenone	C_8H_7ClO	2.38	B	Z	70
o-nitroacetophenone	$C_8H_7NO_3$	4.77	B	Z	70
p-nitroacetophenone	$C_8H_7NO_3$	3.26	B	Z	70
styrene	C_8H_8	0.181	QV	QV	71*
acetophenone	C_8H_8O	2.96	C	L	72
o-aminoacetophenone	C_8H_9NO	1.90	B	Z	70
N,N-dimethylnicotinamide	$C_8H_{10}N_2O$	3.99	B	Sm^{22}	63
N-ethylnicotinamide	$C_8H_{10}N_2O$	3.44	B	Sm^{22}	63
p-nitroso-N,N-dimethylaniline	$C_8H_{10}N_2O$	$\mu_g = 6.45$ $\mu_e = 12^{29}$	Hx^{28}	Z	73
p-nitro-N,N-dimethylaniline	$C_8H_{10}N_2O_2$	$\mu_g = 6.85$ $\mu_e = 14.5^{29}$	B	Z	73
1,8-dichlorooctane	$C_8H_{16}Cl_2$	2.528^{23}	Hx	Os	10
indene	C_9H_8	0.62	B	L	74
5-bromo-2-methylacetophenone	C_9H_9BrO	1.96	B	Z	70
5-chloro-2-methylacetophenone	C_9H_9ClO	2.01	B	Z	70
5-iodo-2-methylacetophenone	C_9H_9IO	1.94	B	Z	70
2-methyl-5-nitroacetophenone	$C_9H_9NO_3$	2.95	B	Z	70
p-N,N-dimethylamino-benzonitrile	$C_9H_{10}N_2$	$\mu_g = 6.55$ $\mu_e = 12.8^{27}$	D	Z	73
o-methylacetophenone	$C_9H_{10}O$	2.65	B	Z	70
p-methylacetophenone	$C_9H_{10}O$	3.19	B	Z	70
2,6-dimethylanisole	$C_9H_{12}O$	1.28	B	Gu	75
3,5-dimethylanisole	$C_9H_{12}O$	1.26	B	Gu	75
2-methyl-4-oxooctahydro-1-pyridine (Me axial)	$C_9H_{14}NO$	3.16	Solution	D	76
2-methyl-4-oxooctahydro-1-pyridine (Me equitorial)	$C_9H_{14}NO$	2.90	Solution	D	76

Table III (Continued)

Name	Formula	Dipole Moment	State	Method	Ref.
1-nitronaphthalene	$C_{10}H_7NO_2$	3.96	B	Z	77
3-nitro-1-naphthylamine	$C_{10}H_8N_2O_2$	5.47	D	Z	77
4-nitro-1-naphthylamine	$C_{10}H_8N_2O_2$	6.40	B	Z	77
4-nitro-1-naphthylamine	$C_{10}H_8N_2O_2$	7.04	D	Z	77
4-nitro-2-naphthylamine	$C_{10}H_8N_2O_2$	4.70	B	Z	77
4-nitro-2-naphthylamine	$C_{10}H_8N_2O_2$	4.99	D	Z	77
5-nitro-1-naphthylamine	$C_{10}H_8N_2O_2$	5.16	B	Z	77
5-nitro-1-naphthylamine	$C_{10}H_8N_2O_2$	5.78	D	Z	77
5-nitro-2-naphthylamine	$C_{10}H_8N_2O_2$	5.42	D	Z	77
6-nitro-1-naphthylamine	$C_{10}H_8N_2O_2$	5.14	B	Z	77
6-nitro-1-naphthylamine	$C_{10}H_8N_2O_2$	5.51	D	Z	77
6-nitro-2-naphthylamine	$C_{10}H_8N_2O_2$	6.04	B	Z	77
6-nitro-2-naphthylamine	$C_{10}H_8N_2O_2$	7.13	D	Z	77
7-nitro-1-naphthylamine	$C_{10}H_8N_2O_2$	4.41	B	Z	77
7-nitro-1-naphthylamine	$C_{10}H_8N_2O_2$	4.74	D	Z	77
7-nitro-2-naphthylamine	$C_{10}H_8N_2O_2$	5.89	B	Z	77
7-nitro-2-naphthylamine	$C_{10}H_8N_2O_2$	6.44	D	Z	77
8-nitro-2-naphthylamine	$C_{10}H_8N_2O_2$	4.82	D	Z	77
α-naphthol	$C_{10}H_8O$	$\mu_g = 1.48$ $\mu_e = 2.67$	-	Z	78
β-Naphthol	$C_{10}H_8O$	$\mu_g = 1.56$ $\mu_e = 3.28$	-	Z	78
1-naphthylamine	$C_{10}H_9N$	1.74	D	Z	77
4-nitro-2,3-dimethylindole	$C_{10}H_{10}N_2O_2$	6.56	D	HK	56
5-nitro-2,3-dimethylindole	$C_{10}H_{10}N_2O_2$	7.37	D	HK	56
6-nitro-2,3-dimethylindole	$C_{10}H_{10}N_2O_2$	6.58	D	HK	56
7-nitro-2,3-dimethylindole	$C_{10}H_{10}N_2O_2$	4.00	D	HK	56
2,3-dimethylindole	$C_{10}H_{11}N$	3.05	D	HK	56
dicyclopentadiene	$C_{10}H_{12}$	0.40	C	L	63
2,4,6-trimethylbenzaldehyde	$C_{10}H_{12}O$	2.95	C	L	72
durene	$C_{10}H_{14}$	0	C	L	72
N,N-diethylnicotinamide	$C_{10}H_{14}N_2O$	4.15	B	Sm[22]	63
1,10-dichlorodecane	$C_{10}H_{20}Cl_2$	2.581[23]	Hx	Os	10
tri-n-propyl orthoformate	$C_{10}H_{22}O_3$	1.64	C	L	61
2,4,6-trimethylacetophenone	$C_{11}H_{14}O$	2.81	C	L	72

Table III (Continued)

Name	Formula	Dipole Moment	State	Method	Ref.
β-naphtylmethylether	$C_{11}H_{10}O$	$\mu_g = 1.2$ $\mu_e = 2.8$	-	Z	78
2,4-dibromophenol	$C_6H_4Br_2O$	1.35	B	Z	65
p,p'-dichloroazobenzene	$C_{12}H_8Cl_2N_2$	0.64	B	QV	79*
p,p'-dichloroazoxybenzene	$C_{12}H_8Cl_2N_2O$	1.32	B	QV	79*
p,p'-dichloroazothiobenzene	$C_{12}H_8Cl_2N_2S$	0.74	B	QV	79*
azobenzene-2-sulfenyl bromide	$C_{12}H_{10}BrN_2$	6.34	B	Sm	80
azobenzene-2-sulfenyl bromide	$C_{12}H_{10}BrN_2$	6.44	D	Sm	80
axobenzene-2-sulfenyl chloride	$C_{12}H_{10}ClN_2$	6.02	B	Sm	80
azobenzene-2-sulfenyl chloride	$C_{12}H_{10}Cln_2$	6.14	D	Sm	80
azobenzene-2-sulfenyl iodide	$C_{12}H_{10}IN_2$	6.75	D	Sm	80
azobenzene-2-sulfenyl iodide	$C_{12}H_{10}IN_2$	6.61	B	Sm	80
4-amino-4'-nitrobiphenyl	$C_{12}H_{10}N_2O$	$\mu_g = 6.05$ $\mu_e = 19.7$[37]	B[38]	Z	73
azothiobenzene	$C_{12}H_{10}N_2S$	1.15	B	QV	79*
2,3,5,6-tetramethylacetophenone	$C_{12}H_{16}O$	2.81	C	L	72
tri-n-butylamine	$C_{12}H_{27}N$	1.20	Cy	Z	62
4-amino-4'-cyanobiphenyl	$C_{13}H_{10}N_2$	$\mu_g = 5.65$ $\mu_e = 9.0$	B[38]	Z	73
2-amino-7-nitrofluorene	$C_{13}H_{10}N_2O_2$	$\mu_g = 5.65$ $\mu_e = 20.3$[37]	B[38]	Z	73
azobenzene-2-sulfenylcyanide	$C_{13}H_{10}N_2S$	3.64	B	Sm	80
azobenzene-2-sulfenylcyanide	$C_{13}H_{10}N_2S$	3.66	D	Sm	80
C,N-diphenylnitrone	$C_{13}H_{11}NO$	3.37	B	He	81
tri-n-butyl orthoformate	$C_{13}H_{28}O_3$	1.66	C	L	61
4-amino-4'-nitrostilbene	$C_{14}H_{12}N_2O_2$	$\mu_g = 6.5$ $\mu_e = 21.0$[37]	B[38]	Z	73
C-(m-nitrophenyl)-N-benzylnitrone	$C_{14}H_{12}N_2O_3$	4.67	B	He	81
C-phenyl-N-benzylnitrone	$C_{14}H_{13}NO$	3.47	B	He	81
p,p'-dimethylazoxybenzene	$C_{14}H_{14}N_2O$	1.78	B	QV	79*
p,p'-dimethylazothiobenzene	$C_{14}H_{14}N_2S$	1.46	B	QV	79*

Table III (Continued)

Name	Formula	Dipole Moment	State	Method	Ref.
C-acetoxy-C,N-diphenylnitrone	$C_{15}H_{13}NO_3$	3.95	B	He	81
4-dimethylamino-4'-nitro-stilbene	$C_{16}H_{16}N_2O_2$	$\mu_g = 7.05$ $\mu_e = 21.9$	C^{28}	Z	73
C-(N,N-dimethylaminophenyl)-N-benzylnitrone	$C_{16}H_{18}N_2O$	3.79	B	He	81
4-dimethylamino-4'-cyanostilbene	$C_{17}H_{16}N_2$	$\mu_g = 6.95$ $\mu_e = 17.5^{29}$	B^{28}	Z	73
2-phenoxybiphenyl	$C_{18}H_{14}O$	1.14	B	Gu	82
4-phenoxybiphenyl	$C_{18}H_{14}O$	1.14	B	Gu	82
2-phenylthiobiphenyl	$C_{18}H_{14}S$	1.37	B	G	82
4-phenylthiobiphenyl	$C_{18}H_{14}S$	1.55	B	Gu	82
C-phenyl-N-(α,α-diacetoxy-benzyl) nitrone	$C_{18}H_{17}NO_5$	4.44	B	He	81
C,C-diphenyl-N-benzylnitrone	$C_{20}H_{18}NO$	3.40	B	He	81
triisoamylammonium picrate	$C_{21}H_{36}N_4O_6$	12.1	B	Gu	83
bis(2-biphenylyl) ether	$C_{24}H_{18}O$	1.03	B	Gu	82
bis(4-biphenylyl) ether	$C_{24}H_{18}O$	1.20	B	Gu	82
2,2'-diphenoxybiphenyl	$C_{24}H_{18}O_2$	1.25	B	Gu	82
4,4'-diphenoxybiphenyl	$C_{24}H_{18}O_2$	1.49	B	Gu	82
2,2'-bis(phenylthio) biphenyl	$C_{24}H_{18}S_2$	1.55	B	Gu	82
4,4'-bis(phenylthio) biphenyl	$C_{24}H_{18}S_2$	1.85	B	Gu	82
bis(diphenylmethyl) ether	$C_{26}H_{22}O$	1.12	B	Z	84
bis(diphenylmethyl) ether	$C_{26}H_{22}O$	1.01	C	Z	84
bis(diphenylmethyl) ether	$C_{26}H_{22}O$	1.08	D	Z	84
bis(diphenylmethyl) ether	$C_{26}H_{22}O$	1.05	diphenylmethane solution	Z	84
tetraphenylcyclopentadienone	$C_{29}H_{20}O$	3.42	B	Z	84
tetraphenylcyclopentadienone	$C_{29}H_{20}O$	3.42	C	Z	84
tetraphenylcyclopentadienone	$C_{29}H_{20}O$	3.43	D	Z	84
tetraphenylcyclopentadienone	$C_{29}H_{20}O$	3.38	diphenylmethane solution	Z	84
Metallic and Nonmetallic-Organic Compounds					
triisopropanolamine borate	$C_9H_{18}BNO_3$	6.61	B	L	85
bis-[(aminooxy)di-n-butylborane]	$C_{16}H_{40}B_2N_2O_2$	0.0	C	Gu	86
bis-[(n-butylaminooxy)di-n-butylborane]	$C_{24}H_{56}B_2N_2O_2$	0.0	C	Gu	86

Table III (Continued)

Name	Formula	Dipole Moment	State	Method	Ref.
trichlorochloromethylgermane	CH_2Cl_4Ge	2.10	B	L	87
trichloro-β-chloroethenylgermane	$C_2H_2Cl_4Ge$	1.86	B	L	87
ethenyltribromogermane	$C_2H_3Br_3Ge$	2.47	B	L	87
bromotrimethylgermane	C_3H_9BrGe	2.84	B	-	88
chlorotrimethylgermane	C_3H_9ClGe	2.78	B	-	88
fluorotrimethylgermane	C_3H_9FGe	2.51	B	-	88
iodotrimethylgermane	C_3H_9GeI	2.81	B	-	88
trimethylchloromethylgermane	$C_4H_{11}ClGe$	1.85	B	L	87
ethynyltrimethylgermane	$C_5H_{10}Ge$	0.79	B	L	87
α-chloroethenyltrimethylgermane	$C_5H_{11}ClGe$	1.82	B	L	87
β-chloroethenyltrimethylgermane	$C_5H_{11}ClGe$	1.86	B	L	87
cyclopentyltrimethylgermane	$C_8H_{18}Ge$	0	B	L	87
methinophosphide[15]	CH P	0.390	G	St	89
dimethylphosphine	C_2H_7P	1.23	G	St	90
triethylphosphine	$C_6H_{15}P$	1.48	B	Sm	91
triethylphosphine oxide	$C_6H_{15}OP$	4.37	B	Sm	91
tri-n-propylphosphine	$C_9H_{21}P$	1.48	B	Sm	91
tri-n-propylphosphine oxide	$C_9H_{21}OP$	4.36	B	Sm	91
tri-n-butylphosphine	$C_{12}H_{27}P$	1.49	B	Sm	91
tri-n-butylphosphine oxide	$C_{12}H_{27}OP$	4.35	B	Sm	91
tributyl phosphate	$C_{12}H_{27}O_4P$	3.01	C	L	92
tri-n-pentylphosphine	$C_{15}H_{33}P$	1.48	B	Sm	91
tri-n-pentylphosphine oxide	$C_{15}H_{33}OP$	4.35	B	Sm	91
triphenylphosphine	$C_{18}H_{15}P$	1.49	B	Sm	91
triphenylphosphine oxide	$C_{18}H_{15}OP$	4.44	B	Sm	91
trisilylamine	H_9NSI_3	0	G	D	93
ethynyltrimethylsilane	$C_5H_{10}Si$	0.45	B	L	87
triethyltin acetate	$C_8H_{18}O_2Sn$	2.05	B	D	94
triethylethoxytin	$C_8H_{20}OSn$	2.19	octane solution	D	94
dibutyltin diacetate	$C_{12}H_{24}O_4Sn$	1.39	B	D	94
hexaethyldistannoxane	$C_{12}H_{30}OSn_2$	1.36	octane solution	D	94
tributylmethoxytin	$C_{13}H_{30}OSn$	2.18	octane solution	D	94
tributyltin acetate	$C_{14}H_{30}O_2sn$	2.03	B	D	94
dichlorotetrabutyldistanoxane	$[C_{16}H_{36}Cl_2\text{-}OSn_2]_2$	2.24	decane solution	D	94

Table III (Continued)

Name	Formula	Dipole Moment	State	Method	Ref.
tetrabutyldistannoxane diacetate	$[C_{20}H_{42}O_5\text{-}Sn_2]_2$	2.87	decane solution	D	94
hexabutyldistanoxane	$C_{24}H_{54}OSn_2$	1.43	decane solution	D	94
dibutyltin dilaurate	$C_{30}H_{64}O_4Sn$	1.45	B	D	94
tetrabutyldistannoxane dilaurate	$[C_{38}H_{82}O_5Sn]_2$	3.31	B	P	94
	Complexes				
beryllium chloride + 2 cinnamaldehyde	$BeCl_2 \cdot 2\ C_9H_8O$	7.33	B	He	68
cadmium iodide + 2 pyridine	$CdI_2 \cdot 2C_5H_5N$	9.37	B	He	68
chromium pentacarbonyl dimethyl sulfoxide	$C_7H_6CrO_6S$	4.33	B	D	95
chromium pentacarbonyl n-propylamine	$C_8H_9CrNO_5$	5.84	B	D	95
chromium pentacarbonyl pyrrolidine	$C_9H_9CrNO_5$	5.88	B	D	95
chromium dicarbonyl dimethyl sulfoxide	$C_{10}H_{12}CrO_3S$	3.10	B	D	95
chromium pentacarbonyl cyclohexyl isonitrile	$C_{12}H_{11}CrNO_5$	5.62	B	D	95
chromium tricarbonyl p-hydroquinone diacetate	$C_{13}H_{10}CrO_7$	4.14	B	D	95
chromium dicarbonyl pyridine benzene	$C_{13}H_{11}CrNO_2$	5.04	B	D	95
chromium dicarbonyl dimethyl sulfoxide mesitylene	$C_{13}H_{18}CrO_3S$	3.47	B	D	95
chromium dicarbonyl acetonitrile p-hydroquinone diacetate	$C_{14}H_{13}CrNO_6$	4.73	B	D	95
chromium dicarbonyl dimethyl sulfoxide p-hydroquinone diacetate	$C_{14}H_{16}CrO_2S$	3.00	B	D	95
chromium dicarbonyl pyridine mesitylene	$C_{14}H_{17}CrNO_2$	5.45	B	D	95
chromium dicarbonyl cyclohexyl isonitrile benzene	$C_{15}H_{17}CrNO_2$	4.50	B	D	95
chromium dicarbonyl quinoline benzene	$C_{17}H_{13}CrNO_2$	5.15	B	D	95
chromium dicarbonyl pyridine p-hydroquinone diacetate	$C_{17}H_{15}CrNO_6$	4.89	B	D	95

Table III (Continued)

Name	Formula	Dipole Moment	State	Method	Ref.
chromium dicarbonyl piperidine p-hydroquinone diacetate	$C_{17}H_{21}CrNO_6$	4.30	B	D	95
chromium dicarbonyl aniline p-hydroquinone diacetate	$C_{18}H_{17}CrNO_6$	3.83	B	D	95
chromium tetracarbonyl bis[cyclohexyl isonitrile]	$C_{18}H_{22}CrN_2O_4$	0	B	D	95
chromium dicarbonyl benzonitrile p-hydroquinone diacetate	$C_{19}H_{15}CrNO_6$	5.10	B	D	95
chromium dicarbonyl cyclohexyl isonitrile p-hydroquinone diacetate	$C_{19}H_{21}CrNO_6$	4.48	B	D	95
chromium dicarbonyl quinoline mesitylene	$C_{20}H_{19}CrNO_2$	5.42	B	D	95
chromium dicarbonyl quinoline p-hydroquinone diacetate	$C_{21}H_{17}CrNO_6$	5.00	B	D	95
chromium pentacarbonyl triphenylphosphine	$C_{23}H_{15}CrO_5P$	5.14	B	D	95
chromium dicarbonyl quinoline hexamethylbenzene	$C_{23}H_{25}CrNO_2$	5.73	B	D	95
chromium dicarbonyl triphenylphosphine benzene	$C_{24}H_{21}CrO_2P$	4.13	B	D	95
chromium dicarbonyl triphenylphosphine mesitylene	$C_{29}H_{27}CrO_2P$	4.61	B	D	95
chromium dicarbonyl triphenylphosphine p-hydroquinone diacetate	$C_{30}H_{25}CrO_6P$	3.98	B	D	95
chromium dicarbonyl triphenylphosphine hexamethylbenzene	$C_{32}H_{33}CrO_2P$	5.16	B	D	95
chromium tetracarbonyl bis[triphenylphosphine]	$C_{40}H_{30}CrO_4P$	0	B	D	95
bis-(3-chloro-N-n-propylsalicylaldimino)-cobalt (II)	$C_{20}H_{22}Cl_2CoN_2O_2$	6.32	-	L	96
bis-(5-chloro-N-n-propylsalicylaldimine)-cobalt (II)	$C_{20}H_{22}Cl_2CoN_2O_2$	4.72	-	L	96

Table III (Continued)

Name	Formula	Dipole Moment	State	Method	Ref.
bis-(N-n-propylsalicylal-imino) cobalt (II)	$C_{20}H_{24}CoN_2O_2$	4.67	-	L	96
bis-(N-n-amylsalicylald-imino) cobalt (II)	$C_{24}H_{32}CoN_2O_2$	4.62	-	L	96
bis-(N-phenylsalicyaldimino) cobalt (II)	$C_{26}H_{20}CoN_2O_2$	4.16	-	L	96
bis-(3,4-benzo-N-n-propylsalicylaldimino)-cobalt (II)	$C_{28}H_{28}CoN_2O_2$	4.10	-	L	96
tris-(3-chloro-N-n-propylsalicylaldimino)-cobalt (III)	$C_{30}H_{33}Cl_3CoN_3O_3$	6.27	-	L	96
tris-(5-chloro-N-n-propyl-salicylaldimino)-cobalt (III)	$C_{30}H_{33}Cl_3CoN_3O_3$	4.98	-	L	96
tris-(n-phenylsalicylal-dimino) cobalt (III)	$C_{39}H_{30}CoN_3O_3$	3.70	-	L	96
tris-(3,4-benzo-N-n-propylsalicyaldimino)-cobalt (III)	$C_{42}H_{42}CoN_3O_3$	4.28	-	L	96
tris-(5,6-benzo-N-n-propylsalicyaldimino)-cobalt (III)	$C_{42}H_{42}CoN_3O_3$	3.96	-	L	96
cyclopentadienylmanganese dicarbonyl sulfur dioxide	$C_7H_5MnO_4S$	2.05	B	D	95
methylcyclopentadienyl-manganese dicarbonyl sulfur dioxide	$C_8H_7MnO_4S$	2.01	B	D	95
cyclopentadienylmanganese dicarbonyl acetonitrile	$C_9H_8MnNO_3$	4.92	B	D	95
cyclopentadienylmanganese dicarbonyl dimethyl sulfoxide	$C_9H_{11}MnO_3S$	3.01	B	D	95
cyclopentadienylmanganese dicarbonyl dimethyl sulfite	$C_9H_{11}MnO_5S$	3.32	B	D	95
methylcyclopentadienyl-manganese dicarbonyl dimethyl sulfoxide	$C_{10}H_{13}MnO_3S$	3.35	B	D	95
cyclopentadienylmanganese dicarbonyl tetramethylene sulfide	$C_{11}H_{13}MnO_2S$	4.05	B	D	95
cyclopentadienylmanganese dicarbonyl pyridine	$C_{12}H_{10}MnNO_2$	5.35	B	D	95

Table III (Continued)

Name	Formula	Dipole Moment	State	Method	Ref.
cyclopentadienylmanganese dicarbonyl piperidine	$C_{12}H_{16}MnNO_2$	4.70	B	D	95
cyclopentadienylmanganese dicarbonyl aniline	$C_{13}H_{12}MnNO_2$	3.88	B	D	95
cyclopentadienylmanganese dicarbonyl benzonitrile	$C_{14}H_{10}MnNO_2$	5.24	B	D	95
cyclopentadienylmanganese dicarbonyl cyclohexyl isonitrile	$C_{14}H_{14}MnNO_2$	4.64	B	D	95
cyclopentadienylmanganese dicarbonyl quinoline	$C_{16}H_{12}MnNO_2$	5.42	B	D	95
methylcyclopentadienyl-dicarbonyl diphenyl sulfoxide	$C_{20}H_{17}MnO_3S$	2.91	B	D	95
cyclopentadienylmanganese dicarbonyl triphenyl-phosphine	$C_{25}H_{20}MnO_2P$	4.14	B	D	95
mercuric chloride + dioxane	$HgCl_2 \cdot C_4H_8O_2$	3.71	D	He	68
mercuric bromide + 2 tetra-hydrothiophene	$HgBr_2 \cdot 2C_4H_8S$	4.84	B	D	97
mercuric bromide + 2 diethyl sulfide	$HgBr_2 \cdot 2C_4H_{10}S$	4.47	B	D	97
mercuric bromide + 2 dipropyl sulfide	$HgBr_2 \cdot 2C_6H_{14}S$	3.97	B	D	97
mercuric bromide + 2 dibutyl sulfide	$HgBr_2 \cdot 2C_8H_{18}S$	4.57	B	D	97
mercuric bromide + 2 diisoheptyl sulfide	$HgBr_2 \cdot 2C_{14}H_{30}S$	4.45	B	D	97
mercuric bromide + 2 diheptyl sulfide	$HgBr_2 \cdot 2C_{14}H_{30}S$	4.50	B	D	97
molybdenum pentacarbonyl acetonitrile	$C_7H_3MoNO_5$	6.84	B	D	95
molybdenum tetracarbonyl bis[acetonitrile]	$C_8H_6MoN_2O_4$	9.65	B	D	95
molybdenum pentacarbonyl cyclohexyl isonitrile	$C_{12}H_{11}MoNO_5$	5.70	B	D	95
nickel carbonyl trimethoxyphosphine	$C_9H_9NiO_6P$	3.22	Cy	Gu	98
nickel carbonyl triethylphosphine	$C_9H_{15}NiO_3P$	4.24	Cy	Gu	98
nickel carbonyl bis-trimethoxyphosphine	$C_{14}H_{18}NiO_8P_2$	3.11	Cy	Gu	98

Table III (Continued)

Name	Formula	Dipole Moment	State	Method	Ref.
nickel carbonyl bis-triethylphosphine	$C_{14}H_{30}NiO_2P_2$	4.40	Cy	Gu	98
nickel carbonyl tris-triemethoxyphosphine	$C_{19}H_{27}NiO_{11}P_3$	2.80	Cy	Gu	98
tungsten pentacarbonyl dimethyl sulfoxide	$C_7H_6O_6SW$	4.82	B	D	95
tungsten pentacarbonyl triphenyl phosphine	$C_{23}H_{15}O_5PW$	5.36	B	D	95
zinc chloride + 2 pyridine	$ZnCl_2 \cdot 2C_5H_5N$	9.06	D	He	68
zinc chloride + 2 aniline	$ZnCl_2 \cdot 2C_6H_7N$	6.69	D	He	68
zinc chloride + 2 benzonitrile	$ZnCl_2 \cdot 2C_7H_5N$	7.88	D	He	68
zinc chloride + 2 p-toluidine	$ZnCl_2 \cdot 2C_7H_9N$	7.85	D	He	68
	Polymers				
polycyclopentadiene	$(C_5H_6)_n$ n = 3	0.51	B	L	64
polycyclopentadiene	$(C_5H_6)_n$ n = 4	0.55	B	L	64
polycyclopentadiene	$(C_5H_6)_n$ n = 9.1	0.55	B	L	64
polycyclopentadiene	$(C_5H_6)_n$ n = 22.3	0.58	B	L	64
polycyclopentadiene	$(C_5H_6)_n$ n = 30.7	0.56	B	L	64
poly (n-butyl methacrylate) (isotactic)	$(C_8H_{14}O_2)_n$	1.88^{26}	B	H-K	99
poly (tert-butyl methacrylate) (isotactic)	$(C_8H_{14}O_2)_n$	1.95^{26}	B	H-K	99
polyindene	$(C_9H_8)_n$ n = 3.5	1.08	B	L	74
polyindene	$(C_9H_8)_n$ n = 4.9	1.10	B	L	74
polyindene	$(C_9H_8)_n$ n = 7.4	1.21	B	L	74
polyindene	$(C_9H_8)_n$ n = 13.3	1.14	B	L	74
polyindene	$(C_9H_8)_n$ n = 20.0	0.91	B	L	74
polyindene	$(C_9H_8)_n$ n = 23.0	0.88	B	L	74

Table III (Continued)

Name	Formula	Dipole Moment	State	Method	Ref.
polyindene	$(C_9H_8)_n$ $n = 30.0$	0.87	B	L	74
polyindene	$(C_9H_8)_n$ $n = 36.0$	1.10	B	L	74

Table IV. Unresolved Relaxation Times

Name	Formula	Temp.	State	τ	α	Method	Ref.
		Organic Compounds					
trichlorofluoromethane	CCl_3F	20°	D	6.3	0	CC	42
chloroform	$CHCl_3$	20°	L	5.4	0	CC	42
chloroform	$CHCl_3$	20°	D	16.5	0	CC	42
formamide[3]	CH_3NO	25°	L	39	-	D	5
acetonitrile[3]	C_2H_3N	30°	L	3.8	0.14	CC	100
acetonitrile	C_2H_3N	30°	B	2.4	-	Kr	48
N-methylformamide[3]	C_2H_5NO	11.1°	L	250	-	D	5
acetone	C_2H_6O	25°	D	4.5	-	CC	53
ethylamine[3]	C_2H_7N	0°	L	4.72	0.07	CC	13
propionitrile[3]	C_3H_5N	30°	L	4.7	0.08	CC	100
propionitrile	C_3H_5N	30°	B	3.2	-	Kr	48
N,N-dimethylformamide[3]	C_3H_7NO	37.3°	L	13	-	D	5
N-methylacetamide[3]	C_3H_7NO	31.4°	L	74	-	D	5
glycerol[21]	$C_3H_8O_3$	-6.7°	L	3.85×10^4	0.66^{20}	CD	101
n-propylamine[3]	C_3H_9N	0°	L	4.0	0.0	CC	13
butyronitrile[3]	C_4H_7N	30°	L	6.2	0.02	CC	100
butyronitrile	C_4H_7N	30°	B	3.82	-	Kr	48
N-methylpropionamide[3]	C_4H_9NO	28.2	L	127	-	D	5
n-butylamine[3]	$C_4H_{11}N$	0°	L	5.74	0.0	CC	13
diethylamine[3]	$C_4H_{11}N$	0°	L	8.16	0.07	CC	13
pyridine	C_5H_5N	25°	C	5.8	-	CC	53
methyl methacrylate	$C_5H_8O_2$	-80°	S^{25}	$f_m = 35$ Hz	$\alpha\frac{\pi}{2} = 26°$	CC	15
pivalonitrile[3]	C_5H_9N	30°	L	7.5	0.00	CC	100
pivalonitrile	C_5H_9N	30°	B	5.1	-	Kr	48
tetrahydrofurfuryl alcohol	$C_5H_{10}O_2$	30°	L	61	0.025	CC	16
1,5-pentanediol	$C_5H_{12}O_2$	26°	L	13.2×10^3	0.70^{20}	CD	16
n-amylamine[3]	$C_5H_{13}N$	0°	L	5.01	0.08	CC	13

Table IV (Continued)

Name	Formula	Temp.	State	τ	α	Method	Ref.
2,6-dibromo-p-nitrophenol[3]	$C_6H_3Br_2NO_3$	20°	B	56	0.03	CC	65
2,6-dichloro-p-nitrophenol[3]	$C_6H_3Cl_2NO_3$	20°	B	69	0	CC	65
2,4-dibromophenol[3]	$C_6H_4Br_2O$	20°	B	23	0.24	CC	65
2,6-dibromophenol[3,17]	$C_6H_4Br_2O$	20°	B	23	0.13	CC	65
2,6-dichloro-p-nitro aniline[3]	$C_6H_4Cl_2N_2O_2$	20°	B	61	-	Z	65
bromobenzene	C_6H_5Br	20°	Cy	12.0	-	CC	53
o-chloroaniline	C_6H_6ClN	35°	B	5.4	-	Kr	102
γ-picoline	C_6H_7N	25°	Cy	8.1	-	CC	53
2-methyl-2,4-pentanediol[3]	$C_6H_{14}O_2$	30°	L	13.0×10^3	0.65[20]	CD	16
di-n-propylamine[3]	$C_6H_{15}N$	0°	L	12.44	0.13	CC	13
o-chlorobenzaldehyde	C_7H_5ClO	27°	B	11.0	-	Kr	67
m-chlorobenzaldehyde	C_7H_5ClO	27°	B	12.5	-	Kr	67
p-chlorobenzaldehyde	C_7H_5ClO	27°	B	15.2	-	Kr	67
benzaldehyde	C_7H_6O	27°	B	10.6	-	Kr	67
o-nitrobenzaldehyde	$C_7H_5NO_3$	27°	B	15.8	-	Kr	67
p-nitrobenzaldehyde	$C_7H_5NO_3$	27°	B	17.2	-	Kr	67
o-chlorotoluene	C_7H_7Cl	35°	B	6.9	-	Kr	102
o-toluidine	C_7H_9N	35°	B	4.8	-	Kr	102
p-toluidine	C_7H_9N	35°	B	6.1	-	Kr	102
o-hydroxyacetophenone[3]	$C_8H_8O_2$	20°	Cy	16.4	0	CC	103
o-hydroxyacetophenone[3]	$C_8H_8O_2$	20°	D	31.0	0.05	CC	103
di-n-butylamine[3]	$C_8H_{19}N$	0°	L	17.09	0.00	CC	13
o-methoxyacetophenone[3]	$C_9H_{10}O_2$	20°	Cy	26.4	0.04	CC	103
o-methoxyacetophenone[3]	$C_9H_{10}O_2$	20°	D	33.5	0	CC	103
m-methoxyacetophenone[3]	$C_9H_{10}O_2$	20°	D	46.5	0.14	CC	103
2,6-dimethylanisole[3,17]	$C_9H_{12}O$	20°	B	25	0.12	CC	75
3,5-dimethylanisole[3,17]	$C_9H_{12}O$	20°	B	16	0.14	CC	75
D-camphor[3]	$C_{10}H_{16}O$	-20°	S	43.0	0.07	CC	29
benzophenone[3]	$C_{13}H_{10}O$	-10°	L	7.95×10^3	-	Z	104
2-naphthyl o-hydroxybenzoate[3]	$C_{17}H_{12}O_3$	20°	L	1.06×10^5	0.44	CC	18
triisoamylammonium picrate	$C_{21}H_{36}N_4O_6$	19°	B	230[1]	1.00[4]	CC	83
bis(diphenylmethyl) ether	$C_{26}H_{22}O$	20°	B	130	-	Z	84

Table IV (Continued)

Name	Formula	Temp.	State	τ	α	Method	Ref.
bis(diphenylmethyl) ether	$C_{26}H_{22}O$	20°	C	265	-	Z	84
bis(diphenylmethyl) ether	$C_{26}H_{22}O$	20°	D	257	-	Z	84
bis(diphenylmethyl) ether	$C_{26}H_{22}O$	30°	diphenyl-methane solution	320	-	Z	84
tetraphenylcyclopenta-dienone	$C_{29}H_{20}O$	20°	B	215	-	Z	84
tetraphenylcyclopenta-dienone	$C_{29}H_{20}O$	20°	C	284	-	Z	84
tetraphenylcyclopenta-dienone	$C_{29}H_{20}O$	20°	D	365	-	Z	84
tetraphenylcyclopenta-dienone	$C_{29}H_{20}O$	30°	diphenyl-methane solution	540	-	Z	84

Table V. References to Charts and Graphs

Name	Formula	State	Parameters Listed	Freq. Range	Temp. Range	Ref.
Inorganic Compounds						
aluminum oxide	Al_2O_3	P	ϵ', $\tan\delta$	3.7×10^{10} Hz	0-400°	105
aluminum oxide	Al_2O_3	P	ϵ', ϵ'', σ	10^2 - 8.6×10^9 Hz	25 - 1000°	106
antimony sulfide iodide	SbSI	S (001 faces)	ϵ_0	1 kHz	0 to 60°	107
barium titanate	$BaTiO_3$	P	ϵ', $\tan\delta$	10^3 to 10^8 Hz	-160 to 300°	108
barium zirconate	$BaZrO_3$	P	ϵ_0, ρ	1 MHz	25 - 500°	109
boron nitride	BN	S	ϵ', ϵ'', σ	10^2 - 8.6×10^9 Hz	25 - 1000°	106
chromium oxide	Cr_2O_3	S	ϵ', ϵ''	10^2 - 8.6×10^9 Hz	25 to 500°	106
ice	H_2O	S	ϵ_0	Z	77 to 135°K	110
lanthanum aluminate	$LaAlO_3$	S	ϵ', ϵ''	10^2 - 5×10^5 Hz	25 to 500°	106
lead magnesium niobate	$Pb(Mg_{1/3}Nb_{2/3})O_3$	P	ϵ', $\tan\delta$	10^3 - 10^8 Hz	-160 to 300°	108
lead magnesium tungstate	$Pb(Mg_{1/2}W_{1/2})O_3$	P	ϵ', $\tan\delta$	10^3 to 10^8 Hz	-160 to 300°	108

Table V (Continued)

Name	Formula	State	Parameters Listed	Freq. Range	Temp. Range	Ref.
lithium fluoride	LiF	S	$\frac{1}{\epsilon}\frac{d\epsilon}{dT}$	1 MHz	20 to 400°	111
lithium sulfate	$LiSO_4 \cdot H_2O$	P	ϵ', ϵ'', tan δ	0.1 Hz - 44 MHz	RT	112
magnesium oxide	MgO	P	ϵ', ϵ'', σ	10^2 - 3×10^9 Hz	25 to 1200°	106
nickel boracite	$Ni_3B_7O_{13}Cl$	S	ϵ', tanδ	100 kHz - 48 MHz	-100 to 400°	113
potassium bromide	KBr	S	ϵ', ϵ'', τ	5×10^5 - 5×10^6 Hz	600 to 722°	114
potassium bromide	KBr	S	$\frac{1}{\epsilon}\frac{d\epsilon}{dT}$	1 MHz	20 to 400°	111
potassium chloride	KCl	S	$\frac{1}{\epsilon}\frac{d\epsilon}{dT}$	1 MHz	20 to 400°	111
potassium chloride	KCl	S	ϵ', ϵ'', τ	1 - 10 MHz	65 to 775°	115
potassium iodide	KI	S	$\frac{1}{\epsilon}\frac{d\epsilon}{dT}$	1 MHz	20 to 400°	111
fused quartz	SiO_2	S	ϵ', tan δ	3.7×10^{10} Hz	0 to 400°	105
quartz	SiO_2	S	ϵ', ϵ''	50 Hz - 100 kHz	RT to 573°	116
rubidium nitrate	$RbNO_3$	S	$\epsilon_{\parallel}$, $\epsilon_{\perp}$	1 MHz	100 to 250°	117
sapphire	Al_2O_3	S	ϵ', ϵ''	10^2 - 8.6×10^9 Hz	25 to 500°	106
silicon monoxide	SiO	F	ϵ', ϵ''	10^{-2} Hz - 30 MHz	-170 to 28°	118
silica	SiO_2	Am	ϵ', ϵ'', σ	10^2 - 6×10^9 Hz	200 to 1000°	106
sodium chloride	NaCl	S	ϵ', ϵ'', τ	10^6 - 7×10^6 Hz	707°	114
sodium chloride	NaCl	S	tan δ, ϵ', ϵ''	50 Hz - 500 kHz	100 to 400°	119
sodium chloride	NaCl	S	$\frac{1}{\epsilon}\frac{d\epsilon}{dT}$	1 MHz	20 to 400°	111
sodium fluoride	NaF	S	$\frac{1}{\epsilon}\frac{d\epsilon}{dT}$	1 MHz	20 to 400°	111
sodium nitrite	$NaNO_2$	S (010 plate)	$1/\epsilon$, tan δ	10 kHz	155 to 200°	120
sodium nitrite	$NaNO_2$	S	ϵ_b	100 kHz	0 to 200°	121

Table V (Continued)

Name	Formula	State	Parameters Listed	Freq. Range	Temp. Range	Ref.
sodium potassium tartrate (Rochelle Salt)	$KNaC_4H_4O_6 \cdot 4H_2O$	S	ϵ', ϵ''	9.61×10^4 Hz	-30 to 40°	122
thorium oxide	ThO_2	P	ϵ', ϵ''	$10^2 - 10^6$ Hz	25 to 500°	106
water	H_2O	L	ϵ', ϵ''	$\lambda = 9$ to 22.52 cm	25°	31
cyclopentanol	$C_5H_{10}O$	S,L	ϵ', ϵ'', τ	5 Hz - 8.5 GHz	-80 to 20°	17
cyclohexanone	$C_6H_{10}O$	S,L	ϵ', ϵ'', τ	5 Hz - 8.5 GHz	-80 to 20°	17
cyclohexyl chloride	$C_6H_{11}Cl$	S,L	ϵ', ϵ'', τ	5 Hz - 8.5 GHz	-80 to 20°	17
cyclohexanol	$C_6H_{12}O$	S,L	ϵ', ϵ'', τ	5 Hz - 8.5 GHz	-80 to 20°	17
			Polymers			
polytetrafluoroethylene	$(C_2F_4)_n$	S	ϵ', $\tan\delta$, f_m	4.7×10^8 Hz	20 to 120°	123
poly(vinyl chloride)	$(C_2H_3Cl)_n$	Am	ϵ', f_m	10^{-1} Hz - 10^5 Hz	84.5 to 103.5°	124
polyethylene	$(C_2H_4)_n$	S	ϵ', $\tan\delta$	7.5 - 26.3 GHz	22 to 26°	125
polyethylene	$(C_2H_4)_n$	S	ϵ', $\tan\delta$	24.3 GHz	211 to 373°K	126
poly(ethylene oxide)	$(C_2H_4O)_n$	S	ϵ', ϵ''	$10^2 - 10^9$ Hz	60 to 70°	127
polyvinyl alcohol[6]	$(C_2H_4O)_n$	S	ϵ', ϵ''	60 Hz - 300 kHz	-50 to 76°	128
polyacrylonitrile	$(C_3H_3N)_n$	F	ϵ', ϵ'', f_m	100 Hz - 2 MHz	-70 to 150°	129
polypropylene (isotactic)	$(C_3H_6)_n$	S	ϵ', ϵ''	50 Hz	-35 to 160°	130
poly(methyl methacrylate)	$(C_5H_8O)_n$	S	ϵ', $\tan\delta$	24.3 GHz	211 to 373°K	126
poly(methyl methacrylate)	$(C_5H_8O_2)_n$	S	$\log f(\tan\delta_{max})$[21]	40 Hz	20 to 200°	131
poly(methyl methacrylate)	$(C_5H_8O_2)_n$	S	ϵ', ϵ'', f_m	10^{-1} - 10^6 Hz	15 to	132
polystyrene	$(C_8H_8)_n$	Am	f_m	10^{-1} - 10^5 Hz	$1/T = 2.5$ to 2.7×10^{-3} °K	124

Table V (Continued)

Name	Formula	State	Parameters Listed	Freq. Range	Temp. Range	Ref.
poly-γ-benzyl-L-glutamate	$(C_{12}H_{15}NO_4)_n$	S	ϵ', ϵ''	0.3 - 10^6 Hz	18 to 58°	133
poly(4,4'-isopropylidene-diphenol sebacate)	$(C_{25}H_{30}O_4)_n$	S	ϵ', ϵ''	5 x 10^7 - 10^{10} Hz	-110 to 150°	134

Footnotes

1. Data are given for several concentrations. The entry given here is for the lowest, 0.0299 mole/liter.
2. Data are given for the change in ϵ in applied fields to 100 kV/cm.
3. Data are given for other temperatures.
4. Distribution parameter based on relation:

$$(\omega\tau)^n = \left(\frac{\epsilon'_0 - \epsilon'}{\epsilon''} \right) \sin \frac{n\pi}{2} - \cos \frac{n\pi}{2}$$

5. Data also are given for mixtures with water.
6. Data also are given for polyvinyl alcohol samples that have been partially cyanoethylated.
7. There is a wide range in the data due to the use of samples with different but not uniquely specified directions of crystallinity. Data also are given for dielectric saturation effects.
8. Value for ϵ'. $\epsilon'' = 0.857$.
9. Value for ϵ'. $\epsilon'' = 1.73$.
10. The measurements represent a combination of data due to conventional microwave spectrometry and molecular beam electronic resonance data. The μ_i refer to the excited vibrational states.
11. This measurement is from the 3390 Å band for the excited state due to the $\pi^* - n$ transition.
13. A graph is presented of ϵ' and tan δ as a function of frequency and temperature.
14. Data in the form of graphs also are given for ϵ' and tan δ as a function of frequency and temperature. Also, data are presented in graphs for a ceramic of $\alpha - Ta_2O_5$.
15. For the deuterated form, μ 0.397.
16. The value of μ given is that for the cis rotamer.
17. The data in the original paper has also been interpreted in terms of two single relaxation times.
18. Data are given for a wide range of temperatures and densities, both for liquid and gaseous para-hydrogen.
19. The data are from a molecular beam electric resonance apparatus and refer to the first few vibrationally excited states for the J = 1 rotational state.

20. The parameter given is β of the Cole-Davidson distribution

$$\frac{\epsilon^* - \epsilon_\infty}{\epsilon_0 - \epsilon_\infty} = \frac{1}{(1 + i\omega\tau)^\beta}$$

21. Data are given for a range of pressures.
22. Other methods were also used to calculate μ.
23. μ was calculated for several concentrations. The value quoted is for the most dilute solution. Also, an effective μ using a form of Kirkwood's formula was calculated. See the original paper.
24. Data are given for other frequencies and also tan δ values.
25. Data are also given for various mixtures with paraffin oil.
26. Per monomer unit.
27. By fluoresence polarization. Values also given for determination by electrical dichroism.
28. Values also given for other solvents.
29. Value determined by electrical dichroism.

References

1. Dunn, A. F., Can. J. Phys. 42, 1489-98 (1964).
2. Amey, R. L. and Cole, R. H., J. Chem. Phys. 40, 146-8 (1964).
3. Stewart, J. W., J. Chem. Phys. 40, 3297-306 (1964).
4. Munson, R. A., J. Chem. Phys. 40, 2044-6 (1964).
5. Bass, S. J., Nathan, W. I., Meighan, R. M., and Cole, R. H., J. Phys. Chem. 68, 509-15 (1964).
6. Dannhauser, W. and Bahe, L. W., J. Chem. Phys. 40, 3058-66 (1964).
7. Vaughn, W E. and Katochvil, B., J. Chem. Phys. 39, 1617-18 (1963).
8. Dannhauser, W. and Flueckinger, A. F., J. Phys. Chem. 68, 1814-19 (1964).
9. Chelkowski, A., Acta Phys. Polon. 24, 165-89 (1963).
10. v. Dahl, W. and Mueller, F. H., Kolloid-Z. 198, 27-53 (1964).
11. LeHuerou, M. L. and Guerillot, C. R., Compt. Rend. 258, 2549-51 (1964).
12. Vaughn, J. W., J. Chem. Eng. Data 9, 427 (1964).
13. Garg, S. K. and Kadaba, P. K., J. Phys. Chem. 68, 737-44 (1964).
14. Vaughn, J. W. and Kawkins, C. F., J. Chem. Eng. Data 9, 140-2 (1964).
15. Reinisch, L., J. Chim. Phys. 60, 1374-80 (1963).
16. Haranadh C., Trans. Faraday Soc. 59, 2728-34 (1963).
17. Corfield, G. and Davies, M., Trans. Faraday Soc. 60, 10-24 (1964).
18. Komandin, A. V. and Shimit, B. D., Zh. Fiz. Khim. 37, 2289-98 (1963).

19. Belyaev, L. M., Belikova, G. S., Dobrzhanskii, G. F., Netesov, G. B., and Shaldin, Yu. V., Fiz. Tverd. Tela 6, 2526-8 (1964).

20. Ezuchevskaya, V. M., Syrkin. Ya. K., and Shchelokov, R. N., Zh. Neorg. Khim. 9, 1758-9 (1964).

21. Tambovtsev, D. A., Skorikov, V. M., and Zheludev, I. S., Kristallografiya 8, 889-93 (1963).

22*. Nakano, K., Satuka, A., and Saruwatari, K., Nippon Kagaku Zasshi 84, 902-9 (1963).

23. Gibbs, D. F. and Hill, G. J., Phil. Mag. 9, 367-75 (1964).

24. Simhony, M., J. Phys. Chem. Solids 24, 1297-300 (1963).

25. Schmidt, M. and Sand, T., J. Inorg. Nucl. Chem. 26, 1189-90 (1964).

26. Ezuchevskaya, V. M., Syrkin, Ya. K., and Deichman, E. N., Zh. Neorg. Khim. 9, 1495 (1964).

27. Kilja, R. and Stubb, T., Acta Polytech. Scand., Phys. Nucl. Ser. 28, 32 pp. (1964).

28. Pavlovic, A. S., J. Chem. Phys. 40, 951-6 (1964).

29. Davies, M., Proc. Intl. Symp. Mol. Struct. Spectry., Tokyo (1962), C320/1-4.

30. Daniel, V., Trans. Faraday Soc. 60, 1299-1309 (1964).

31. Haase, J., Sistig, E., and Zeil, W., Z. Naturforsch. 19a, 660-1 (1964).

32. Kocharyan, N. M., Akopyan, A. N., Barsamyan, S. T., Tolapchyan, L. S., and Pikolova, V. N., Dokl. Akad. Nauk. Arm. SSR 37, 263-7 (1963).

33. Hebert, A. J., Breivogel, F. W., Jr., and Street, K., Jr., J. Chem. Phys. 41, 2368-76 (1964).

34. Lide, D. R., Jr., Cahill, P., and Gold, L. P., J. Chem. Phys. 40, 156-9 (1964).

35. Hodgeson, J. A., Sibert, E. E., and Curl, R. F., Jr., J. Phys. Chem. 67 2833-5 (1963).

36. Esterowitz, L. and Rosenthal, J., J. Chem. Phys. 40, 1986-7 (1964).

37. Anantakrishnan, S. V. and Rao, D. S., Proc. Indian Acad. Sci. Sect. A 59, 292-8 (1964).

38. Bauer, R. K. and Lew, H., Can. J. Phys. 42, 830-1 (1964).

39. Powell, F. X. and Lide, D. R., Jr., J. Chem. Phys. 41, 1413-19 (1964).

40. Meighan, R. M. and Cole, R. H,,J. Phys. Chem. 68, 503-8 (1964).

41. Boggs, J. E., Coffey, D., Jr., and Davies, J. C., Jr., J. Phys. Chem. 68, 2383-4 (1964).

42. Antony, A. A. and Smyth, C. P., J. Am. Chem. Soc. 86, 152-6 (1964).

43. Freeman, D. E. and Klemperer, W., J. Chem. Phys. 40, 604-5 (1964).

44. Muenter, J. S. and Laurie, V. W., J. Am. Chem. Soc. 86, 3901-2 (1964).

45. Mukhtarov, I. A., Opt. i Spektroskopiya 15, 563-4 (1963).
46. Dobyns, V., J. Am. Chem. Soc. 85, 3553-6 (1963).
47. Mukhtarov, I. A., Dokl. Akad. Nauk SSSR 151, 1076-8 (1963).
48. Mansingh, A., Indian J. Pure Appl. Phys. 2, 33-4 (1964).
49. Buczkowski, Z., Piotrowska, H., and Urbanski, R., Bull. Acad. Polon. Sci., Ser. Sci. Chim. 11, 197-200 (1963).
50. Sastry, K. V. L. N. and Curl, R. F., Jr., J. Chem. Phys. 41, 77-80 (1964).
51. Rao, V. M. and Curl, R. F., Jr., J. Chem. Phys. 40, 3688-90 (1964).
52. Beaudet, R. A., J. Chem. Phys. 40, 2705-05 (1964).
53. Hassell, W. F., Magee, M. D., Tucker, S. W., and Walker, S., Tetrahedron 20, 2137-55 (1964).
54. Butcher, S. S. and Wilson, E. B., Jr., J. Chem. Phys. 40, 1671-8 (1964).
55. Oka, T., Tsuchiya, K., Iwata, S., and Morino, Y., Bull. Chem. Soc. Japan 37, 4-7 (1964).
56. Lumbroso, H. and Papalardo, G., Bull. Soc. Chim. France 1961, 1131-5.
57. Soundararajan, S., Indian J. Chem. 1, 503-6 (1963).
58. Stiefvater, O. L. and Sheridan, J., Proc. Chem. Soc. (1963), 368.
59. Lide, D. R., Jr. and Jen, M., J. Chem. Phys. 40, 252-3 (1964).
60. Lawrence, A. R. and Matuszko, A. J., J. Phys. Chem. 68, 199-201 (1964).
61. Aroney, M. J., LeFevre, R. J. W., and Singh, A. N., J. Chem. Soc. 1964, 3523-8.
62. Krishna, B. and Srivastava, A. N., Dielectrics 1, 193-4 (1964).
63. Purcell, W. P., J. Phys. Chem. 68, 266-70 (1964).
64. LeFevre, R. J. W. and Sundaram, K. M. S., J. Chem. Soc. 1964, 3518-23.
65. Antony, A. A., Fong, F. K., and Smyth, C. P., J. Phys. Chem. 68, 2035-9 (1964).
66. Quivoron, C. and Neel, J., J. Chim. Phys. 61, 554-71 (1964).
67. Ahmad, S. I., Indian J. Pure Appl. Phys. 1, 434-5 (1963).
68. Jain, S. R. and Soundararajan, S., J. Inorg. Nucl. Chem. 26, 1255-61 (1964).
69. Desai, D. D. and Pandhare, N. H., Indian J. Pure Appl. Phys. 2, 6-10 (1964).
70. Baliah, V. and Aparajithan, K., Tetrahedron 19, 2177-83 (1963).
71*. Plamondon, J. E., Buenker, R. J., Koopman, D. J., and Dolter, R. J., Proc. Iowa Acad. Sci. 70, 163-6 (1963).
72. Aroney, M. J., Corfield, M. G., and LeFevre, R. J. W., J. Chem. Soc. 1964, 648-52.
73. Czekalla, J., Chimia (Aarau) 15, 26-31 (1961).

74. LeFevre, R. J. W. and Sundaram, K. M. S., J. Chem. Soc. (1964), 556-62.

75. Fong, F. K. and Smyth, C. P., J. Chem. Phys. 40, 2404-7 (1964).

76. Kokoreva, I. Yu., Zh. Strukt. Khim. 5, 314 (1964).

77. Richards, J. H. and Walker, S., Tetrahedron 20, 841-53 (1964).

78. Kawski, A., Naturwissenschaften 51, 823 (1964).

79*. Jannelli, L., Sciacovelli, O., and Carpanelli, C., Ann. Chim. (Rome) 53, 1541-51 (1963).

80. Barbara, A. K. and Mahanta, P. C., Indian J. Pure Appl. Phys. 2, 304-5 (1964).

81. Kokoreva, I. Yu., Neiman, L. A., Syrkin, Ya. K., and Kirillova, S. T., Dokl. Akad. Nauk SSSR 156, 412-14 (1964).

82. Sanesi, M., Lazzarone, M., and Gazzaniga, A., Ric. Sci. Rend. Sez A 3, 939-50 (1963).

83. Davies, M. and Johansson, G., Acta Chem. Scand. 18, 1171-9 (1964).

84. Nelson, R. D., Jr. and Smyth, C. P., J. Phys. Chem. 68, 2704-8 (1964).

85. Aroney, M. J., LeFevre, R. J. W., and Saxby, J. D., Australian J. Chem. 17, 289-93 (1964).

86. Thompson, H. B., Kuhn, L. P., and Inatome, M., J. Phys. Chem. 68, 421-2 (1964).

87. Kartsev, G. N., Syrkin, Ya. K., Kravchenko, A. L., and Mironov, V. F., Zh. Strukt. Khim. 5, 492-3 (1964).

88. Kartsev, G. N., Syrkin, Ya. K., Kravchenko, A. L., and Mironov, V. F. Zh. Strukt. Khim. 5, 639-2 (1964).

89. Tyler, J. K., J. Chem. Phys. 40, 1170-1 (1964).

90. Nelson, R., J. Chem. Phys. 39, 2382-3 (1963).

91. Cumper, C. W. N., Foxton, A. A., Read, J., and Vogel, A. I., J. Chem. Soc. 1964, 430-4.

92. Michalczyk, J., Nukleonika 8, 237-44 (1963).

93. Varma, R., MacDiarmid, A. G., and Miller, J. G., J. Chem. Phys. 39, 3157-8 (1963).

94. Zemlyanskii, N. N., Gol'dshtein, I. P., Gur'yanova, E. N., Panov, E. M., Slovokhotova, N. A., and Kocheshka, K. A., Dokl. Akad. Nauk SSSR 156, 131-4 (1964).

95. Strohmeier, W. and Hellmann, H., Ber. Bunsenges. Physik. Chem. 68, 481-8 (1964).

96. Ciampolini, M., Maggio, F., and Cavasino, F. P., Inorg. Chem. 3, 1188-91 (1964).

97. Faizullina, N. K. and Gur'yanova, E. N., Zh. Obshch. Khim. 34, 941-6 (1964).

98. Bigorgne, M. and Messier, C., J. Organometal. Chem. 2, 79-88 (1964).

99. Mikhailov, G. P. and Burshtein, L. L., Vysokomolekul. Soedin 6, 1713-16 (1964).
100. Krishnaji and Mansingh, A., J. Chem. Phys. 41, 827-31 (1964).
101. McDuffie, G. E., Jr. and Kelly, M. V., J. Chem. Phys. 41, 2666-70 (1964).
102. Ahmad, S. I., Indian J. Pure Appl. Phys. 2, 70 (1964).
103. Antony, A. A. and Smyth, C. P., J. Am. Chem. Soc. 86, 156-8 (1964).
104. Komandin, A. V. and Smirnova, A. D., Zh. Fiz. Khim. 38, 783-5 (1964).
105. Mashkovich, M. D., Ermilin, K. K., and Rozenberg, N. Yu., Pribary i Tekhn. Eksperim. 4, 176-9 (1964).
106. Westphal, W. B., U. S. At. Energy Comm. NP-13431 (1963), 86 pp.
107. Mori, T. and Tamura, H., J. Phys. Soc. Japan, 19, 1247 (1964).
108. Khuchua, N. P. and Lychkataya, L. F., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 708-13 (1964).
109. Koenig, J. and Jaffe, B., J. Am. Ceram. Soc. 47, 87-9 (1964).
110. Dengel, O., Eckner, U., Pilz, H., and Riehl, N., Phys. Letters 9, 291-2 (1964).
111. Ranchenko, V. V., Fiz. Tverd. Tela. 6, 584-9 (1964).
112. van Beek, L. K. H., Physica 29, 1323-8 (1963).
113. Tar, D., Helv. Phys. Acta 37, 165-72 (1964).
114. Economou, N. A. and Sastry, P. V., Phys. Status Solidi 6, 135-40 (1964).
115. Sastry, P. V. and Srinivasan, T. M., Phys. Rev. 132, 2445-9 (1963).
116. Snow, E. H. and Gibbs, P., J. Appl. Phys. 35, 2368-74 (1964).
117. Dantsiger, A. Ya. and Fesenko, E. G., Kristallografiya 8, 894-9 (1963).
118. Hirose, H. and Wada, Y., Japan J. Appl. Phys. 3, 179-90 (1964).
119. Kessler, A. and Mariani, E., Czech. J. Phys. 1964, 757-64.
120. Tagaki, Y. and Gesi, K., J. Phys. Soc. Japan 19, 142-3 (1964).
121. Sawada, S., Nomura, S., and Asao, Y., J. Phys. Soc. Japan 16, 2207-12 (1961).
122. Baeumler, P., Blum, W., and Deyda, H., Z. Physik 180, 96-104 (1964).
123. Mikhailov, G. P., Lobanov, A. M., Shevelev, V. A., and Orlova, T. P., Vysokomolekul. Soedin 6, 868-70 (1964).
124. Kaestner, S., Schlosser, E., and Pohl, G., Kolloid-Z. 192, 21-8 (1963).
125. Sistig, E. and Zeil, W., Z. Physik. Chem. 41, 236-44 (1964).
126. Zeil, W. and Sistig, E., Kolloid-Z. 196, 8-17 (1964).
127. Connor, T. M., Read, B. E., and Williams, G., J. Appl. Chem. (London) 14, 74-80 (1964).
128. Flowers, L. C. and Berg, D., J. Electrochem. Soc. 111, 1239-43 (1964).
129. Ishida, Y., Amano, O., and Takayanagi, M., Kolloid-Z. 172, 129-32 (1960).

130. Pegoraro, M. and Zelinger, J., Chim. Ind. (Milan) 46, 258-62 (1964).

131. Heydemann, P., Kolloid-Z. 195, 122-8 (1964).

132. Murakami, I., Ishii, T., and Yamamura, H., J. Sci. Hiroshima Univ. Ser. A-II 27, 125-32 (1964).

133. Hikichi, K., Saito, K., Kaneko, M., and Furuichi, J., J. Phys. Soc. Japan 19, 577 (1964).

134*. Mikhailov, G. P. and Lobanov, A. M., Vysokomolekul. Soedin., Geterotsepnye Vysokomolekul Soedin. 1964, 175-80.

Supplemental Bibliography

1. Konopa, R., Bull. Soc. Amis Sci. Lettres Poznan Ser. B 16, 131-8 (1960-1961).
The dielectric constant at 20° was measured for nitrobenzene, m-nitrotoluene, o-nitrotoluene, and o-nitroanisole mixtures with benzene or carbon tetrachloride over the entire range of concentrations.

2. Malecki, J., Bull. Soc. Amis Sci. Lettres Poznan Ser. B 16, 93-113 (1960-1961).
The dielectric constant and dielectric saturation of 2-methyl-1-propanol, n-butanol, n-pentanol, and n-hexanol and their mixtures with benzene or hexane were measured at 20°.

3. Pietrzak, J., Bull. Soc. Amis Sci. Lettres Poznan Ser. B 16, 139-62 (1960-1961).
The effect of hydrostatic or one dimensional pressure on the dielectric constant of $BaTiO_3$ in the direction of spontaneous polarization was measured.

4. Hirose, H. and Wada, Y., Shinku 5, 286-32 (1962).
Two dielectric dispersion regions were found in SiO films, one at several kHz and the other below 45 Hz.

5. Krajewski, T., Poznan. Towarz Przyjacol Nauk Wydzial Mat.-Przyrod. Prace Komisji Mat. Przyrod. 11, 175-96 (1962).
The dielectric constant of ammonium pentaborate perpendicular to the crystal axes was measured from -200 to 150°.

6. Imanov, L. M. and Mirzoev, F. G., Izv. Akad. Nauk Azerb. SSR, Ser. Fiz.-Mat. i Tekhn. Nauk 1963, 37-43.
At 1 MHz, ϵ_0 of acetic acid and its solutions in benzene was measured. Also, ϵ^* was measured at 3.26 cm.

7. Sastry, P. B., NASA Doc. N64-13963 (1963), 14 pp.
The high temperature dielectric constant of KBr was investigated.

8. Atakhodzhaev, A. K., Tukhvatullin, F. Kh., Rozhdestvenskii, M. I., Egamkulov, A., and Yarmukhametov, G. D., Ukr. Fiz. Zh. 9, 552-5 (1964).
The relaxation times for biphenyl, diphenylmethane, diphenylamine, benzophenone, 1,2-diphenylethane, and stilbene were measured at 30 to 240°.

9. Hilczer, T., Poznan. Towarz. Prezyjacol Nauk Wydzial Mat. Przyrod. Prace Komisji Mat. Przyrod. 11, 137-48 (1964).
The dielectric constant to 700 atmospheres pressure was measured of benzene nitrobenzene, o-nitroanisole, o-nitrotoluene, and 1,2-dibromoethane.

10. Imanov, L. M., Izv. Akad. Nauk Azerb. SSR, Ser. Fiz.-Tekhn. i Mat. Nauk 1964, 71-80.
The complex dielectric constant of methanol, ethanol, propanol, isopropanol, butanol, and isobutanol at wave lengths from 30 to 100 cm at 293°K and of propanol, butanol, and isobutanol at the frequencies 0.3 to 32 MHz at 20 to 160° was measured.

11. Kocharyan, N. M., Barsamyan, S. T., and Pikalova, V. N., Dokl. Akad. Nauk Arm. SSR 38, 295-9 (1964).
At 20°, the dipole moments of dimethyl-methylethylvinylethynyl-, cyclohexylvinylethynyl-, methylphenylethynyl-, methyl-t-butyl-vinylethynyl-, methylvinylethynyl-, ethylvinylethynyl-, and propylvinylethynylcarbinol were measured.

12. Krajewski, T. and Blaszkiewicz, B., Poznan. Towarz. Przyjacol Nauk, Widzial Mat. Przyrod. Prace Komisji Mat. Przyrod. 11, 213-26 (1964).
The dielectric constant of $KH_4B_5O_{10} \cdot H_2O$ was measured from -60 to 160°.

13. Mal'tsev, A. V. and Berdinskii, V. F., Uch. Zap. Leningr. Ped. Inst. 207, 219-26 (1964).
The frequency and temperature dependence of the dielectric constant of muscovite mica was studied.

14. Yastremskii, P. S., Uch. Zap. Leningr. Ped. Inst. 207, 227-32 (1964).
At 9.4 GHz and 18°, ϵ^* was measured for aqueous solutions of LiCl, NaCl, NaI, and KI over a large range of concentrations.

CHAPTER III

MOLECULAR AND IONIC INTERACTIONS IN DIELECTRICS

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I. Introduction

It is our impression that, although there were no spectacular new developments during 1964, many significant theoretical and experimental studies were reported. Space permits only cursory reference here to some of the more interesting.

The calculation by Karplus (Section III-A) of the polarizability of the H_2 molecule represents the first attempt at a priori calculation of the frequency dependence of the polarizability of a molecule. A number of calculations of static polarizabilities (III-A) and dipole moments (IV-A) of diatomic molecules have been made.

Herzfeld (III-B) has drawn attention to the lack of an adequate inertial theory to explain the absence in the visible region of the intense absorption predicted on the basis of the simple Debye theory to lie on the high-frequency side of the dielectric absorption band in water and other polar liquids.

The difficulties associated with accurate measurement of absolute infrared intensities are illustrated by the disagreement between the intensities reported for the fundamental vibration band of NO by James (III-D), Breeze and Ferrizo (III-D), and earlier workers cited by these authors. Tipton, Deam, and Boggs (III-E) were able to estimate the errors in earlier intensity measurements of the infrared bands of SF_6 and CF_4 from accurate measurement of the molar polarization of these nonpolar gases.

Improvements in the measurement of the static dielectric constants of gases (Dunn: VI-B, Meighan and Cole: IV-B), and thus in the accuracy of

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*Present address: Canadian General Electric Company, Toronto, Canada dipole moments given by the classical method, were accompanied by application of the molecular beam electric-resonance method of measuring the radio-frequency Stark effect ($< m_J = \pm 1$) (Herbert, Breivogel, and Street: IV-B). Dipole moments to at least ±0.001 D, as well as quadrupole and rotational constants to high accuracy, have been measured by this technique. An approximate method of determining dipole moments when the microwave Stark components are not resolved has been described by Lindfors (IV-B). An interesting confirmation of the recently-measured quadrupole moment of CO_2 was provided by the study by Maryott and Kryder (V-B) of the microwave absorption induced in non-polar gases by collisions with CO_2.

As in other years there have been many studies of molecular structures based on dipole moment determinations (IV) and of association and complex formation in liquids and solutions based on measurements of the temperature and concentration dependence of dielectric constants (VI). New evidence is provided that the H atom of the CH bond is negative with respect to the C atom in aliphatic molecules (Constantinides: IV-A) but positive in aromatic molecules (Cole: III-D). The existence of a very small dipole moment in $HC{\equiv}CD$ has been demonstrated by observation of a microwave transition line by Muenter and Laurie (IV-B).

Macdonald and Barlow (II) have discussed the integral relations between forcing and response functions for mechanical and dielectric relaxation, and Macdonald (II) has proposed an expression for the free energy of activation of relaxation and diffusion from which temperature dependence of the type described by the Vogel and Williams, Landel, and Ferry equations may be derived. It may be pointed out that the failure of the Vogel equation to fit the relaxation times of isoamyl bromide for all temperatures between 120°K (where the relaxation time is 10^{-3} sec.) and 300°K (10^{-11}sec.) illustrates again that the features common to structural relaxation in polymers and liquids at low temperatures are no longer present in mobile liquids at higher temperatures. The Vogel equation with the usual value of B accurately describes the temperature dependence of the relaxation times of isoamyl bromide greater than 10^{-7} sec.

Smyth and his co-workers (V-D) have contributed a series of studies dealing with the interesting question of the contributions of restricted rotations of polar groups within various derivatives of benzene to the microwave absorption in solution. Fong (V-A) has elaborated a mechanism consisting of small coupled rotations of phenyl rings about the C—O bonds to account for the rapid relaxation of diphenyl ether, while Knobloch and Stockhausen (V-D) have supported the inversion mechanism for the fast relaxation of triphenyl amine by showing that the relaxation time is increased by a factor of 100 when the N atom is replaced by P or As. Nelson and Smyth have provided new evidence that molecular relaxation times are closely related to solvent viscosity only when the solute molecules are considerably larger than the molecules of solvent. Changes in the local structure of solutions at temperatures near the critical solution temperature have been studied (Quinn and Smyth; Arkhangel'skii V-D).

The study of rotator-phase solids, in which molecular reorientation takes place at rates similar to those of liquids, has been extended by Corfield and Davies (V-F) to cyclohexane derivatives, in which no ring inversion was found, and by Garg and Kadaba to primary alkyl amines. A number of studies of clathrates have been reported (VII-C); in some of these the encaged molecules have orientational relaxation times at liquid air temperature about as small as those of liquid molecules at room temperature.

Many studies of dielectric loss in ionic solids, particularly alkali halides, have been made (V-G). Loss has generally been attributed to relative migration of impurity and vacancy pairs, but there has been no general agreement between the concentration of such defects and the magnitude of the loss, and no general consensus about the presence of loss in the absence of impurities.

Only a few papers, considered particularly relevant to dielectrics, have been abstracted in the section dealing with electrical conductivity (IX). Eigen, de Maeyer, and Spatz (IX-B) have further refined experimentally the proton transfer processes that take place in pure ice and confirmed that proton jumping is the rate determining step in ionic mobility. Two quantum-mechanical treatments of the tunneling process have appeared (Sussmann: II; Gosar and Pintar: IV-B), and there appears to be a trend toward treatment of other relaxation processes in terms of phonon modes and semiconductor-like exciton theory (Shakhparonov: II; Bhagavantam and Pantulu: V-A).

Perhaps the most significant experimental trend of the year was the increased number of published reports of measurements made as a function of pressure. The pressure dependence of refractive indices (Waxler, Weir, and Schamp: III-B) and of the Kerr effect (Kuss and Heydemann: III-C) of liquids were studied, as were the variation with pressure of the dielectric constants of diamond (Gibbs and Hill: III-E) and of some nonpolar (Brown: XII) and polar (Hilczer: VI-C) liquids. McDuffie and Kelly (V-C) examined the effect of pressure on the dielectric relaxation and viscosity of glycerol and Williams (V-H) the effect on the relaxation of polymethyl acrylate. For theoretical reasons measurements under high pressures are likely to become increasingly numerous. Information about molecular interactions should be forthcoming from studies of such static properties as the Clausius-Mossotti function of solids and nonpolar liquids and the corresponding dielectric virial coefficients of gases (Lawley and Sutton: VI-B). As has been discussed by Williams (V-A), studies of the pressure dependence of relaxation processes may provide a crucial test of the applicability of the free volume and other models of relaxation. Besides the advantage of a knowledge of relaxation times at constant volume, volumes of activation should supplement the usual energies of activation in the study of relaxation mechanisms. Thus, reorientation of polar groups within molecules should be less dependent on pressure than over-all molecular reorientation, and there is reason to suspect that, because of electrostriction, rate-determining steps which involve the formation of ions may in some cases be identified by negative volumes of activation.

Although it was of course not possible to include abstracts of papers not dealing directly with dielectric aspects of molecular interaction, some mention should be made of related studies of orientational relaxation. There have been many studies of ultrasonic, viscoelastic, and nuclear magnetic relaxation times. Direct comparison of dielectric relaxation times with ultrasonic (Moriamez: X) and nuclear magnetic resonance correlation times and distribution functions (Connor: II) has been attempted. Woessner (J. Chem. Phys. 40, 2341 (1964)) has studied molecular reorientation in liquid D_2O and deuterated benzene by means of the quadrupole spin-lattice relaxation times. Several investigations of the inelastic scattering of cold neutrons make it evident that this comparatively new technique will provide valuable information about molecular motions and relaxation effects in condensed systems. Information about rotational motions in liquids is also provided by analysis of light scattered anisotropically (Tukhvatullin and Vuks: X, Shakhparonov: XII), and Lombardi, Raymonda, and Albrecht (J. Chem. Phys. 40, 1148 (1964)) have reported a novel method of following rotational relaxation in very viscous media by observing the rotational depolarization of emitted light.

Abbreviations

ϵ - dielectric constant
ϵ'' - loss factor
ϵ_0 - static dielectric constant
ϵ_∞ - high frequency dielectric constant
$\tan \delta$ - loss tangent
n - refractive index
d - density
μ - dipole moment
τ - relaxation time

II. General Theory

Semenchenko, V. K., Zh. Fiz. Khim. 38, 2080-4, 1964.
The properties are analyzed for the statistical anologue of the thermodynamic potential, $\phi(E,V,T)$, for a system of dipoles. If $\epsilon = (\partial D/\partial E)_{T,V}$ is determined, the Curie and Curie-Weiss laws follow as a first and second approximation from the properties of ϕ only far from the critical or Curie point. In the statistical theory of dipolar dielectrics, the internal field does not enter as the average statistical field in the expression for induction, polarization, and ϵ. For an ideal dipolar gas, in first approximation, the expressions which are obtained for ϵ from $(\partial\phi/\partial E)_{T,V}$ (i.e. $\epsilon = D/E$) and from $(\partial^2 \phi/\partial E^2)_{T,V} = (4\pi/V)$ $[(\partial D/\partial E)_{T,V}]$ are identical. In second approximation they differ only in the values of the numerical coefficients with respect to the term in E.

Gandel'man, G. M. and Ermachenko, V. M., Zh. Eksperim. i Teor. Fiz. 45, 522-31. (Russian). Translation: Soviet Phys.-JETP 18, 358-64, 1964.
The investigation of the integral equation for the inverse ϵ operator begun by Falk and Adler is continued and an expression for $\epsilon(\omega)$ is obtained which is valid for the direct calculation of the dependence of $\epsilon(\omega)$ on the medium density. The behavior of ϵ_0 during metalization is investigated under certain assumptions and the singularities of $\epsilon(\omega)$ at the beginning of the absorption band are determined. It is shown that optical anisotropy of cubic crystals can be taken into account.

Sussmann, J. A., Phys. kondens. Materie 2, 146-160, 1964.
A quantum-mechanical analysis is given of the change of position or orientation of an atom, ion, or molecule as it occurs in a crystal in, for example, the processes of diffusion or hindered molecular rotation. Limitations of the classical rate theory are discussed. Wave functions of a particle in equivalent and non-equivalent potential wells are given, and transitions involving

one-phonon processes, Raman processes, and indirect processes in which two or more phonons interact with the particle are treated. The analysis is applied to the reorientation of the O_2- center in alkali halides under the influence of mechanical stresses at low temperatures, as experimentally studied by Känzig. The dependence of τ on temperature and applied stress can be explained by a one-phonon process. The method is also applied to proton motion in ice and iron. Raman processes are mainly responsible for proton tunneling in ice. The proton mobility depends little on temperature, in agreement with experiment.

Hoernschemeyer, D. L., Dissertation Abstr. 25, 2255, 1964.
The calculation of dispersion forces by the fluctuating reaction field technique is analyzed. The nonpolar dielectric equation of Böttcher and the statistical expansion of the Clausius-Mossotti function are compared and discussed.

Stepin, L. D., Zh. Tekhn. Fiz. 34, 1742-6, 1963. (Russian). Translation: Soviet Phys.-Tech. Phys. 9, No. 10, 1964.
The electrostatic problem of multilayer dielectric spheres in an electric field is examined. A formula is derived for a mixture in which ϵ of the inclusions is some function of distance from the center of the particles. In the case of nonuniform spherical particles the problem can be approximated to by a series of spherical layers in which ϵ is assumed to be constant within the limit of each layer. The larger the number of layers considered, the more accurate are the results obtained.

Verma, P. D. S., Intern. J. Eng. Sci. 2, 21-26, 1964.
The electrostatic field and the stress tensor are determined by applying Eringen's theory of homogeneous, isotropic, hyperelastic dielectrics to the symmetric expansion of a thick spherical shell. The radial stress is increased by the effect of polarization.

Salvage, G., Proc. IEE 111, 1162-72, 1964.
When a dielectric is contained between two infinite plane parallel electrodes whose distance apart is not great compared with the dimensions of a cavity in the dielectric, the electric stress in the cavity is in general no longer uniform. The distribution of electric stress within an elliptical cylindrical cavity with the minor axis of its elliptic cross-section parallel to the field and an oblate spheroidal cavity with its axis parallel to the field is calculated in terms of the stress in the solid dielectric, using a technique devised by Rayleigh for solving the Laplace equation.

Ibid. 1173-6.
The methods of the preceding paper were used for calculation of the stresses at conducting surfaces of shapes similar to those already treated.

Leite, R. C. C. and Tai, C. T., IEEE Trans. MTT-12, 117-22, 1964.
Equivalent expressions for the dielectric permittivity and magnetic permeability tensors of artificial dielectrics are derived. These are expressed as functions of particle dimension, shape and density and also as a function of the incident electromagnetic beam direction with respect to the orientation of the particle. Only the case of a uniform density of equally oriented particles is considered. The results are valid in first order for prolate and oblate spheroids. Spheres and discs are obtained as limiting cases.

Mueller, K., Solid State Commun. 2, 205-8, 1964.
The ground state energy of Si was calculated by using a potential $V = -e^2/r\,\epsilon(r)$ which recognizes the variation of the microscopic $\epsilon(r)$ from 1 to ϵ_0 as r goes from 0 to ∞.

Neckel, A. and Virek, G., Z. Physik. Chem. 42, 129-44, 1964.
A method is presented for calculating the Madelung energy of ionic crystals, the ions of which are polyatomic. If the charge distribution of a complex ion is replaced by point charges, the electrostatic lattice potential can be expressed as a series corresponding to a multipole development. The Madelung energy of CaC_2-type crystals was calculated.

Morita, A., J. Phys. Soc. Japan 18, 1437-41, 1963.
The many-body theory of impurity states previously developed is extended to include ionic polarization in polar crystals. The impurity potential is screened by the usual ϵ_0 at large distances from the charged impurity center. But the screening effects of both electronic and ionic polarizations become rapidly ineffective at distances equal to or less than the lattice constant from the impurity center. This result explains the behavior of the electron mobility in PbTe at liquid helium temperature.

Arridge, R. G. C. and Cannon, C. G., Proc. Roy. Soc. 278A, 91-109, 1964.
The dipole energy of a lattice of CONH point dipoles in the configurations of the polyamides 6.6 and 6, of tetradecanamide, and of α and β forms of poly-L-alanine are calculated. The dipole forces contribute 4.8 kcal mole^{-1} to the lattice energy of nylon 6.6 and 4.6 kcal mole^{-1} to that of nylon 6. In tetradecanamide the total energy is 3.9 kcal mole^{-1} of which only 0.7 kcal mole^{-1} is contributed by dimer pairs of $CONH_2$ groups. The calculated energies for α and β-poly-L-alanine are 1.8 and 5.75 kcal mole^{-1}. Dipole forces stabilize the α-helix only in molecules containing more than 14 CONH groups. CO...HN hydrogen bonding contributes to the stability of the helix.

Kasper, U., Ann. Physik 13, 377-84, 1964.
The equations formulated by Schöpf for dielectrics in a gravitational field are solved for the case of spherical symmetry with a dielectric which is a perfect fluid, the central sphere being charged and a surrounding shell consisting of uncharged dielectric.

Davis, L., J. Appl. Phys. 35, 2004-9, 1964.
The spontaneous fluctuations of polarization in polar dielectrics are treated by the Einstein thermodynamic method, a general dielectric theory method, and an equivalent circuit method. Mean square fluctuation of the polarization field, for orientational polarization P_2, is $\langle(P_2 - \bar{P}_2)^2\rangle = [(\epsilon_0 - n^2)/4\pi V]kT$. The frequency spectrum of noise is similar to the polarization dispersion curve, in agreement with equivalent circuit analysis. The magnitude of the noise should be large enough for experimental observation. Noise is a consequence of dielectric dispersion in all matter in accordance with the Nyquist theorem.

Macdonald, J. R., J. Chem. Phys. 40, 1792-1804, 1964.
Previous work of the author (J. Appl. Phys. 34, 538, 1963) dealing with the time and temperature response of a distributed, linear, thermally-activated

relaxation system is extended to include ΔH and ΔS of activation no longer temperature-independent. An expression for the free energy of activation $\Delta G = E\,[1 - (T/T_0)]\,[T/(T - T_\infty)]$ is proposed in which the last factor takes account of the apparent increase in enthalpy of activation with decrease of temperature frequently found in mechanical and dielectric relaxation of polymers, glasses, and liquids at low temperatures, in diffusion, and, under some conditions, in semiconduction. For a system obeying Boltzmann statistics the equations of Vogel and of Williams, Landel, and Ferry follow. The Lawson-Keyes relation $\Delta S/\Delta H \sim 4\,\alpha$ is inadequate and is replaced by an improved relation which provides a possible explanation for the negative values of ΔS sometimes found. An expression for ΔG correct to first order in pressure and temperature is given for situations in which an Arrhenius equation is found and illustrated by analysis of pressure and temperature data for the intrinsic semiconduction in Si and Ge. Analysis of the isoamyl bromide dielectric data of Denney and Glarum between 120 and 300°K gives a much lower value of the coefficient of $(T - T_\infty)^{-1}$ (related to $c_1{}^g c_2{}^g$ of the WLF equation) than is usually found. Cases are treated in which either the pre-exponential factor or the activation parameter E is distributed or both are distributed but linearly related.

Macdonald, J. R. and Barlow, C. A., Jr., Rev. Mod. Phys. 35, 940-6, 1963.
The response functions for application of mechanical stress or voltage are retardation functions, that for applied mechanical strain a relaxation function. Systematic nomenclature for representation of the measured response functions is tabulated, as are relationships between generalized forcing and response functions and their specific forms for mechanical and dielectric systems. Pitfalls in the derivation of the response function from a superposition integral are discussed. It is concluded that the integrand should include impulse functions which ensure that the functions are zero for time less than zero.

Shakhparonov, M. I., Ukr. Fiz. Zh. 9, 444-53, 1964. (Russian).
The dielectric properties of liquids (considered to be proton semiconductors and proton dielectrics) containing intermolecular hydrogen bonds are explained using the concept of proton excitons (exciprotons). The dielectric properties of the liquid proton semiconductors are very similar to those of certain electron semiconductors. This concept is applied to explain the dielectric properties of alcohols.

Weigang, O. E., Jr., J. Chem. Phys. 41, 1435-41, 1964.
Perturbation theory is applied to the evaluation of the electric dipole strength and the rotatory strength of a condensed system of negligibly overlapped, randomly oriented solute and solvent molecules. Besides the traditional Lorentz field corrections, a correlation factor is obtained which is a function of inductive and dipolar solute-solvent interactions. The effect of solvent fields arising from the static dipole moment of the solvent molecule is predicted to be a decrease in solute absorption intensity and optical activity.

Hersping, A., Z. Angew. Phys. 17, 329-32, 1964. (German).
Using an approximation process by Cole-Cole, a relationship is derived, for the conversion of the dielectric displacement time constant τ_ϵ, as derived

from ϵ measurements, into the physically more significant polarizability time constant τ_ρ. By covering a range of time constants, this relationship amplifies one given by Debye. It is also shown that for certain special cases of low frequency relaxation, τ_ϵ may be calculated from τ_ρ.

Connor, T. M., Trans. Faraday Soc. 60, 1574-91, 1964. The effect of some specific distributions of correlation times on the theoretical values of the nuclear spin-lattice relaxation time T_1 is discussed. Types of distribution determined from dielectric studies provide the basis for a comparison of dielectric and nuclear magnetic resonance measurements. It appears possible to remove partially the discrepancy between the temperature dependence of the two kinds of correlation time. A procedure, independent of the type of distribution present, is suggested for determining the activation energy. T_1 measurements on polyethylene glycol 200, polyoxymethylene, and glycerol are interpreted in terms of the expressions developed and temperature dependence analyzed in terms of a logarithmic dependence on $1/(T - T_\infty)$.

III. Polarizability and Optical Refraction

A. Theory

Chang, Y-H., Hua Hsueh Hsueh Pao 30, 357-9 1964.
Earlier methods of calculating atomic refractions do not apply to metals. A more general relation of the form $Z/R = aX + b$ is proposed. Z is the atomic number, R the square root of the atomic refraction, and X the Pauling electronegativity.

Lippincourt, E. R. and Stutman, J. M., J. Phys. Chem. 68, 2926-40, 1964.
Molecular polarizabilities were calculated from a semi-empirical δ-function model by using a variational function and δ-function electronic wave functions. Mean polarizabilities for diatomic and polyatomic molecules are obtained by summation of components and agree to within an average deviation of ±10% with observed values for 55 molecules studied.

Mortensen, E. M., NSF Progr. Report No. 4, and ONR Tech. Report No. 72, 1964.
Expression has been obtained for the polarizability of molecules considering internal field effects, using a point dipole approximation.

Isihara, A., Physica 30, 265-70, 1964.
A rigorous and systematic development of the Clausius-Mossotti function for ϵ of nonpolar gases was obtained using Thiele's semi invariants. Corrections to the Clausius-Mossotti function are discussed.

Karplus, M., J. Chem. Phys. 41, 880-3, 1964.
The variation-perturbation method is employed for calculation of the frequency-dependent polarizability and refractive index of H_2. Use of a one-term expression for each component of the perturbation function leads to a simple formula for the frequency dependence. Application of the formula is made to seven approximate ground-state wave functions. Good agreement with experiment is obtained only from certain molecular orbital wave functions. This may be partly fortuitous and more refined calculations are needed, particularly for examination of the high-frequency range where experimental data are lacking.

Hoyland, J. R., J. Chem. Phys. 41, 3153-8, 1964.
An unambiguous exact variational procedure is given for the calculation of certain weak interaction energies starting from any given approximate ground-state wave function. The method is illustrated by calculation of the diamagnetic susceptibility, proton-shielding constant, and electrical polarizability of H_2 using 5 different ground-state wave functions. The poor agreement with the experimental α along the axis of H_2 and the good agreement with the component at right angles to the axis may be partly due to uncertainties in the experimental values.

Stevens, R. M. and Lipscomb, W. N., J. Chem. Phys. 40, 184-94, 1964.
Optimal basis sets within the perturbed Hartree-Fock theory have been found for the first-order wave function of HF for the operators x, z, $M_x(F)$, and $M_x(H)$. These sets yielded calculated values of the polarizability components, magnetic susceptibility, magnetic shielding at H and F, rotational magnetic moment and spin rotational constants of H and F. Excellent agreement with experimental molecular beam rotational constants is found. The components of α were 0.859 Å^3 parallel to the axis and 0.623 Å^3 perpendicular to it. Values of the molecular μ vary from 1.919 to 1.963 D. Maps are presented for the first-order change of electron density in an electric field.

Stevens, R. M. and Lipscomb, W. N., J. Chem. Phys. 40, 2238-47, 1964.
Previous perturbed Hartree-Fock calculations of the magnetic susceptibility and shielding of LiH are extended and refined. The method is also applied to the perpendicular component of α, calculated to be 4.063 Å^3. No experimental value is available for comparison.

Mazo, R. M., J. Am. Chem. Soc. 86, 3470-4, 1964.
A theory of the deviation of the Lorentz-Lorenz function, $(n^2-1)/(n^2+2)d$, for the solid rare gases, from its gas phase value is given. A tight binding exciton model for the excitations in the solid and the mathematical formalisms of the second quantization and the quantum mechanical Green's functions are used. The results agree with experiment.

Lucas, A., Phys. Letters 12, 325-7, 1964.
A model for long-range interaction treats a rare-gas crystal as an assembly of harmonic oscillators, interacting through the usual dipole-dipole term. These electronic oscillations are treated in the same way as ionic vibrations by the introduction of phase waves of electronic polarization.

Hopfield, J. J. and Thomas, D. G., Phys. Rev. 132, 563-72, 1963.
The classical dielectric theory of optical properties is a local theory and results in an ϵ dependent only on frequency. The dielectric behavior can be written as a sum over resonances, each occurring at a particular frequency. The spatial dispersion effect considered is the effect of the wave-vector dependence of the resonance frequencies on optical properties. The additional boundary condition required is discussed for resonance due to an exciton band. Experimental data on the reflected peaks due to excitons in CdS and ZnTe show gross departures from classical theory, but are well represented in terms of the theory of spatial resonance dispersion.

Mickevicius, V., Lietuvos Fiz. Rinkinys, Lietuvos TSR Mokslu Akad. Lietuvos TSR Aukstosiis Mokyklos. 4, 81-5, 1964. (Russian).
Kirkwoos's variational method is used to calculate the polarizability of some ions (Na, K, F, Cl) with filled shells and the results tabulated and compared with the data of Sternheimer.

Pirenne, J. and Kartheuser, E., Physica 30, 2005-18, 1964.
An analysis of experimental refractivities of alkali halides leads to an improved table of ion polarizabilities and reveals neighboring ion interaction. A phenomenological representation of the latter leads to two new polarizability tables which make possible polarizability calculations to within a standard deviation of 1%. Agreement with theoretical estimates for free ions seems to be improved. The theoretical value of the Lorentz factor is confirmed, although the results are rather insensitive to this value.

Lawless, W. N. and de Vries, R. C., J. Phys. Chem. Solids 25, 1119-24, 1964.
The validity of the point-dipole approximation in the treatment of anisotropic optical behavior in partially ionic crystals is tested by determining the least-squares O polarizability ellipsoid in fitting the n's of 8 carbonate minerals. By ignoring the C polarizability and including only nearest neighbor dipole interactions, the 16 n's were fitted to within an average error of 0.92% by using O polarizabilities of 1.384 and 1.328 Å^3 perpendicular and parallel to the CO_3^{--} plane.

Altick, P. L., J. Chem. Phys. 40, 238-9, 1964.
Oscillator strengths of the resonance and higher valence-shell transitions of Mg, Ca, Sr, and Ba have recently been measured by Russian workers. These make it possible to calculate the dipole polarizabilities α_d of these elements from $\alpha_d = \sum_m f_m/(E_m-E_o)^2$, where f_m is the absorption oscillator strength for the transition from the mth state to the ground state. Upper and lower limits of α_d are tabulated.

B. Measurements in the Ultraviolet and Visible Regions

Herzfeld, K. F., J. Am. Chem. Soc. 86, 3468-9, 1964.
According to the original Debye theory, the absorption of electromagnetic waves by dipole liquids should rise to a constant value with increasing frequency. Water and the alcohols would then be opaque in the visible. Rocard has taken inertia into account. This results in a decrease of the absorption from the plateau at even higher frequencies. This decrease is, however, too slow to account for the measurements.

Waxler, R. M., Weir, C. E., and Schamp, H. W., Jr., J. Res. Nat'l. Bur. Std. 68A, 489-98, 1964.
An interferometer was used to determine absolute n's for benzene, carbon tetrachloride, and water at 8 wavelengths in the visible region, pressures to 1100 bars, and temperatures between 0 and 55°. The data for the first two liquids were fitted to one-term dispersion equations of the Drude and Lorentz-Lorenz types. Changes with temperature and pressure were attributed to changes in density and shifts in the fundamental absorption frequency. For water a second term was required in the Drude equation.

Ko, C. and Lin, W-C., J. Chinese Chem. Soc. 11, 1-13, 1964.
Intermolecular association in chloroform-acetone and diethyl ether-chloroform systems was studied in terms of polarization at optical frequencies. For the first system the association ratio (acetone: chloroform) was 1:1 and 1:2 and for the second system the ratio was 1:1.

Hyber, H. and Wright, G. F., Can.J. Chem. 42, 2065-72, 1964.
Diphenylmercury shows a large atomic polarization P_A from integrated intensities in the far infrared. Even without this contribution to the polarization the measured electron polarization P_E extrapolated to infinite wavelength exceeds P_{E+A}, measured for the solid at 1 Mc. The difference, defined as the "phenyl effect," is suggested to be general for aromatic compounds. The distortion polarization is said not to be reliably evaluated by optical methods.

Knobler, C. M., Abbiss, C. P., and Pings, C. J., J. Chem. Phys. 41, 2200-1, 1964.
The n's of liquid Ar, methane, and carbon tetrafluoride were measured and the Lorentz-Lorenz functions calculated. The L-L function for the liquid below the critical temperature is less than that of the gas at 0° by 1% or more for these substances as well as for nitrogen and oxygen. The value for liquid hydrogen is less than that for the gas by only 0.4%.

Eatwell, A. J. and Jones, G. O., Phil. Mag. 10, 1059-66, 1964.
The n of solid argon was measured at 5461 Å from 20°K to the triple point by the method of minimum deviation. Some additional measurements at 4348 and 5893 Å showed a small dispersion. The atomic polarizability, as expressed by the Lorentz-Lorenz function $(n^2-1)/(n^2+2)d$, decreased with increasing d, and at highest d's was roughly proportional to $d^{-1/3}$. A shell model, with a single frequency of oscillation of the shell relative to the core, is discussed. The ϵ_0, by extrapolation, is 1.63_5 at 50°K and 1.59_5 at the triple point.

Heilmeier, G. H., Appl. Opt. 3, 1281-7, 1964.
The crystal growth, dielectric properties, optical properties, and the electrooptic effect of the cubic molecular crystal hexamine, $(CH_2)_6N_4$, were studied. n_D^{25} was 1.5911 and the change in n between 4860 and 6560 Å was 0.0095. ϵ was frequency-independent to 22 Gc. at 77-300°K. The electrooptic coefficient, $\Delta n/\Delta E$, was 4.18×10^{-10} cm/v; that calculated by a model 13.2×10^{-10} cm/v.

Walker, W. C. and Osantowski, J., Phys. Rev. 134, A153-7, 1964.
The absolute reflection spectrum of type IIa diamond was measured at room temperature from 4 to 30 eV, and analyzed by dispersion techniques to give the optical parameters. Structure observed in ϵ near 7, 12, 16, 20, and 24 eV was attributed to interband transitions at critical points in the joint density-of-states function.

Cox, J. T., Haas, H., and Ramsay, J. B., J. Phys. 25, 250-4, 1964.
Optical properties at wavelengths between 0.2 and 1.6 microns are given for films of the oxides of Si, Al, Th, and Zr. Methods of preparation and applications of these films are described.

Fabre, D., Romand, J., and Vodar, B., J. Phys. 25, 55-59, 1964.
The principle of the method for determining the optical constants in thin dielectric films in the far ultraviolet and results for some alkali fluorides and alkaline earth fluorides are given.

Lavilla, R. E. and Mendlowitz, H., J. Phys. 25, 114-118, 1964.
A method of determining optical constants of a substance from a knowledge of its electron energy absorption spectrum and optical properties is applied to a study in the far ultraviolet of Al and polystyrene.

Potter, R. F., J. Opt. Soc. Am. 54, 904-6, 1964.
Given the experimentally determined minimum ratio of the reflectances for the components ($R_{\parallel}/R_{\perp}$) and the angle of incidence at that minimum for a specular surface, an analytical determination of ϵ' and ϵ'' can be made. Calculated values of ϵ', ϵ'', and real and imaginary parts of n are given for a GaSb sample at wavelength 5800 Å.

Mahan, G. D., Dissertation Abstr. 25, 1990-1, 1964.
The theory of spatial dispersion is investigated for molecular solids and semiconductors. The theory in semiconductors is developed for cadmium sulfide. The theory of wurtzite valence bands is extended to estimate the effective masses in cadmium sulfide for the relevant bands. The boundary conditions appropriate to each of the two solids are derived.

C. Kerr Effect; Light Scattering

Kuss, E. and Heydemann, H.-H., Z. Phys. Chem. 43, 97-112, 1964.
Apparatus is described for the measurement of the pressure-dependence of the Kerr constants of gases and liquids and results given for liquid carbon tetrachloride, n-heptane, and benzene to 1000 atm. The effect of pressure on the electric double-refraction of benzene is appreciably greater than given by the Langevin-Born theory, for the other liquids smaller. The polarizability in the plane of the benzene ring is increased by pressure, that at right angles decreased.

LeFevre, R. J. W. and Williams, A. J., J. Chem. Soc. 1964, 562-5.
Standard procedures were used for determination of μ's and molar Kerr constants of a number of non-polar and slightly polar solutes in chlorobenzene. Results are compared with previous results in chloroform and carbon tetrachloride.

LeFevre, R. J. W. and Orr, B. J., Australian J. Chem. 17, 1098-1105, 1964.
μ and molar Kerr constant of 1,2-dichloroethane in carbon tetrachloride are determined and discussed in relation to internal rotation. The results are consistent with a mixture of 31.3% gauche and 68.7% trans isomers.

Aroney, M. J., Chia, L. H. L., LeFevre, R. J. W., and Saxby, J. D., J. Chem. Soc. 1964, 2948-54.
μ's, molar Kerr constants, and refractivities are given for $(RO)_3PO$ in which R is methyl, ethyl, n-propyl, isopropyl, amyl, and phenyl and for $(RO)_3P$ in which R is methyl, ethyl, isopropyl, decyl, and phenyl. The principal polarizability semiaxes have been calculated assuming C_3 symmetry. Configurations are discussed.

Aroney, M. J., Corfield, M. G., and LeFevre, R. J. W., J. Chem. Soc. 1964, 645-52.
μ's and molar Kerr constants are reported for 2,4,6-trimethylbenzaldehyde, acetophenone, 2,4,6-trimethylacetophenone, and 2,3,5,6-tetramethylacetophenone in CCl_4. Conformations are discussed.

Aroney, M. J., LeFevre, R. J. W., and Singh, A. N., J. Chem. Soc. 1964, 3518-23.
Values of apparent μ's and molar Kerr constants in carbon tetrachloride are given for trialkyl orthoformates, where the alkyl group is methyl, ethyl, n-propyl, and n-butyl. The first appears to exist as a mixture of rotational isomers in which each methyl group is staggered with respect to the H atom on the central C atom and the O atoms of the neighboring CH_3O groups.

Aroney, M. J., LeFevre, R. J. W., and Saxby, J. D., Australian J. Chem. 17, 289-93, 1964.
ϵ's, d's, electric birefringences and n's of solutions of tri(isopropanolamine) borate in benzene at 25°C are reported.

Eckert, J. M. and LeFevre, R. J. W., J. Chem. Soc. 1964, 3200-3.
μ's and molar Kerr constants are reported for cis-2-decalol and for 3 samples of cis-2-decalyl chloride prepared from the alcohol by three different methods. The Kerr constants for the 3 chlorides were compared with those calculated from polarizabilities and discussed in terms of the steric courses for the replacement reaction.

LeFevre, R. J. W. and Sundaram, K. M. S., J. Chem. Soc. 1964, 3518-23.
μ's and molar Kerr constants are given for cyclopentadiene, dicyclopentadiene, and 5 polycyclopentadienes of different degrees of polymerization. The dimer is shown to be the endo isomer by calculation of the anisotropic polarizabilities.

LeFevre, R. J. W. and Sundaram, K. M. S., J. Chem. Soc. 1964, 556-62.
The apparent μ's and molar Kerr constants are reported for 8 polyindenes of molecular weights of 400 to 4200. μ's are insensitive to molecular weight. The Kerr constants can be satisfactorily predicted from bond and benzene polarizabilities.

Coumou, D. J., Mackor, E. L., and Hijmans, J., Trans. Faraday Soc. 60, 1539-47, 1964.
The mean square fluctuation of ϵ, $<(\Delta\ \epsilon)^2>$, appearing in the Einstein equation for isotropic light-scattering intensity is usually calculated with ϵ taken to depend only on d. Since ϵ is a function of d and temperature or of d and pressure, additional terms in temperature or pressure fluctuations should be taken into account. These terms have been evaluated for a number of liquids from measured pressure and temperature derivations of n. The contribution of temperature fluctuations is negligible but that of pressure fluctuations may amount to 10%. It is concluded that $(\partial n/\partial d)_T$, and not $(\partial n/\partial d)_p$, should be used. The ratio of isotropic scattering factors so calculated to the measured total Rayleigh factors agrees with the Cabannes factor obtained from the measured depolarization values of a number of liquids.

D. Infrared Measurements

James, T. C., J. Chem. Phys. 40, 762-71, 1964.
Satellite bands in the infrared spectrum of NO which correspond to forbidden transitions were observed and found, in agreement with theory, to be ~ 10^{-4} less intense than the fundamental. The intensity of the fundamental was 138 cm^{-2} atm^{-1} at 273°K.

Breeze, J. C. and Ferriso, C. C., J. Chem. Phys. 40, 1276-82, 1964.
Total integrated intensities of the 3 Fermi-coupled bands in the 1.9-μ region of the infrared spectrum of CO_2 have been measured in the temperature range 1400 to 2500°K, heat being generated by a shock wave technique. The integrated intensity increases with temperature at high temperatures; it is discussed in terms of a harmonic oscillator approximation. At STP the integrated intensity is 2.07 cm^{-2} atm^{-1}.

Ibid. 41, 3420-7, 1964.
Similar measurements (see preceding digest) were made on the 5.3-μ fundamental and the 2.7-μ overtone bands of NO. The integrated intensities were respectively 76 and 2.8 cm^{-2} atm^{-1} at STP, the first being temperature-independent, the latter increasing slightly with temperature.

Cole, A. R. H. and Michell, A. J., Spectrochim. Acta 20, 739-46, 1964.
Infrared intensity measurements of an out-of-plane CH bending vibration band of benzene and 50 methyl- and halo-benzenes give 0.64 ± 0.01 D for the μ of the sp^2 C-H bond, with indications that the polarity is C^{-}-H^{+}.

Lisitsa, M. P. and Khalimonova, I. N., Optika i Spektroskopiya 14, 793-7, 1963. (Russian). Translation: Optics and Spectrosc. 14, 420-22, 1963.
The dispersion of tolan was studied in $\lambda = 0.75 - 17$ micron region. The oscillator strengths of the vibrational transitions, which cause anomalous behavior in the dispersion curves, were calculated by Kramers' dispersion equations and a comparison between the oscillator strengths obtained from the dispersion and the absorption data was made. The reasons for observed discrepancies are discussed.

Harris, L. and Piper, J., J. Opt. Soc. Am. 53, 1271-5, 1963.
Far infrared measurements on oriented bismuth deposits have yielded indexes of absorption and refraction together with the electrical conductivities and ϵ's and τ's of the holes and electrons in the deposits. The values of ϵ for these deposits were found to approach 0 near the wavelength of the reflection minimum.

Harris, L. and Corrigan, F. R., J. Opt. Soc. Am. 54, 1437-41, 1964.
The reflectances and transmittances of Sb deposits on Al_2O_3 substrates were measured in the 4 to 140 micron region. The optical and electrical properties were evaluated. The lattice ϵ and the τ's for the electrical carriers in Sb were derived from the change of the electrical parameters with wavelength.

Geick, R., Phys. Letters 10, 51-52, 1964.
The infrared fundamental dispersion frequency and ϵ_0 of PbS have been determined to be 70 ± 1.5 cm^{-1} and 140 ± 20 respectively by means of transmission and reflection measurements in the wavelength range from 40 microns to 2 mm.

Malitson, I. H., J. Opt. Soc. Amer. 54, 628-32, 1964.
n was determined for BaF_2 at 25°C for 46 wavelengths between 0.2652 to 10.346 microns. Measured values were fitted to a 6-constant dispersion equation. Tentatively $\frac{dn}{dt}$ was -12×10^{-6} deg^{-1}C. Various dispersion parameters are graphically presented and transmittance data from the literature reviewed.

Reik, H. G., Kauer, E., and Gerthsen, P., Phys. Letters 8, 29-30, 1964.
The reflectivity of $LaCoO_3$ at 290°K has been measured in the spectral region 2 to 15 microns. ϵ is expressed as the sum of a real value due to the lattice and a complex value due to polarons. Good agreement is found between experiment and theory with a suitable choice of polaron relaxation time.

Hunt, G. R., Perry, E. H., and Ferguson, J., Phys. Rev. 134, 688-91, 1964
The data obtained from the transmittance measurements (800 to 70 cm^{-1}) and reflectance measurements in the far infrared of potassium magnesium fluoride and magnesium fluoride were analyzed using the Kramers-Kronig relation to obtain the dielectric dispersion of the materials.

Camagni, P., Cingolani, A., and Manara, A., U. S. At. Energy Comm. EUR-463.e, 18 pp, 1963.
The electrical conductivity and polarizability of polycrystalline uranium and uranium carbide were measured for the region of the spectrum from ~ 0.35 micron to ~ 2.8 microns. A comparison between the electronic structures of the two materials is made from the results.

E. Static Dielectric Constants of Nonpolar Substances

Amey, R. L. and Cole, R. H., J. Chem. Phys. 40, 146-8, 1964.
ϵ's of A, Kr, Xe, and CH_4 have been measured in the liquid and in the solid near the melting point. Values of the derived Clausius-Mossotti function are in all cases less than for the gas, indicating a decrease in effective polarizability attributed to overlap effects.

Stewart, J. W., J. Chem. Phys. 40, 3297-306, 1964.
ϵ of liquid and gaseous para-H was measured between 24 and 100°K and 2 and 326 atm. encompassing the density range 0.002 to 0.080 g/cm^3. The results are combined with PVT data to calculate the Clausius-Mossotti function which is not constant within the range considered, but rises with increasing density from 1.00427 to a value 0.2% higher and then decreases. The data are represented by equating the reciprocal of the Clausius-Mossotti function to a quadratic function of density. The deviations from constancy are too small for correlations with existing polarizability theories.

Tipton, A. B., Deam, A. P., and Boggs, J. E., J. Chem. Phys. 40, 1144-7, 1964.
ϵ's of SF_6 and CF_4 between 295° and 630°K at 800 Mc were measured employing a microwave cavity technique. The molar polarization was found to be independent of temperature in the range studied. The calculated values of atomic polarization were compared with previous measurements of absolute infrared absorption intensities in the two gases. The use of precise ϵ measurements as a check on the accuracy of infrared intensity measurements is discussed.

Gibbs, D. F. and Hill, G. J., Phil. Mag. 9, 367-375, 1964.
The variation of ϵ with pressure to 10,000 kg/cm² of 2 diamonds has been determined. If an atomic polarizability α is calculated from the Clausius-Mossotti equation, it is found that $V/\alpha(\partial\alpha/\partial V)_T$ has the value 1.2, which conforms closely to its value for silicon and germanium. There is some uncertainty as to the elastic constants of diamond and it seems possible that both these and $V/\alpha(\partial\alpha/\partial V)_T$ may depend significantly on the impurity content of the stones.

IV. Dipole Moments

A. Theory

Kern, C. W. and Karplus, M., J. Chem. Phys. 40, 1374-89, 1964.
Electron density maps and their appropriately weighted analogs (e.g., dipole-weighted density maps) are found to provide a consistent and useful tool for the analysis and comparison of atomic and molecular charge distributions obtained with different wave functions. Application is made to HF, for which a series of single determinant SCF-LCAO-MO wave functions permit a study of the changes that occur in the electron density as the Hartree-Fock solution is approached. An examination of alternative basis-set functions of essentially the same size and energy shows that significantly different charge distributions can result; this points out the need for a careful selection of basis functions in large scale molecular calculations. Various methods for summarizing wave functions in terms of characteristic parameters of the charge distribution are considered. The forces acting on the nuclei are analyzed in relation to the Hellmann-Feynman theorem and a necessary condition on the exact molecular Hartree-Fock solution is obtained. Analysis of the contributions to the total observed μ shows that the bond orbitals approximately cancel the nuclear contribution and that the lone pairs give the principal contribution.

Chan, S. I., Ikenberry, D., and Das, T. P., J. Chem. Phys. 41, 2107-10, 1964.
The determination of μ's from isotopic variations of the rotational magnetic moment may be accompanied by appreciable errors if the effects of vibrational motion on the high-frequency part of the magnetic susceptibility are neglected. When vibrational corrections are made, the μ of HF as determined from the rotational magnetic moments of HF and DF is 1.83±0.05D (instead of 1.65D) and agrees with the value 1.818±0.008D obtained by the molecular beam electrical resonance method.

Coppens, P. and Hirschfeld, F. L., Israel J. Chem. 2, 117-9, 1964.
Atomic positions in crystals as revealed by X-ray diffraction may be different from those determined by neutron diffraction because of electron pairs in asymmetrical orbitals. Refined X-ray and neutron diffraction data for hexamethylenetetramine indicate a difference in position of 0.019 Å for the N-atom. This difference is consistent with the presumed atomic moment of N in NH_3 of ca. 1.0D.

Whiffen, D. H., Trans. Faraday Soc. 60, 1198-1201, 1964.
A theoretical treatment of linear YXY' molecules showed that μ depends on the harmonic force constants and the derivative of μ with respect to the bending

coordinate as well as on the anharmonic potential constants and the derivatives of μ with respect to bond-stretching coordinates. The respective contributions to μ of $^{16}OC^{18}O$ are 1.5 x 10^{-4} and 11.5 x 10^{-4}D.

Constantinides, E., Proc. Chem. Soc. 1964, 290.
Pauling's expression for calculating electronegativities of elements from bond dissociation energies was extended to the calculation of the electronegativities of the CH_3, C_6H_5, CN, CF_3 and OH groups. The value for CH_3 indicates a polarity $CH_3{}^+H^-$ in CH_4 and a μ_{CH} = ~ 0.3 D in agreement with other theoretical and spectroscopic values. The value for OH indicates a polarity Cl^+OH^- in HClO. The CF_3 group is more negative than the CH_3 group.

Sharma, R. R. and Das, T. P., J. Chem. Phys. 41, 3581-91, 1964.
μ's of the deformable O^{2-} ions in the corundum-type crystals Al_2O_3, Cr_2O_3, and Fe_2O_3 are calculated. In magnitude and sign these μ's depend on the crystal parameters and vary widely over the 3 oxides. The dipolar contributions to the crystalline field components at the metal ion sites were evaluated and found to be sufficiently important as in some cases to alter the sign of the field components obtained from point charges alone. The effect on the optical parameters is quantitatively treated.

Kollrack, R., J. Phys. Chem. 68, 2052-7, 1964.
The induced μ of a F ion was calculated for the complex ions $[M^{IV}F_6]^{2-}$, $[M^{II}F_6]^{4-}$, $[M^{III}LF_5]^{2-}$, $[M^{III}L_5F]^{2+}$ and trans-$[M^{III}L_4F_2]^+$ by using ligand field theory (L = dipolar molecule like H_2O or NH_3). μ of a given F^- ligand is induced by the inhomogeneous electric field which is caused by the influence of the other ligands and the central M ion.

Kawski, A., Naturwissenschaften 51, 82-3, 1964.
For α-naphthol, β-naphthol, and β-naphthyl methyl ether values of μ in the ground and first excited states are calculated from expressions previously developed (Z. Naturforsch. 18a, 10-15, 1964). Ground and excited state μ's are, respectively, 2.67, 1.48; 3.28, 1.56; and 2.8, 1.2D.

Syamalamba, K. and Premaswarup, D., Indian J. Pure Appl. Phys. 2, 11-13, 1964.
μ's of 23 disubstituted naphthalenes were calculated by the method of Smallwood and Herzfeld. When the effect of induced moments was included, better agreement with experimental μ's was usually obtained than when simple vector addition was used.

Flory, P. J., Proc. Nat'l. Acad. Sci. U.S. 51, 1060-7, 1964.
The configurational properties of chain molecules were studied theoretically by applying methods, developed for the Ising lattice, of point dipoles in one dimension. A rotational isomeric state model, elaborated by Volkenstein, was applied to the determination of mean-square μ's of chain molecules, without the previous restrictions that chains should be long and should consist of identical structural units regularly repeated.

Eliezer, I., J. Chem. Phys. 41, 3276-7, 1964.
The discrepancies between various literature values of the μ's of mercuric halides in dioxane are discussed. It is suggested that the finite μ's in dioxane and benzene are due to interaction with the solvents, probably producing bent halide molecules. This interaction makes the solubility greater in these solvents than in paraffinic ones.

B. Gaseous Molecules

Lindfors, K. R., Dissertation Absts. 24, 3557, 1964.
A new technique is developed from measuring μ's in cases where the conventional Stark splitting of microwave lines is difficult. The new method may be used where first or second order Stark effect equations are obeyed for splittings less than one half-width. It consists of measuring the intensities of the signals at weak fields relative to the intensity of the zero-field line and gives permanent μ's to an accuracy of a few percent. It is not necessary that the individual Stark components be resolved.

Sanders, P. G. H. and Lipworth, E., Phys. Rev. Letters 13, 718-20, 1964.
A study by the atomic beam method shows that the static electric μ for the Cs atom is $d_A = (2.2 \pm 0.1)\ 10^{-19}$ cm x e. A relativistic analysis of this result indicates that the static electric μ of the free electron is $d_e \leqq 2 \times 10^{-21}$ cm x e.

Herbert, A. J., Breivogel, F. W., Jr., and Street, K., Jr., J. Chem. Phys. 41, 2368-76, 1964.
Study of the radio-frequency and microwave spectra of $^6Li^{79}Br$ and $^6Li^{81}Br$ by the molecular beam electric-resonance method gave dipole moments of the $J = 1$, $v = 0$, 1, and 2 and $J = 2$, $v = 0$ states to an accuracy of ±0.001D. Quadrupole interaction and spin-rotation interaction constants of Br and molecular rotational constants were also obtained. The apparatus is described.

Hollowell, C. D., Hebert, A. J., and Street, K., Jr., J. Chem. Phys. 41, 3540-5, 1964.
Study of the radio-frequency and microwave spectra of NaF by the molecular beam electric-resonance method gave dipole moments for the first three vibrational states and various rotational and coupling constants. μ's were slightly but significantly lower than those reported by Bauer and Lew (Can. J. Phys. 42, 830, 1964) for the same vibrational levels.

Esterowitz, L. and Rosenthal, J., J. Chem. Phys. 40, 1986-7, 1964.
Stark effect measurements made for the $8_{08} \rightarrow 7_{17}$ rotational transition of $^{15}N^{16}O_2$ gave $\mu = 0.294 \pm 0.015$ D.

Boggs, J. E., J. Phys. Chem. 68, 2379-81, 1964.
ε data on the $2NO_2 = N_2O_4$ equilibrium is reinterpreted to remove the existing disagreements. Low frequency dielectric and microwave Stark-effect data are compatible if μ of NO_2 is 0.316 D and that of N_2O_4 zero with a comparatively large value (2.82 cc) for the atomic polarization for N_2O_4.

Tyler, J. K., J. Chem. Phys. 40, 1170-1, 1964.
The frequencies of several lines in the microwave spectra of four isotopic forms of HCP (methinophosphide), the phosphorus analog of HCN, were measured. Stark effect μ's were 0.390 and 0.397 D, for HCP and DCP, respectively. These values are much smaller than the μ of HCN (3.0 D), illustrating the much smaller electronegativity of P.

Muenter, J. S. and Laurie, V. W., J. Am. Chem. Soc. 86, 3901-2, 1964.
The J = 0 → 1 transition of $HC \equiv CD$ at 59,450.6 Mc was observed, unequivocal evidence of a permanent μ. Since it has been found that the μ of $CH_3 C \equiv CD$ is 0.012 D lower than that of $CH_3C \equiv CH$, it may be assumed that the μ of $HC \equiv CD$ is approximately equal to the isotope shift in μ of this related molecule. The anisotropy of the polarizability is 1.85 ± 0.05 Å^3.

Freeman, D. E. and Klemperer, W., J. Chem. Phys. 40, 604-5, 1964.
μ for the excited vibronic $^1A_2$ state of formaldehyde as determined from Stark splittings of some rotational lines of the 3390-Å band is 1.48 D compared with 2.34 D for the ground electronic state.

Boggs, J. E., Coffey, D., Jr., and Davies, J. C., Jr., J. Phys. Chem. 68, 2383-4, 1964.
The μ of CF_3NO is estimated to be 0.31 ± 0.03 D, a value much smaller than predicted from tabulated bond moments and reasonable C-N-O angles. There is appreciable contribution to the structure from the ionic form $(N\equiv O)^+CF_3^-$, as supported by the Fn.m.r. chemical shift at -100° and the mass spectrum of the dimer.

Dreizler, H. and Dendl, G., Z. Naturforsch. 19a, 512-14, 1964.
The absorption lines of dimethyl sulfoxide $(CH_3)_2SO$ and $(CD_3)_2SO$ were investigated in the frequency range 5.5 - 55 Gc. The rotation constants and the μ were determined.

Varma, R., MacDiarmid, A. G., and Miller, J. G., Inorg. Chem. 3, 1754-7, 1964.
Gas phase μ's of disiloxane and methoxysilane were 0.24 and 1.166 D, respectively. These μ's are compared with that of dimethyl ether and the structures of the three ethers compared.

Meighan, R. M. and Cole, R. H., J. Phys. Chem. 68, 503-8, 1964.
μ's of N-methyl- and N,N-dimethylformamide, of acetamide and its N-methyl and N,N-dimethyl derivatives, and of N-methylpropionamide were obtained from ϵ measurements in the vapor phase at 110° and pressures of 1 to 20 mm. Measurements were also made on solutions in benzene at concentrations between 0.0001 and 0.03 molar at 25° of N, N-dimethylformamide and N-methylacetamide. Monomer-dimer equilibrium exists in solutions of the latter and a dimer μ of 1.6 times the μ of the monomer is inferred. The transformer bridge method using two matched cells is described. The principal factors limiting the accuracy of the measurements appear to be related to adsorption and traces of impurity rather than electrical instrumentation.

Kawski, V. A., Acta Phys. Polon. 25, 285-90, 1964. (German).
A value of 6.8 Debye units was obtained for μ of the excited state of 4-aminophthalimide, with an angle of 16° between the directions of the μ in the ground and excited states.

Dobyns, V. and Pierce, L., J. Am. Chem. Soc. 85, 3553-6, 1963.
The microwave spectrum, structure, μ, and quadrupole coupling constants of 1,2,5-thiadiazole are reported.

Haeusler, C. and Meyer, C., Compt. Rend. 258, 5383-5, 1964.
Six lines representing the transition υ_{0-3} within 100 cm^{-1} of the 6448 cm^{-1} band were measured at 24° and pressures close to atmospheric for HI gas. The electric moment can be calculated as a function of J from the integrated absorption coefficient. The μ matrix element is taken as the ordinate intersect and is 1.10×10^{-3} D.

C. Molecules in Solution

Hassel, W. F., Magee, M. D., Tucker, S. W., and Walker, W., Tetrahedron 20, 2137-55, 1964.
An improved bridge technique for measurement of dielectric absorption at microwave frequencies was used to determine μ's of polar molecules in non-polar solvents with results in excellent agreement with those of the low-frequency Halverstadt-Kumler method. μ's were evaluated from the Debye equation for molecules characterized by a single τ. Applicability of dielectric absorption to the study of molecular interactions was discussed.

Buenker, R. J. and Schulte, G. N., Proc. Iowa Acad. Sci. 70, 187-90, 1964.
Substitution of the actual physical constants of benzene into Guggenheim's short formula for orientation polarization leads to a simple relation for μ. Its accuracy was tested with the data used in some 100 μ measurements with agreement within 0.02 D of the moments calculated from the Kumler-Halverstadt equations.

Ananthakrishnan, S. V. and Rao, D. S., Proc. Indian Acad. Sci. A59, 292-8, 1964.
μ's of NO_2 were measured in a number of aromatic and non-aromatic solvents. In all cases both NO_2 and its dimer had small but definite μ's: about 0.4 for the monomer and 0.5 to 0.6 D for the dimer. Solutions in benzene were strongly colored. A planar, symmetric structure for N_2O_4 is excluded. The structure suggested involves a folded N-O-N-O ring and two O bridges.

Jain, S. R. and Soundararajan, S., Tetrahedron 20, 1589-92, 1964.
The μ's of chloral and bromal hydrates determined in benzene and dioxane prove them not to be molecular compounds with water, but normal covalent compounds. Possible structures are suggested.

Plamondon, J. E., Buenker, R. J., Koopman, D. J., and Dolter, R. J., Proc. Iowa Acad. Sci. 70, 163-6, 1963.
μ of styrene calculated for 18 solutions ranging in weight fractions from 0 to 100% was 0.181 D. The atomic polarization in styrene is small, and thus is taken into account by measuring the mole fraction at the Na D-line. The large μ's of *trans-p,β*-dinitrostyrene and *trans-p,β*-dicyanostyrene are partly attributed to abnormally large atomic polarizations.

Soundararajan, S., Indian J. Chem. 1, 503-6, 1963.
Charge distributions, μ's, and structures of 24 nitriles are discussed.

Drefahl, G., Heublein, G., and Voigt, D., J. Prakt. Chem. 23, 157-72, 1964. Infrared spectra and μ's at 20.2 and 50.8° were determined for 6 1,2-dinitriles R(NC) CHCHR'CN where R is CH_3 or C_6H_5 and R' is H, CH_3, or C_6H_5. The effect of temperature on the relative abundance of rotational isomers is discussed.

Dahl, W. v. and Mueller, F. H., Kolloid-Z. 198, 27-53, 1964. μ's of the normal α,ω-dichlorinated hydrocarbons from 1,2-dichloroethane to 1,10-dichlorodecane at 25° over the entire concentration range in n-hexane were related to the g-factors of the Kirkwood-Frohlich theory. Correlation of μ's of neighboring molecules is responsible for partial conversion of the non-polar trans form of 1,2-dichloroethane to the polar gauche form. Further separation of the Cl's is accompanied by almost complete conversion.

Mathias, S. and Cecchini, R. G., Annales Real Soc. Espan. Fis. Quim. B60, 241-56, 1964. μ's were determined from measurements of ε's of pure $Br(CH_2)_NSH$, and of their solutions in benzene, where n ranged from 2 to 6 for the α,ω-dibromoalkanes and from 3 to 5 for the alkanedithiols. For the former μ's calculated from the solution data were about 0.20 D less than for the pure liquids, for the latter about 0.10 D less. The relation between μ's and configuration was discussed.

Soundararajan, S., Z. physik. Chem. (Leipzig) 226, 302-8, 1964. μ's were measured of 7,8- and 5,6-benzoquinolines, 8-hydroxyquinoline, and 6-nitroquinoline in benzene solution. The agreement with μ's calculated from the net formal charges given by a molecular orbital treatment is said to be unsatisfactory.

Quivoron, C. and Neel, J., J. Chim. Phys. 61, 554-71, 1964. μ's of α-, β-, γ-, and δ-isomers of 1, 2, 3, 4, 5, 6-hexachlorocyclohexane were measured in benzene. It is not possible to calculate μ's from the geometry of the cyclohexane ring by simple vector addition of bond moments because the μ of the C-Cl bond is variable. By taking account of inductive effects on the C-Cl bond, satisfactory agreement is obtained.

Barassin, J., Ann. Chim. 8, 637-66, 1963. Many μ data of pyridine and N-phenylsuccinimide derivatives are collected and discussed in terms of the molecular configurations of the compounds studied.

Kokoreva, I. Yu., Zh. Strukt. Khim. 5, 314, 1964. (Russian). μ's of two spatial isomers of 2-methyl-4-oxooctahydro-1-pyridine were determined in benzene solutions. The isomer with the lower boiling point has the methyl group in the axial configuration, the second has an equatorial methyl group. The smallness of the difference between the μ's (3.16 and 2.90 D, respectively) shows both isomers to have the same ring conformation.

Desai, D. D. and Pandhare, N. H., Indian J. Pure Appl. Phys. 2, 6-10, 1964. μ's of o-, m-, and p-anisidines, measured at 30° in benzene, toluene and xylene, decreased in that order. μ's always increased in the order o-, m-, and p-. Solvent effects are discussed.

Krishna, B. and Srivastava, A. N., Dielectrics 1, 193-4, 1964.
The μ's of tributylamine in cyclohexane solution and isobutylamine in cyclohexane and benzene solutions were determined. Values of molar polarization at various values of the mole fraction are also given.

Richards, J. H. and Walker, S., Tetrahedron 20, 841-53, 1964.
μ's of 10 mononitronaphthyl amines with substituents in non-adjacent ring positions, of 1-nitronaphthalene and of 1-naphthylamine were measured in benzene and dioxane. Mesomeric and electromeric contributions to the μ's are discussed.

Purcell, W. P., J. Phys. Chem. 68, 2666-70, 1964.
μ's were measured of pyridine, nicotinamide, and of N-methyl, N,N-dimethyl, N-ethyl, and N,N-diethyl derivatives of nicotinamide in benzene. The amide group μ's increase with alkyl group substitution which appears to produce an electron releasing effect. Aromatic amide group μ's were calculated from free and restricted rotation models.

Soundararajan, S., Tetrahedron 19, 2171-75, 1963.
μ's of some aliphatic nitro compounds and oximes were evaluated. The mesomeric moment obtained as a difference between the calculated and observed values shows how the positive and negative mesomeric effects operate in such systems.

Lawrence, A. R. and Matuszko, A. J., J. Phys. Chem. 68, 199-201, 1964.
μ's of 1,2-dinitroxy alkanes increase with size of the alkyl group (R) because the number of molecules (with almost 0 moment) in the *trans* conformation of nitroxy groups decreases. For 2,3-dinitroxy alkanes, *bulky* R increases μ as before for *dl*- or *threo*- compounds, but decreases μ for *meso*- or *erythro*- ones because sterically the *trans* conformation is now promoted.

Fernandez-Alonso, J. I. and Oliete, J. L., Annales Real. Soc. Espan. Fis. Quim. Ser. B 60, 183-94, 1964.
Measurements of the μ of 1,1'-azonaphthalene in cyclohexane solution indicate a *trans* configuration.

Cumper, C. W. N., Foxton, A. A., Read, J., and Vogel, A. I., J. Chem. Soc. 1964, 430-4.
μ's of triethyl, tri-n-propyl, tri-n-butyl, tri-n-pentyl, and triphenyl phosphine and of their oxides were determined in benzene and related to the conformations of the molecules and the μ of the P-O bond.

Stadnichuk, M. D., Mingaleva, K. S., and Petrov, A. A., Zh. Obshch. Khim. 34, 3289-91, 1964.
The μ's and structures of 1,3-dienic silicon hydrocarbons are discussed.

Huang, H. H. and Hui, K. M., J. Organometal. Chem. 2, 288-90, 1964.
μ's are measured for various substituents in the 4 position of the phenyl group of $C_6H_5Sn(CH_3)_3$ and $C_6H_5Si(CH_3)_3$. Substituent groups include $(CH_3)_2N$, CH_3, Cl, Br. Measured μ's are compared with those calculated from bond moments and geometry.

Kartsev, G. N., Syrkin, Ya. K., Kravchenko, A. L., and Mironov, V. F., Zh. Strukt. Khim. 5, 492-3, 1964. (Russian).
μ's of some organic germanium compounds, measured in benzene solution, are reported. The contributions of the atomic polarization is large in these compounds and was established to be about 20% of the electric polarization. The bonds of the central atom with the substituents are less polar in the Ge compounds than in the analogous Si compounds.

Kartsev, G. N., Syrkin, Ya. K., Kravchenko, A. L., and Mironov, V. F., Zh. Strukt. Khim. 5, 639, 1964. (Russian).
μ's of 4 Ge trimethyl halides, Me_3GeX, were measured at 25° in benzene solutions by the heterodyne method. Calculation of μ on the basis of moments 3.00 D and 3.15 D found earlier for the bonds Ge-Cl and Ge-Br yielded values agreeing with experimental values. From this the moment of the Ge-F bond was estimated as 2.8 D and that of Ge-I bond as 3.1 D.

Lamanna, W., Sciacovelli, O., and Jannelli, L., Gazz. Chim. Ital. 94, 567-77, 1964.
Densities, n's, and μ's of dehydrated sulfolane were determined. μ's are 4.68, 4.80, and 4.91 D in carbon tetrachloride, benzene, and dioxane, respectively. The moment increase is attributed to contraction of the C-S-C angle. Infrared spectra in various solvents show a parallelism with aliphatic saturated sulfones.

Lumbroso, H. and Montaudo, G., Bull. Soc. Chim. France, 1964, 2119-24.
μ's in benzene at 25° of 11 aromatic sulfides, sulfoxides, and sulfones were measured. The spatial configurations and electronic structures of the compounds were determined. Phenoxanthin S-oxide had the equatorial configuration. Thianthrene S, S'-dioxide had the cis-cis conformation.

Barbara, A. K. and Mahanta, P. C., Indian J. Pure Appl. Phys. 2, 304-5, 1964.
μ's of iodide, bromide, chloride, and cyanide of azobenzene-2-sulphenyl were determined in dilute solutions of dioxane and benzene. The high values obtained for the μ's of chloride, bromide, and iodide require a cis form of the azobenzene skeleton, whereas the value obtained for the cyanide needs a trans disposition. The ionic character of the S-halogen bond and also the solvent effects to some extent may be the other contributory factors for the high values obtained for the halides.

Kesler, M., Croat. Chem. Acta 36, 165-8, 1964.
μ's of alkyl Hg oxide, sulfide, and selenide were determined and related to bond length, valence angle, and electronegativity differences between Hg and O, S, and Se. Angles of 110° and 100° for methyl Hg oxide and selenide, and lengths of ~ 2.47 and 2.67 A for the Hg-S and HgSe bonds, respectively, were deduced.

Osipov, O. A., Ismailov, Kh. M., Kashireninov, O. E., Garnovskii, A. D., and Orlova, L. V., Dokl. Akad. Nauk Azerb. SSR 21-4, 1963. (Russian).
μ's of dialkylaminomethylphenols and aromatic sulfides were calculated from dielectric permittivities measured in benzene at 25°C.

Kokoreva, I. Yu., Neiman, L. A., Syrkin, Ya. K., and Kirillova, S. T., Dokl. Akad. Nauk SSSR 156, 412-414, 1964.
μ's of C,N-diphenylnitron, C-phenyl-N-benzylnitrone, C,C-diphenyl-N-benzylnitron, C-(N,N-dimethylamino-phenyl)-N-benzylnitron, C-(m-nitrophenyl)-N-benzylnitron, C-acetoxy-C,N-diphenylnitron, and C-phenyl-N-(,α,α-diacetoxy-benzyl)nitron were determined in dilute benzene solution at 25°. Results are tabulated and discussed.

Kocharyan, N. M., Barsamyan, S. T., and Pikalova, V. N., Dokl. Akad. Nauk Arm. SSSR 38, 295-9, 1964. (Russian).
μ's of dimethyl-, methylethyl- vinylethynyl-, cyclohexylvinylethynyl-, methylphenylethynyl-, methyl-tert-butylvinylethynyl-, methylvinylethynyl-, ethylvinylethynyl-, and propylvinylethynyl carbinols were determined at 20 ± 0.5°. μ's in general depend on the presence of the strongly polar carbinol bond, the μ of which is 1.5-1.7 D. n's of all carbinols studied have the same value and obey the Lorentz-Lorenz formula.

Osipov, O. A., Simonov, A. M., Minkin, V. I., and Garnovskii, A. D., Tr. Soveshch. po Fiz. Metodam Issled. Organ. Soedin. i Khim. Protsessov, Akad. Nauk Kirg. SSSR Inst. Organ. Khim., Frunze 1962, 61-7, (Pub. 1964). (Russian).
μ's were measured of imidazole and of 11 of its derivatives. The dependence of ε on concentration is typical for compounds containing the imino group and forming intermolecular hydrogen bonds. The imidazole association is by the NH...N type of hydrogen bond rather than by formation of ionic compounds of the ammonium salt type, as shown by association constants considerably greater than 2.

Mazeika, I., Avota, L., Sokolov, G., and Hillers, S., Ibid. 68-71.
μ's were measured of pyridazine and of 10 of its derivatives and compared with those calculated by vector addition of bond moments. Differences were related to the effect of substitution on the electron density distribution.

Pozharskii, A. F. and Simonov, A. M., Zh. Obshch. Khim. 34, 224-7, 1964. (Russian).
μ's in benzene and/or dioxane were determined of 1-propyl, 1-phenyl, and N-(2,4-dinitrophenyl) derivatives of imidazole and benzimidazole and of 1-benzylbenzimidazole. The results are discussed in terms of interaction of the phenyl and imidazole rings.

Chylinska, J. B. and Urbanski, T., J. Heterocyclic Chem. 1, 93-5, 1964.
A most probable stereochemical structure for dihydro-1, 3-oxazine derivatives was suggested on the basis of μ measurements.

Riemschneider, R. and Grabitz, E. B., Monatsh. 95, 190-3, 1964.
μ's of 1,1,2,3,8,9-hexachloro-4,7-methylenetetrahydroindene and of a methyl homolog were measured and compared with values calculated from the structures.

Zemlyanskii, N. N., Gol'dshtein, I. P., Gur'yanova, E. N., Panov, E. M., Slovokhotova, N. A., and Kocheshkev, K. A., Dokl. Akad. Nauk SSSR 156, 131-4, 1964. (Russian).
Molar polarizations at infinite dilution in benzene and μ's are reported for 11 compounds containing one or more stannoxane (Sn-O) bonds. Assuming a μ of

2.7 D for this bond, the authors attempt to determine the steric configurations of the compounds. The presence of acceptor groups increases the donor properties of the Sn atom and permits formation of donor-acceptor bonds.

Thompson, H. B., Kuhn, L. P., and Inatome, M., J. Phys. Chem. *68*, 421-2, 1964.
The small μ's (0.0 ± 0.2 D) of the dimers of (amino-oxy) dibutylborane and (butylaminooxy) dibutylborane in carbon tetrachloride indicate a nonpolar chair configuration.

Hirsjarvi, P. and Krieger, H., Suomen Kemistilehti *37B*, 140-1, 1964. (German).
The ε's of *endo*-norbornanol, *exo*-norbornanol, and norbornane in benzene at 25° gave μ's of 0.24, 1.66, and 1.63 D, respectively.

Balaban, A. T., Bally, J., Bishop, R. J., Rentea, C. N., and Sutton, L. E., J. Chem. Soc. *1964*, 2382-7.
The large μ (8.24 D) of 5(7)-methyl-1,3,2-dioxaboraazulene-2-spiro-2'-(1',3',2'-benzodioxaborole) measured in benzene confirms the spiran co-ordinated structure previously suggested. The chemistry of some novel spiroborates is discussed.

D. Molecular Complexes

Smith, J. W., J. Chim. Phys. *61*, 125-30, (discussion 130-1), 1964.
Hydrogen bonding between weak acids and weak bases involves only a relatively small contribution to μ of the complex formed. Interaction is formulated between free acid AH and base B:

$$\mathrm{AH + B} \rightleftharpoons \underset{\substack{\text{hydrogen}\\ \text{bonded}}}{\mathrm{AH...B}} \rightleftharpoons \underset{\substack{\text{Ion pair}\\ \text{(hydrogen-bonded)}}}{\mathrm{A^-...\ HB^+}} \rightleftharpoons \underset{\substack{\text{Free}\\ \text{ions}}}{\mathrm{A^- + HB^+}}$$

As the strength of AH or B or both is increased, the apparent contribution of ion pair forms becomes more important. In the association of acids of medium strength with tributylamine or triethylamine the energies of the H-bonded and ion pair forms become nearly equal with the result that the two exist in tautomeric equilibrium in solution.

Young, R. P., Holt, A., and Walker, S., Tetrahedron *20*, 2351-9, 1964.
The possibility of estimation of interdipole distances between certain hydrogen-bonded species in solution from μ measurements is treated. μ's of chloroform, iodoform,and trinitromethane were measured in hexane and p-xylene solutions and of bromoform in hexane. Induced moments in the π-electron cloud of p-xylene for various distances from the polar molecule were calculated and thence the probable interdipole distances.

Treiner, C., Skinner, J. F., and Fuoss, R. M., J. Phys. Chem. *68*, 3406-9, 1964.
Dimerization of dipolar molecules in nonpolar solvents because of electrostatic interaction is proposed. A method is derived for determining association constants (K) and dimer μ's from measurements of ε and d. If the molecular μ's are antiparallel in the dimer, the dimer μ is *ca*. 0, as experimental

results suggest for p-nitroaniline, m-nitrophenol, and pyridinium dicyanomethylide in dioxane. Log K is linear in μ^2 of the monomers, as expected from simple theory.

Faizullina, N. K. and Gur'yanova, E. N., Zh. Obzhch. Khim. 34, 941-6, 1964. (Russian).
μ's of 10 complexes of mercuric bromide with organic sulfides measured in benzene were calculated from dielectric data.

Arzamanova, I. G. and Gur'yanova, E. N., Dokl. Akad. Nauk SSSR 157, 375-7, 1964.
The properties of donor-acceptor bonds depend primarily on the charge transfer. This is shown by a correlation of the heats of formation Δ H, UV spectra, and μ's of the complexes between iodine and organic sulfides R_2S for the following R: cyclohexyl, propyl, butyl, acetyl, sec-heptyl, sec-octyl, benzyl, allyl and phenyl. Mulliken's theory is confirmed.

Jain, S. R. and Soundararajan, S., J. Inorg. Nucl. Chem. 26, 1255-61, 1964.
Dielectric measurements of molecular complexes of halides of group II metals with various aromatic amines and nitriles were made in dioxane or benzene solutions. The polarizations of the Be, Zn, and Cd halide complexes were interpreted in terms of tetrahedral configurations. In the $HgCl_2$ complexes the polarization was attributed to dissociation of the complex. μ's were tabulated.

Lumbroso, H., J. Chim. Phys. 61, 132-38, 1964.
ϵ measurements of solutions of pyrrole and N-methylpyrrole in cyclohexane and carbon tetrachloride were used to determine equilibrium constants for formation of nonpolar cyclic dimers possessing two π-electron hydrogen bonds between anti-parallel coplanar monomer units. μ's and equilibrium constants of the 1:1 complexes between pyrrole and triethylamine, pyridine, s-collodine, and propionitrile in the same solvents were determined. The enhancement of the μ's of the first three complexes indicates that these are linear, with NH...N bonds along the axis of the pyrrole molecule. An orthogonal bond between the NH group and the π electrons of CN bond exists in the pyrrole-propionitrile complex. In the tetrahydropyranpyrrole complex, hydrogen-bonding takes place preferentially to the equatorial orbital of the O atom.

Ciampolini, M., Maggio, F., and Cavasino, F. P., Inorg. Chem. 3, 1188-91, 1964.
The molecular polarizations of Co(II) and Co(III) complexes with substituted salicylaldimines are given. The μ values indicate that the Co(III) compounds have the trans-octahedral configuration.

Strohmeier, W. and Hellman, H., Ber. Bunsenges.-Physik. Chem. 68, 481-8, 1964.
From the measured μ's of 48 metal carbonyl derivatives were calculated the direction and magnitude of the bond moments μ(Ar-M) of the link between the central metal atom M (principally Cr and Mn) and the aromatic component Ar in $XArM(CO)_2D$. (D is an electron donor molecule). μ(Ar-M) points toward the central atom. For the same types of acceptor and donor the bond moments of the donor-acceptor links μ(D-M) are the same in $M(CO)_5D$, $XArM(CO)_2D$ and $C_5H_5M(CO)_2D$ and were found to be 4-5.9 D for the σ-bond between the metal atom and nitrogen bases.

Bigorgne, M. and Messier, C., J. Organometal. Chem. 2, 79-88, 1964. (French).
μ's were measured of a series of $P(C_2H_5)_3$ and $P(OCH_3)_3$ derivatives of Ni carbonyl. If the negative charge is centered near the C atom the charges residing in each of the ligands in the various derivatives decrease linearly with increase in the degree of substitution. Similar conclusions may be drawn from published μ's of substituted Mo carbonyls.

Hurwic, J., Jarzynska, S., and Michalczyk, J., Nukleonika 9, 486, 1964. (Polish).
The μ of the 1:3 complex between lanthanum nitrate and tributyl phosphate in CCl_4 solution was 7.3 D.

Ibid. 9, 484, 1964.
The authors (see last abstract) find the μ of the 1:2 complex between thorium nitrate and tributyl phosphate in CCl_4 to be 5.8 D.

Bauge, K. and Smith, J. W., J. Chem. Soc. 1964, 4244-9.
ϵ's of benzene solutions of some quaternary ammonium salts show the ion pairs of some to form larger aggregates even at very low concentrations. A method of determining the μ's of free ion pairs is suggested. Charge separations in the ion pairs, calculated from μ's, correlate with the ionic sizes, but are less than the interatomic distances derived from conductivity measurements.

V. Dielectric Dispersion and Loss

A. Theory

Veselovskii, P. F. and Suchkov, Yu. D., Fiz. Tverd. Tela 5, 2728-30, 1963. (Russian). Translation: Soviet Phys.-Solid State 5, 1995-7, 1964.
Simplification of the calculation of tan δ by the resonance circuit method is proposed by a method which requires a knowledge of the dependence of the resonance frequency on the permittivity of the sample.

Scaife, B. K. P., Proc. Phys. Soc. (London) 84, 616-7, 1964.
A study of the Brownian motion of a dipolar molecule surrounded by a dispersive dielectric medium resulted in the following generalization of Onsager's equation: $(\epsilon-\epsilon_\infty)(2\epsilon^*+\epsilon_\infty)(2\epsilon+1)/[3\epsilon(2\epsilon^*+1)] = (4\pi N\mu^2/3kTV)\,[(\epsilon_\infty+2)^2/9(1+i\omega\tau_\mu')]$, where τ_μ' is a microscopic relaxation time which includes the effect of dipole-dipole coupling and ϵ^* the complex ϵ.

Williams, G., Trans. Faraday Soc. 60, 1548-55, 1964.
Arrhenius, Eyring, free volume, and dipole diffusion models of dielectric relaxation are discussed in terms of the temperature and pressure dependence of relaxation times and distribution functions. Proper application of the Eyring transition state theory is said to show that the apparent activation energy at constant volume refers to transformation of one mole at the volume of the activated species in its standard state rather than to activation of one mole of unactivated species in its standard state, as has previously been supposed. Free volume theories lead to $(\partial T/\partial T)_\tau = \Delta\beta/\Delta\alpha$, where $\Delta\beta$ is the difference between the isobaric thermal expansion coefficients of the rubbery (liquid-like) and glassy states and $\Delta\alpha$ the difference between the corresponding isothermal compressibilities. Thus $(\partial T/\partial P)_\tau$ is predicted to be independent of τ. The form of ϵ'' vs. pressure plots is analyzed for special cases; these may yield $[\partial \ln\tau/\partial P]_T$.

Fong, F. K., J. Chem. Phys. 40, 132-8, 1964.
Relaxation mechanisms for the anomalously rapid relaxation in diphenyl ether and related compounds are critically examined. It is proposed that short, coupled rotations of the rings about their bonds to the central atom can change the direction of the molecular μ with much less effect upon the surrounding molecules than would be involved in over-all molecular rotation without internal motion. A theory is described whereby such mechanisms, occurring simultaneously with over-all molecular reorientation, are responsible for the observed shortening of τ, and must predominate over possible mesomeric moment effects.

Fong, F. K., RCA Rev. 25, 752-68, 1964.
The concept of simultaneous relaxation mechanisms was extended to a broader class of nonrigid aromatic molecules. Distribution of τ associated with intramolecular group rotations are discussed in terms of the intramolecular interaction, giving rise to potential barriers to such rotations. Expressions involving such a distribution are derived for ϵ' and ϵ''. Methods for the analyses of dielectric data in terms of 2 τ's (one associated with the over-all molecular rotation and the other with group rotation) are evaluated.

Hill, N. E., Proc. Phys. Soc. 82, 723-7, 1963.
A mechanism is proposed for the second dispersion region which occurs in polar liquids at frequencies higher than the Debye frequency. This mechanism is a vibration of molecules about temporary equilibrium positions determined by the arrangement of the neighbors. It leads to a value of the high-frequency limit ϵ_∞ for the Debye dispersion given by $(\epsilon_\infty - n^2)/(\epsilon_0 - n^2) = 2kT/IW_0^2$, where W_0 is the frequency of the vibration, and I the mean moment of inertia of the molecules about axes normal to the dipole axis.

Schmieder, R. W., Am. J. Phys. 31, 885-6, 1963.
A suddenly applied electric field induces an acceleration of molecules in a polar liquid causing an additional electric field which may be calculated by considering the generation of a magnetic field due to the rotation of molecules with permanent μ's. The changing magnetic field in turn implies an additional electric field. For HCl it is 3.6×10^{-10} times the applied field and hence has negligible effect on the Debye τ.

Krishnaji and Mansingh, A., Indian J. Pure Appl. Phys. 2, 176-8, 1964.
An expression for τ, namely $\tau = (B/T)\eta^X$ (where η is viscosity and $X = (\Delta H_\epsilon/\Delta H_\eta)$, derived from the theory of rate process) is suggested. 15 polar liquids were classified according to whether dipole rotation is not permitted (I) or is permitted (II) on solidification. For I, value of X ranges from 0.5 to 1 and for II from 0 to 0.5.

Stockmayer, W. H. and Baur, M. E., J. Am. Chem. Soc. 86, 3485-9, 1964.
Dielectric dispersion, relaxation of the Kerr effect, and relaxation of the Benoit-Wippler effect are discussed for flexible-chain molecules in terms of the model used by Zimm to treat viscoelastic behavior of dilute polymer solutions. Low-frequency dispersion is related to the long-wave Fourier components of the electrical charge distribution along the chain backbone.

Cohan, M. V. and Weissman, J., Nature 201, 490, 1964.
Dunitz (ibid., 197, 860, 1963) proposed a new model for the valence (orientational) defects in ice responsible for the dielectric relaxation. The X defect of Dunitz is compared with a model previously proposed by the authors, namely a modified D defect with both water molecules rotated. Both models are energetically equivalent since only rough magnitudes can be estimated for the quantities involved. Energies for a number of models are calculated.

Bhagavantam, S. and Pantulu, P. V., Proc. Indian Acad. Sci. 58A, 183-196, 1963.
Group-theoretical methods are developed for studying trapped and untrapped point defects in crystals and the associated relaxation phenomena. A close analogy exists between the relaxation modes and the normal oscillations which makes possible application of many of the concepts and results of molecular spectroscopy to relaxation. Simple rules are given for determining the relaxation modes, their activities with respect to external electric and mechanical fields, and the associated τ's. Ca-doped NaCl and ThO_2 are treated as examples of systems with trapped point defects and TiO_2 (rutile) as a system with three kinds of mobile point defects.

Franklin, A. D., Shorb, A., and Wachtman, J. B., Jr., J. Res. Nat'l. Bur. Std. 68A, 425-38, 1964.
An analysis of the relaxation mode is presented for the cases of matched defect pair (impurity ion vacancy) and unmatched point defect pair (vacancy pair) in NaCl. τ's and polarizabilities are calculated at -46° and 227° from the results of the analysis.

Schlömann, E., Phys. Rev. 135, A413-418, 1964.
Disregarding the disorder in the distribution of mass and force constants (which accompanies the disordered charge distribution), a theory of dielectric losses in non-conducting ionic crystals is described. Detailed results are derived for crystals with the inverse spinel structure. The theory is also applied to a discussion of the additional losses to be expected in polycrystals with very small grain size. It is concluded that this contribution to the loss tangent should be insignificant unless the grain size is extremely small.

Rivail, J. L., J. Chim. Phys. 61, 1245, 1964.
The system formed by a charged particle of low mobility which can occupy more than two equilibrium positions regularly displaced has a dielectric behavior of the Debye type governed by superposition of τ's. The value of τ depends essentially on the number of equilibrium positions. Application of the theory to holes in semiconductors of the NiO type shows the possible existence of dielectric absorption bands of electronic origin.

B. Gases

Maryott, A. A. and Kryder, S. J., J. Chem. Phys. 41, 1580-2, 1964.
Measurements of the increase in dielectric loss accompanying the addition of various foreign gases (He, H, Ar, N, CH_4, C_2H_6, SF_6) to CO_2 were made at a frequency near 24 Gc and 25°. This loss is attributed to dipoles induced in

the foreign gases by the molecular quadrupole field of CO_2. Excluding mixtures with He and H, for which the effect is very small, the values of the quadrupole moment of CO_2 derived from the losses is $\sim 4.4 \times 10^{-26}$ esu in all cases. This agrees with the value 4.1×10^{-26} esu reported by Buckingham and Disch.

Kadaba, P. K. and Garg, S. K., J. Phys. Chem. 68, 1298-303, 1964.
The dispersion and absorption of microwave radiation of 1650 ± 1 Mc by $CClF_3$, CHF_3, $CHClF_2$ and COS has been studied in concentrations in helium ranging from 5 to 30% at a temperature of 28 ± 0.2°. Measurements were made up to a pressure of 50 atm. The data for $CClF_3$ up to the concentrations studied and the 10 and 20% mixtures of CHF_3 in helium closely fit the Debye equation. The Clausius-Mossotti function in the various mixtures, over the pressure ranges studied, was not constant but depended more or less linearly on pressure.

C. Pure Liquids

Hasted, J. B., Shah, M. A., and Mason, P. R., Nature 202, 140-2, 1964.
A method by which a change observed in the complex ϵ of nitrobenzene at 3.33 cm and at 20°C, when steady electric fields up to 10^4 v/cm are applied, is described. The change is consistent with a decrease in the τ which could arise from the field depression of the energy barrier associated with dipole relaxation.

Antony, A. A., Jr., Dissertation Abstr. 25, 117, 1964.
Four different types of hydrogen bonded systems and their dielectric properties were studied. The relation of dielectric relaxation and infrared spectroscopy to hydrogen bonding has been investigated.

Bhandari, R. C. and Sisodia, M. L., Indian J. Pure Appl. Phys. 2, 132, 1964.
To describe the dependence of τ of water on temperature an equation $\tau = (A/T) \exp [E_\tau/k(T-T_0)]$ is suggested. E_τ is said to be the activation energy for dipole relaxation and T_0 a reference temperature taken as 150°K. The relation incorporates Eyring's theory and the concept of free volume.

McDuffie, G. E., Dissertation Abstr. 25, 3045, 1964.
Complex ϵ's of the associated liquids butanediol-1,3, 2-methyl-pentanediol-2,4, glycerol, and hexanetriol-1,2,6 have been measured between -20° and 10°C for a frequency range 0.01 to 1200 Mc. All these liquids showed asymmetric dispersion curves for which the low-frequency limiting τ's were calculated. Dielectric relaxation in these liquids is compared with their static shear viscosity and their mechanical relaxation processes. The results are discussed in detail.

Martin, G. and Meinnel, J., Compt. Rend. 258, 1197-1200, 1964.
The behavior with respect to supercooling of various polar organic liquids is outlined. The behavior of the complex ϵ in freezing and in "virtrification" is discussed and ϵ' and ϵ'' vs. temperature plotted for two examples, n-butyl chloride and ethyl 2-cyano-3-phenyl-2-butenate. At frequencies between 10^2 and 3×10^6 cps at least two absorption regions are shown, of which the larger was characterized by activation energies greater than 1 eV and entropies greater than 100 e.u. and was said to arise from the reorientation of groups of molecules.

Cachet, H. and Lestrade, J. G., Compt. Rend. 259, 541-4, 1964.
ϵ of liquid ℓ-menthol has been determined from 0.1 to 3300 Mc for the temperature range 36° to 84°. The results, very similar to those obtained for cyclohexanol, show two domains of dielectric relaxation with activation energies of 0.53 and 0.58 eV.

Krishnaji and Mansingh, A., J. Chem. Phys. 41, 827-31, 1964.
ϵ' and ϵ'' were measured for pure methyl, ethyl, propyl, and butyl cyanides at 1.0 Mc, 9.95, 20.8, and 32.0 Gc. τ and the distribution parameters were obtained from Cole-Cole diagrams. The results showed that there could be a rotation of the CN group around the C-CN bond. The most probable enthalpies of activation are less than the corresponding free energies so that the most probable entropies of activation are negative.

Komandin, A. V. and Smirnova, A. D., Zh. Fiz. Khim. 38, 783-5, 1964. (Russian).
Translation: J. Phys. Chem. USSR 38, 424-5, 1964.
ϵ and tan δ were measured for liquid benzophenone between -55 and 95° at frequencies of 50, 800, and 20,000 kc. The activation properties were evaluated and the results compared with those of the esters of o-hydroxy benzoic acid.

Atakhodzhaev, A. K., Tukhvatullin, F. Kh., Rozhdestvenskii, M. I., Egamkulov, A., and Yarmukhametov, G. D., Ukr. Fiz. Zh. 9, 552-5, 1964. (Russian).
τ's of a number of liquids containing molecules with two benzene rings were determined by measuring ϵ'' between 30 and 240° and activation energies derived. Results are discussed in terms of rigidity of the molecules.

Syamalamba, K. and Premaswarup, D., Indian J. Pure Appl. Phys. 2, 281-4, 1964.
The dielectric dispersions of methyl, ethyl, butyl, and amyl butyrates were studied at 9200, 14,140, and 23,500 Mc at 28-70°. As the chain length increases, the distribution parameter α increases greatly, τ increases very little, and the ratios τ/η and τ/v decrease (η viscosity and v molar volume). The activation energy for viscous flow is consistently larger than for the relaxation process.

McDuffie, G. E., Jr. and Kelly, M. V., J. Chem. Phys. 41, 2666-70, 1964.
Complex ϵ of liquid glycerol was measured at -6.7° at frequencies between 0.5 and 100 Mc and at pressures between atmospheric and 4000 kg/cm^2. Viscosities were measured at temperatures between +10 and -10° over the same pressure range. The pressure dependence of τ appears to be of the Arrhenius type (i.e., $\ln\tau$ proportional to pressure), that of viscosity approximately so. The pressure dependence of τ and viscosity η differ, the ratio η/τ varying by about 2 over the experimental pressure range. When the Williams, Landel, and Ferry free-volume theory is applied to the data, the resulting form of the pressure dependence of η is incorrect. Although the hole theory of Eyring predicts the correct pressure dependence, a strongly temperature-dependent hole volume, with a negative temperature coefficient of expansion, is needed to fit the dielectric data.

Komandin, A. V. and Smirnova, A. D., Zh. Fiz. Khim. 38, 89-95, 1964. (Russian). Translation: J. Phys. Chem. USSR 38, 47-50, 1964.
Dielectric relaxation was studied at different frequencies in α,γ-glycerol diacetate (I) from -50 to 20° and in α-glycerol o-hydroxybenzoate (II) from 20 to 40°. τ's at 250°K were 2.63×10^{-8} and 2.24×10^{-3} sec, compared with 3.18×10^{-7} sec for glycerol. For all 3 substances $\log \tau = a + \frac{b}{T}$, to ± 2%. The heat of activation $\Delta H = A - BT \times 10^{-3}$ kcal/mole, where A and B were 26.54 and 1.998 for I and 19.60 and 1.987 for II. The effects of substitution on the thermodynamics of activation and intermolecular interaction of glycerol are discussed.

Santarelli, V. A., Dissertation Abstr. 24, 2951, 1964.
Complex ϵ of toluene (1) and bromotrichloromethane (2) has been measured at λ's between 4 and 9 mm and at 20°, 30°, 40°, and 50°C. A free space method was used. Results indicate a single τ for (1) for which a model of a quasi-crystalline structure gives a mechanism of dipole orientation possibly leading to resonance absorption at higher frequencies. A resonance absorption is reported for (2) in the region of measurements and is treated on the basis of a micro-crystalline liquid structure. Analysis of results suggests that the existence of ordered aggregates in liquids might provide an explanation for the high ϵ_∞ and its strong dependence on temperature observed in liquid measurements in the mm-wave region.

Imanov, L. M., Izv. Akad. Nauk Azerb. SSSR, Ser. Fiz.-Techn. i Mat. Nauk 1964, No. 2, 71-80.
ϵ' and ϵ'' were measured between 300 and 1000 Mc for methyl, ethyl, n- and iso- propyl, and n- and iso- butyl alcohols at 293°K, and also between 0.3 and 32 Mc and 20 and 160°K for n-propyl and the butyl alcohols. Macroscopic and microscopic τ's and activation parameters were evaluated. The main absorption region is characterized by a single τ_1, associated with the dissociation of "microcompounds", molecular chains of limited length formed by hydrogen bonding. The dissociation energy (6 kcal mole^{-1}) is of the order of hydrogen-bond energy. At lower temperatures a second absorption region was characterized by a symmetrical distribution of τ's about τ_2, said to arise from free molecules in about 10% concentration. τ_1 and τ_2 are greater for butyl than for propyl alcohols and greater for normal than for iso alcohols. τ_1/τ_2 is practically the same for all alcohols, but is strongly temperature-dependent. The degree of dipole correlation decreases with increasing size and branching of the molecules. The assignment of τ_1 and τ_2 is supported by comparison with the activation enthalpy for viscosity.

Bass, S. J., Nathan, W. I., Meighan, R. M., and Cole, R. H., J. Phys. Chem. 68, 509-15, 1964.
ϵ_0 of N,N-dimethylformamide, formamide, N-methylformamide, N-methylacetamide, and N-methylpropionamide was measured over their liquid temperature ranges. Values of the Kirkwood correlation factor are near unity for N,N-dimethylamides, about 1.5 for formamide, and are strikingly large for the N-methylamides. A value of almost 10 is obtained for N-methylpropionamide at -39°. A comparison of these results was made with predictions from models of chainwise association by H-bonding. Dielectric relaxation for the N-methylamides in the frequency range 1 to 250 Mc, over a wide range of temperatures, is described by the Debye function. The relaxation processes are so much

faster in N, N-dimethylformamide and in formamide that only absorption conductance could be measured in the range studied; the results are consistent with Debye- type absorption but do not establish it. Linear Arrhenius plots of τ's give activation energies from 2.7 to 7.0 kcal/mole.

D. Non-aqueous Solutions

Nelson, R. D., Jr. and Smyth, C. P., J. Phys. Chem. 68, 2704-8, 1964.
Study of microwave dielectric absorption in two large polar molecules in solvents of increasing molecular size gives values of τ much smaller than those calculated from viscosities and solute volumes when the molecular volume of the solute is less than or about equal to that of the solvent. The calculated values are approached when the volume of the solute is 3 or more times that of the solvent, the remaining differences arising from differences in molecular shapes and location of dipoles in the molecule.

Nelson, R. D., Jr., Dissertation Abstr. 25, 133-4, 1964.
Dielectric studies of dilute solution of large rigid molecules and non-rigid molecules have been made. The data obtained from measurements of the rigid molecules show considerable deviation from Debye's equation. The analysis of the data for non-rigid molecules gives support to the "double internal rotation" mechanism.

Knobloch, P. and Stockhausen, M., Angew. Chem. 76, 186, 1964. (German).
English translation: Angew. Chem. (Internat. Edit.) 3, 230-1, 1964.
τ's of triphenyl-amine, -arsine, and -phosphine, and of tribenzylamine in benzene were obtained from microwave absorption. For triphenylamine τ was ca 0.7×10^{-12} sec., for the others between 60 and 77×10^{-12} sec. The smallness of the former is attributed to inversion of the pyramid at the N atom.

Mansingh, A., Indian J. Pure Appl. Phys. 2, 33-4, 1964.
ϵ', ϵ'', and tan δ were measured for methyl, ethyl, propyl, and butyl cyanides at different concentrations (w, moles/cc) in benzene solution at 9950 Mc and 30°. The values of τ and μ were computed from the results. Tan δ values varied linearly with w and the $\Delta \tan \delta / w$ values increased with chain length. Plots of τ and $\ln \tau$ vs. N, where N is the number of C atoms in the molecule, were straight lines, showing the dependence of τ on molecular size.

Imanov, L. M. and Zul'fugarzade, K. E., Zh. Fiz. Khim. 38, 2437-40, 1964. (Russian).
The effect of concentration on the microwave dielectric relaxation of halobenzenes was studied. Systems studied at 3.26 cm and 20° and at 12.80 cm between 20 and 100° were chlorobenzene, bromobenzene, and iodobenzene in benzene and n-hexane. In solution and in the pure liquid the results are described by a single τ. Dilution increased the rotational mobility, whereas increase in size and asymmetry of the polar molecule shifted the dispersion to lower frequencies. $\epsilon_\infty - n^2$ decreased with dilution. For the solid state, ϵ was slightly greater than n^2.

Forrest, E., Dissertation Abstr. 25, 124-5, 1964.
Microwave dielectric measurements were made on solutions of anisole, p-dimethoxybenzene, phenylacetonitrile, p-xylylene cyanide, 1-(chloromethyl)-naphthalene,

and 1-naphthalene-acetonitrile in benzene. Some of these molecules show intramolecular group rotation. Measurements were made on solutions of water and heavy water in dioxane and results resolved into two relaxation regions. A concentration-independent τ of 4×10^{-12} sec for water and 5.6×10^{-12} sec for heavy water solutions was attributed to either rotation of the OH group about its hydrogen bond or over-all molecular rotation and said to become a pure libration in the extrapolation to pure water. The second and longer τ was concentration-dependent and 1.2 to 1.5 times as great in the heavy water solutions as in the comparable water ones; it is due to the partial breaking and reforming of hydrogen bonds. Binary mixtures of chloro- and bromobenzene and 1-chloro- and 1-bromonaphthalene gave two Debye regions whose relative contribution was the same as the mole ratio. The views of Schallamach are considered and it is concluded that for these non-associative substances the relaxation processes are related to the individual molecular species present.

Fong, F. K. and Smyth, C. P., J. Chem. Phys. 40, 2404-7, 1964.
ϵ' and ϵ'' at wave lengths of 1.25, 3.22, 10.02, 24.99 cm, and 575 m were measured for 2,6-dimethylanisole and 3,5-dimethylanisole in benzene solutions between 20 and 60°. The data were analyzed in terms of two τ's, the smaller in the 3,5-dimethylanisole being consistent with intramolecular rotation of the methoxy group. The lack of interpretation of two τ's in 2,6-dimethylanisole illustrates the difficulties connected with the proper resolution of dispersions involving more than a single τ. μ's of 17 compounds are tabulated, based on values of ϵ_0 and n taken from this and previous papers.

Ahmad, S. I., Indian J. Pure Appl. Phys. 2, 70, 1964.
τ's were obtained from measurements at 35° and 3 cm of hexane solutions of o-chlorotoluene, o-chloroaniline, and o- and p-toluidine. These are related to the rotation of the entire molecule.

Anderson, J. E., Dissertation Abstr. 25, 116-117, 1964.
Various theories of the small τ of diphenyl ether and similar molecules are presented. μ's of 23 substituted phenyl ethers were computed from bond moments and compared with experimental values. ϵ' and ϵ'' of dilute benzene solutions of a number of substituted phenyl ethers were also measured between wavelengths 1.25 and 50 cm and a detailed discussion of the results is given.

Raczy, L., Compt. Rend. 257, 2272-5, 1964. (French).
Complex ϵ's of solutions of phenol in carbon tetrachloride were measured at 25° between 0.53 and 140 Gc, as well as ϵ_0 at 0, 25, and 50°. The Kirkwood g factor passed through a maximum at low concentrations at 0° but not at the higher temperatures. The dispersion was of the Debye type at low concentrations but was resolved into one or more additional low-frequency relaxation regions as the concentration increased. The results are interpreted in terms of equilibria between monomers, open dimers, trimers, etc., equilibrium constants and energies of formation of dimers and trimers being calculated.

Antony, A. A., Fong, F. K., and Smyth, C. P., J. Phys. Chem. 68, 2035-9, 1964.
ϵ's and ϵ''s of dilute benzene solutions of 2,6-dibromophenol (I), 2,6-dibromo- and 2,6-dichloro-p-nitrophenol (II and III), 2,4-dibromophenol (IV), and 2,6-dichloro-p-nitroaniline (V) were determined at 20, 40, and 60° at several

microwave frequencies and τ's evaluated. Intrared spectra in the OH fundamental region were measured for I, II, IV, and o-bromophenol. II and III behave as rigid molecules, but I is treated in terms of two τ's, one due to molecular rotation, the other to OH group rotation. IV probably has more than two τ's. The μ of this molecule can be interpreted in terms of two conformations in which the OH group is coplanar with the benzene ring.

Hiremath, G. C. and Rao, K. S., Indian J. Phys. 38, 194-204, 1964.
ϵ' and ϵ'' of benzene solutions of p-octyl-, p-nonyl-, and p-dodecylphenol were determined at 1 and 9295 Mc at 27°. τ's and μ's were determined.

Antony, A. A. and Smyth, C. P., J. Am. Chem. Soc. 86, 156-8, 1964.
ϵ' and ϵ'' at microwave frequencies and ϵ_0' and n' are given for o-hydroxyacetophenone and o-methoxyacetophenone in cyclohexane and dioxane solution, and for m-methoxyacetophenone in dioxane. From these data τ's and the Cole-Cole α parameters are determined. Infrared carbonyl stretching frequencies are reported for o-hydroxyacetophenone and o-methoxyacetophenone in cyclohexane, carbon tetrachloride, and dioxane. Group rotation is observed for m-methoxyacetophenone, for which steric repulsion is absent.

Vakalov, I. A. and Shakhparonov, M. I., Vestn. Mosk. Univ., Ser. II, Khim., 19 (2), 16-19, 1964. (Russian).
ϵ' and ϵ'' of acetone-hexane solutions at wavelengths 375 m, 3.21 cm, and 8.15 mm and for the temperature range from 10° to 40° were measured. A linear relation between ϵ' and $\frac{1}{T}$ was obtained indicating random orientation of molecules in the solutions.

Shakhparonov, M. I. and Vakalov, I. A., Zh. Fiz. Khim. 38, 1978-83, 1964. (Russian).
The dielectric properties of acetone-chloroform solutions were determined at 10-40° at wavelengths 37,500, 3.21, and 0.815 cm. τ passed through a well-defined maximum at a composition corresponding to a 2:1 chloroform + acetone ratio. This is said not to be due to a complex since the dielectric relaxation in these solutions is not of a dipole nature. It is associated with the redistribution of protons or proton relaxation.

Goremykina, I. A., Vakalov, I. A., and Shakhparonov, M. I., Vestn. Mosk. Univ. Ser. II, Khim. 19 (1), 33-4, 1964. (Russian).
ϵ's of pyridine-chloroform solutions were determined at 1.75 cm at a number of temperatures and analyzed by methods previously used (see reference to Shakhparonov's book). Isotherms of ϵ vs. mole fraction show positive deviations from additivity with maxima at 0.5 mole fraction. The deviations gradually diminish with increasing temperature. This would lead to the conclusion that pyridine-chloroform complexes are present in the solutions if it were not contradicted by the linear relationship between ϵ and $1/T$.

Antony, A. A. and Smyth, C. P., J. Am. Chem. Soc. 86, 152-6, 1964.
Measurements of ϵ' and ϵ'' at microwave frequencies, viscosities, d's, and n's were made at 20° on mixtures of chloroform with cyclohexane, dioxane, and diazabicyclo [2.2.2] octane and of trichlorofluoromethane with dioxane. Except for the amine solution, the α's of the Cole-Cole arc were 0 or nearly so. The μ of chloroform in dioxane is close to 1 D. Hydrogen-bonding of chloroform

to solvent molecules leads to an increase in τ in the solvent series cyclohexane, carbon tetrachloride, benzene, and dioxane. The broad dispersion shown by solutions of chloroform and the amine may be due to two single τ's, one due to chloroform rotation, the other to rotation of the complex formed with the amine.

Constant, E. and Lebrun, A., J. Chim. Phys. 61, 163-173, 1964. (French).
The results of extensive measurements of the complex ϵ's of carboxylic acids as pure liquids and in nonpolar solvents are reviewed. The dispersion of dilute solutions is mainly due to monomeric molecules (since cyclic dimers are nonpolar) and for acetic acid in benzene decreases with increasing concentration. The fraction of monomer and therefore the equilibrium constant for dimerization is determined from the static polarization, suitably corrected for the high frequency polarization. The latter, as experimentally measured, includes an abnormally high atomic polarization for the dimer, said to arise from low-lying infrared vibrations. The dimerization constant for acetic acid is approximately linear in $1/\epsilon_0$ of the solvent and agrees roughly with values obtained by other methods. Enthalpies of dimerization are ca. 10 kcal/mole, but are less for benzene and dioxane solutions in which there is evidence of monomer-solvent complex formation. The complex relaxation behavior of concentrated solutions is like that shown by alcohols, modified by cyclic dimerization. A low-frequency Debye dispersion associated with long chains in pure formic acid is less dominant in acetic acid and disappears in propionic acid. Two other dispersion regions are resolved in acetic acid and two in propionic, valeric, octanoic, and decanoic acids. These are associated with the orientations of dipoles fixed in polymers of limited length and with free molecules and end groups, in order of increasing frequency. With increasing chain length monomers and dimers increasingly predominate. Activation enthalpies for relaxation are given.

Davies, M. and Johansson, G., Acta Chem. Scand. 18, 1171-9, 1964.
ϵ' and ϵ'' of triisoamylammonium picrate in benzene at concentrations between 0.0179 and 0.5394 molar were measured between 120 kc and 8.5 Gc. μ's, τ's, and conductivities are reported. Nearly all the solute was probably present as undissociated ion pairs. There was a slight distribution of τ's. The results suggested a subsidiary relaxation process at low frequencies, more marked at higher concentrations and possibly due to a small concentration of larger aggregates.

Arkhangel'skii, K. V., Mekhanizm i Kinetika Kristallizatsii, Nauchn. Sov. Akad. Nauk Belorussk. SSSR po Fiz. Tverd. Tela 1964, 27-34. (Russian).
The dielectric method was applied to the study of the stability of the nitrobenzene-heptane system (I) in the critical region. Near the critical concentrations the dielectric parameters have a maximum, independent of frequency, at the critical temperature. The relative values of the ϵ and tan δ peaks increase with a decrease in the frequency. Curves of the temperature dependence of ϵ vs. concentration of the system (I) and of $(1/\epsilon)$ vs. temperature for nitrobenzene-hexane and -octane systems are given.

Quinn, R. G. and Smyth, C. P., J. Chem. Phys. 41, 2037-41, 1964.
Measurements were made between 0.5 and 250 Mc and at 1.26 and 3.22 cm on a solution of nitromethane in n-heptanol of 1:8 concentration by weight at

temperatures between 40° and the critical solution temperature T_c (21.1° for this composition). The complex ϵ may be interpreted in terms of two single τ's associated with the two components. The larger τ_1, associated with the alcohol in the solution, is less than that of the pure alcohol by a factor of 3, but shows nearly the same temperature dependence. The τ_2 associated with nitromethane is smaller by 4 than that of pure nitromethane at 40° but approaches it rapidly as T_c is approached. This behavior is attributed to the formation near T_c of micro-clusters rich in alcohol or nitromethane. Since alcohol is already present in large excess, τ_1 is not so greatly affected by cluster formation as τ_2.

Moriamez, M., Raczy, L., Constant, E., and LeBrun, A., J. Chim Phys. 61, 146-61, 1964.
A comparative study is made of the dielectric spectra of 1-heptanol and 3-ethyl-e-pentanol. The measured values of the polarization (or ϵ) permit the evaluation of the different equilibrium constants of association that may exist in the solutions. The data suggest the existence of overlapping dispersion regions in the alcohols studied. The separate dispersion regions arise from linearly independent relaxation mechanisms.

Takashima, S., Biochim. Biophys. Acta 79, 531-8, 1964.
A study of dielectric dispersion of bovine serum albumen (1) and ovalbumin (2) before and after urea denaturation showed that (1) had very small dielectric increment indicating that the charge distribution in this protein is highly symmetrical. Dielectric increment and τ increase on addition of high concentration of urea. The dielectric properties of denatured (1) are not drastically different from those of (1). (2) undergoes more pronounced change in dielectric properties probably due to the formation of aggregates after urea denaturation.

E. Aqueous Solutions

Hoffman, H. J., Z. Physik. Chem. (Leipzig) 225, 372-88, 1964.
Apparatus is described for measuring the complex ϵ of water and aqueous solutions at wave lengths between 9 and 22.5 cm using a method whose theory was previously described (ibid. 224, 110-32, 1963). A short circuit moves in a coaxial line. Data for water show the inaccuracy to be 0.6% for ϵ' and 2% for ϵ''.

Vogelhut, P. O., Sci-Tech. Aerospace Rept. 1 (11), 737, 1963.
A brief review of the electrical characteristics of water, aqueous solutions, and ice is given. Based on the concept of double bond and vacant bond orientational defects a new model of water is suggested. ϵ's of water and of aqueous solutions at α microwave frequency are measured by a cavity-perturbation technique. The results agree with the new model of water and its solutions and are accurate enough for the continuous measurements of changes of ϵ of enzyme substrate mixtures as a function of time after mixing.

F. Molecular and Non-conducting Solids

Corfield, G. and Davies, M., Trans. Faraday Soc. 60, 10-24, 1964.
ϵ' and ϵ'' were measured between 5 cps and 8.5 kMc for solid, liquid, and

solution phases of cyclohexyl chloride, cyclohexanol, cyclohexanone, and cyclopentanol. The chloride and ketone behave as rigid polar molecules having high-temperature rotator phases. The dielectric behavior of the alcohols is dominated by the hydrogen-bonded OH groups whose reorientation requires a large activation energy. A number of solid phases are identified in the alcohols and there are considerable differences between the cooling and heating behavior. There is no evidence of dielectric absorption because of chair-chair conformational changes in the cyclohexane derivatives.

Garg, S. K. and Kadaba, P. K., J. Phys. Chem. 68, 737-44, 1964.
ϵ_0, ϵ' and ϵ'' of ethyl, propyl, butyl, amyl, diethyl, dipropyl, and dibutyl amines were measured at 10, 3, 2, and 1 cm wavelengths from 0° downward over a range of temperatures in the solid phase. Analysis of results shows rotation over hindering potential energy barriers in the crystal lattice in a temperature region not far below the melting points in the case of primary amines. The secondary amines do not show a transition to a rotator phase. The difference in the behavior of amylamine and other amines is discussed.

Tsuge, K., Japan. J. Appl. Phys. 3, 588-604, 1964.
Complex longitudinal wave moduli at 1/3, 1, and 3 Mc and shear moduli at 33 kc and 1 Mc were measured at 20° to -60° for crystals of paraffins of 3 chain lengths. In the same temperature range the complex ϵ's of oxidized paraffins were measured between 30 cps and 1 Mc. The activation energy is the same for mechanical and dielectric dispersion, indicating little effect of oxidation on the molecular motions. The mechanical relaxation "strength" increases with temperature and C content. The results are quantitatively explained by Okano's theory, in which the dispersion arises from incoherent torsional vibrations of chain molecules.

Dryden, J. S. and Welsh, H. K., Trans. Faraday Soc. 60, 2135-43, 1964.
Previous work showed that ϵ'' in many long-chain aliphatic compounds is determined largely by degree of purity and mechanical and thermal history. To study the effects of imperfections the dielectric absorption in two solid esters was re-examined. These esters were chosen to represent extreme cases. Single crystals of dodecyl myristate were grown and plots of ϵ'' vs. frequency are shown for fields applied in 4 crystallographic directions. Variation of maximum ϵ'' with field direction is related to molecular arrangement in the crystal. In a 2-position model the orientations of relative equilibrium differ by 0.8 kcal mole^{-1}; there is a distribution of τ's. Annealing produced no effect for polycrystalline samples whose ϵ'' was close to the average of those for 3 orthogonal directions of the single crystal. Cetyl palmitate was obtained only in polycrystalline form and showed wide variation in dielectric behavior according to impurity content, state of stress, and time. Time-dependence is related to recrystallization rate in the presence of impurities. The dielectric absorption may be related to slip imperfections which affect the molecular packing within a layer.

Dasgupta, S. and Mohan, G., Dielectrics 1, 137-9, 1963.
The product $\epsilon''_{max} \cdot T$ is found to increase with decreasing temperature for α-phase ethyl behenate and stearate, an anomalous behavior explained by assuming an unpolarized state of temperature-dependent energy. These energies are also calculated for tricyclohexylcarbinol and α_3-phase butyl stearate.

Dryden, J. S. and Meakins, R. J., Ibid., 1, 235-6, 1964.
The analysis of Dasgupta and Mohan is criticized. The anomalous temperature dependence may arise from partial conversion of the α- to the β-phase if the measurements were made with increasing temperature. For α-butyl stearate the behavior is not anomalous.

Wentworth, F. L. and Cohn, M., J. Res. Nat'l. Bur. Std. 68D, 681-91, 1964.
Results of measurements of ε and tan δ of samples of Arctic Sea ice of different salinity are given for temperatures between -5 and -40°C and frequencies between 0.1 and 30 Mc.

Ragle, R. H., Blair, R. G., and Persson, L. E., J. Glaciol. 5, 39-59, 1964.
Results of optical, structural, density, and dielectric studies between 150 and 1000 Mc are given for 4 ice cores. Determination of chloride and sulfate content is discussed.

Hirose, H. and Wada, Y., Japan. J. Appl. Phys. 3, 179-90, 1964.
The dc conductivity and a low-frequency loss peak at 10^{-1} cps observed in vacuum deposited SiO films decrease with increasing oxidation, have similar activation energies ($\sim$ 8.6 kcal/mole), and are attributed to diffusion of Si ions. A second loss peak above 10^7 cps is ascribed to torsional vibration of SiO chains. A model of glassy SiO is proposed.

Westphal, W. B., U. S. At. Energy Comm. NP-13431, 86 pp., 1963.
Measurements of ε and loss to 1650° are discussed for frequencies between 100 and 2.5 x 10^{10} cps. Bridges, resonant circuits, standing-wave methods, and resonant cavities are included. Data on crystals of Al_2O_3, Cr_2O_3, MgO, $LaAlO_3$, Y_2O_3 on multicrystalline Al_2O_3, BeO, MgO, Mg_2SiO_4, Ta_2O_5, ThO_2, on glass ceramics, silica glass, and BN are presented over lower temperature and frequency ranges. Pyrolitic BN has a low tan δ (0.0004 at 1375° and 4.8 x 10^9 cps) and a low temperature coefficient of ε. Some aluminas and silicas exhibit tan δ's of $\sim$ 0.0006 at 1000° in the microwave region. Microwave losses are due partly to the charge transfer responsible for low-frequency conductance and partly to infrared absorption spectra. Both losses are increased by impurities.

G. Ionic and Semiconducting Solids

Kaderka, M. and Velicka, I., Czech. J. Phys. B14, 608-14, 1964.
The influence of annealing in atmospheres of HCl, CO_2, nitrogen, and air on the absorption and dielectric losses of NaCl crystals is studied. The reasons for a decrease or even the disappearance of the abxorption band near 1900 Å in unannealed hydrolyzed crystals are discussed. The causes of the shift of the relaxation maxima of the dielectric losses of "pure" NaCl crystals were also studied.

Kessler, A. and Mariani, E., Czech. J. Phys. B14, 757-64, 1964.
Studies of the temperature- and frequency-dependence of ε" of undoped and $CaCl_2$-doped NaCl crystals revealed maxima in addition to the well-known absorption maximum associated with Ca complexes. With rising Ca content these maxima were shifted to lower temperatures at a fixed frequency whereas the

magnitudes of the maxima do not depend on concentration and remain unchanged in the purest crystals. The maxima probably arise from relaxation loss of the crystal lattice itself.

Economou, N. A. and Sastry, P. V., Phys. status Solidi 6, 135-40, 1964.
Dispersion and loss observed in NaCl and KBr at high temperatures and radio frequencies are interpreted in terms of Debye dipolar relaxation of vacancy pairs. The required concentration of dipoles exceeds the expected concentration of vacancy pairs by one or two orders of magnitude.

Tranka, J., Kaderka, M., and Bohun, A., Czech. J. Phys. B14, 63-72, 1964. (German).
The results of measurements of dielectric losses and of thermally-stimulated electron emission and luminescence in Ca-doped NaCl are presented, along with the effects of annealing in air or in hydrogen.

Kaderka, M., Czech. J. Phys. B14, 116-20, 1964.
The dielectric losses and thermally-stimulated electron emission and luminescence were studied in Ca-doped NaCl crystals prepared both from the melt and from solution. The effects of annealing and the causes of the loss peaks are discussed.

Dreyfus, R. W. and Laibowitz, R. B., Phys. Rev. 135, 1413-22, 1964.
Pairing of bivalent metallic impurities with Na^+ vacancies occurs in NaCl below 300°. Stress-induced reorientation of such pairs in NaCl doped with $CaCl_2$ and $MnCl_2$ was studied by means of internal friction measurements. An internal friction peak attributed to pair reorientation under stress was observed near 100°C at $\sim$ 10 kc. Data, yielding information about the rates of relaxation corresponding to various mechanical relaxation modes, are interpreted in terms of an extension of a theory previously applied to dielectric relaxation. The most rapid means for the reorientation of an impurity-vacancy pair between two nearest neighbor sites is for the vacancy to move via a next-nearest-neighbor site.

Sastry, P. V. and Srinivasan, T. M., Phys. Rev. 132, 2445-9, 1963.
Dispersion of ϵ of zone-purified KCl was observed between 1 and 10 Mc above 650°C. It was assumed to arise from vacancy pair defects for which the activation energy was 1.04 eV and the heat of formation 1.34 eV. The number of vacancy pairs given by the dielectric data is larger than acceptable by at least a factor of 10.

Economou, N. A., Phys. Rev. 135A, 1020-2, 1964.
The dipolar contribution to the high-temperature loss of KCl is unaffected by additions of $SrCl_2$ that greatly affect the frequency-independent conductivity and the cation and anion vacancy concentrations. Evidence is thus provided that the loss arises from vacancy pairs whose concentration is independent of Sr content.

Chiba, Y., Weki, K., and Sakamoto, M., J. Phys. Soc. Japan 18, 1092-3, 1963.
Dielectric loss of KCl crystals doped with $CaCl_2$ was measured at 75° as a function of annealing temperature and impurity content. The maximum in ϵ''

occurs at 3.8 kc. The decay of the absorption appears to follow a third-order reaction. The Ca^{++} ions enter the lattice substitutionally and associate with cation vacancies to form dipoles.

Bogdanovich, A. S., Sikorskii, Yu. A., and Yurachkovskii, P. A., Fiz. Tverd. Tela 5, 3524-8, 1963. (Russian). Translation: Soviet Phys.-Solid State 5, 2586-9, 1964.
The location and half-width of the relaxation peak of dielectric losses in $KCl.CaCl_2$ crystals are sensitive to thermal and mechanical treatment of crystals.

Kaenzig, W., Hart, H. R., Jr., and Roberts, S., Phys. Rev. Letters 13, 543-5, 1964.
Complex ϵ of KCl crystals, doped with KOH, was studied between 0.29 and 90°K at 0.1, 1, and 10 kc. ϵ' vs. temperature showed a peak at a temperature which was almost independent of frequency but increased with increasing OH^- concentration, tan δ showed a maximum at a somewhat lower temperature than that of ϵ'. At low impurity levels the concentration of dipoles calculated from the dielectric properties agreed within experimental error with the OH^- concentration. Bivalent impurities immobilized a fraction of the OH^- dipoles, leaving "mobile" dipoles from whose concentration a Curie temperature was calculated from the Clausius-Mossotti relationship. This temperature showed a systematic correlation with that of the ϵ' peak. Reversible temperature changes ("paraelectric cooling") with applied electric field were observed in cooling experiments, in agreement with calculations.

Sastry, P. V., NASA Doc. N64-13963, 14 pp., 1963.
The high-temperature ϵ of KBr showed a dispersion in the range of 1 to 10 Mc similar to that shown by KCl, where the interpretation in terms of the μ's of vacancy pairs led to a concentration of pairs some 50 times as great as expected. Lack of theoretical calculations for KBr prevents a similar comparison of theory and experiment.

Böttger, H., Phys. Status Solidi 4, 669-74, 1964.
Maxima occur in the loss factor vs. temperature curves (at 800 and 9600 cps between 20 and 200°K) for AgBr and AgCl, doped with Cr, Fe, Co, and Ni. They are ascribed to dipoles associated with point defects.

Blanchard, M. L., Peintures, Pigments, Vernis 40, No. 4, 184-8, 1964.
Lattice defects in ZnO crystals with Cu impurities were studied by microwave absorption. Conductivities were low below 200°, appreciably greater above 200°, and weak dipolar absorption occurred near 300°K. The dipolar absorption was attributed to association complexes caused by Cu^+ and O vacancies. Dipolar association could also result from OH^- which diffused into the lattice from the surface.

Vergunas, F. I. and Enikeeva, K. Sh., Fiz. Tverd. Tela 6, 2100-6, 1964. (Russian).
Dielectric properties of ZnS electroluminophosphors show that the conductivity of the second phase can have semiconducting and metallic character. With ultraviolet excitation three frequency maxima are observed for tan δ, and for

increment of capacity, ΔC, three corresponding regions of dispersion. Tan δ maxima are determined by conductivity in non-homogeneous specimens.

Quan, D. T., Compt. Rend. 258, 2045-6, 1964. (French).
Dipole relaxation previously observed in green α-manganese sulfide is shown to be due to adsorbed S.

Yamashita, A. and Asai, K., J. Phys. Soc. Japan 18, 1247-53, 1963.
Measurements were made on a pressed sample of powdered ammonium nitrate between 25 cps and 50 kc. Two dispersions were found. One, at very low frequencies is related to a blocking space-charge effect. The other, at higher frequencies, can be represented by a Cole arc and is attributed to dipolar reorientation. Its activation energy is 0.58 eV in phase III. There was no qualitative change in this dispersion at the III to II and III to IV phase transitions. It is interpreted in terms of cooperative motion of hydrogen-bonded ion pairs. Phase II has a much higher ϵ even at high frequencies, which suggests a further dispersion region.

Tar, D., Helv. Phys. Acta. 37, 165-92, 1964.
ϵ's and tan δ were measured at a number of frequencies in the temperature range -100 to +270°C for several representative crystals of the borazites system $M_3B_7O_{13}X$ where M is a divalent ion and X a halogen. Discontinuities in ϵ were found at the structure transition temperatures. Domain movements on varying the applied field could be observed optically, but no ferroelectric hysteresis effects could be detected electrically.

Zhuravlev, V. K., Fiz. Tverd. Tela 5, 2374-5, 1963. (Russian). Translation: Soviet Phys.-Solid State 5, 1729-32, 1964.
Measurements of ϵ and tan δ of ionic silver oxalate and lead oxalate at 15°C and between 0.02 and 20 kc have been reported. It was found that introduction of impurities gave rise to extrema in the ϵ dependences on the impurity concentration; one of these extrema indicated the formation of an $Ag_2C_2O_4$-CdC_2O_4 solid solution. The dielectric losses were mainly attributed to polarization processes even at the lowest frequencies.

Belyaev, L. M., Belikova, G. S., Dobozhanskii, G. F., Netesov, G. B., and Shaldin, Yu. V., Fix. Tverd. Tela 6, 2526-8, 1964. (Russian).
ϵ' and ϵ" were measured at 10^2 to 40 x 10^9 cps for uniaxial ($NH_4H_2PO_4$, KH_2PO_4) and cubic ($N_4(CH_2)_6$, CuCl) crystals. Use of a broad-band modulator based on the electro-optical effect in $NH_4H_2PO_4$ and KH_2PO_4 is limited by increased thermal effects which lead to decomposition of the crystals at wavelengths in the cm range. $N_4(CH_2)_6$ crystals are more suitable, since tan δ in the mm range is smaller.

Ioffe, V. A., Leonov, A. I., and Razumeenko, M. V., Fiz. Tverd. Tela 6, 2314-21, 1964.
Complex ϵ's were determined of aluminates of rare earth elements with the perovskite-type structure and some solid solutions based on Ce aluminate.

H. Polymers

Williams, G., Trans. Faraday Soc. 60, 1555-73, 1964.
Dielectric dispersion in polymethyl acrylate of weight average molecular weight 2 million was studied between .025 and 100 kc, 14.5 and 90°C, and 1 and 3000 atm. Cells for the dielectric measurements and for determination of $(\partial P/\partial T)_V$ are described. Increase of static dielectric constant with increasing pressure is attributed to increase in the mean square moment of the polymer chain. 20 plots of reduced ϵ' and ϵ'' vs. ω/ω_{max}. for different pressures and temperatures are closely superimposed which is taken to mean that individual τ's in the continuous distribution depend on pressure and temperature in the same way. The distribution function is not symmetrical but weighted on the side of short τ's. Activation energies at constant volume and constant pressure and volumes of activation are evaluated. The discussion suggests limitations to the transition state theory. $\left(\frac{\partial T}{\partial P}\right)_\tau$ (Ibid., 60, 1548-55, 1964) decreases with increasing τ and the simple assumption of the free volume model must be modified to include a temperature and pressure dependence of the compressibilities and coefficients of expansion. Changes in the distribution function in the glass transformation region are discussed.

Work, R. N., McCammon, R. D., and Saba, R. G., J. Chem. Phys. 41, 2950-1, 1964.
The effective μ of the chain unit in atactic polypropylene, calculated from measurements of ϵ'' between 4 and 300°K and 100 cps and 20 kc, was ~ 0.05 D. Dielectric measurements may be capable of yielding useful information about chain dynamics in "nonpolar" polymers.

Letureq, P. and Martinot, H., Compt. Rend. 258, 5367-70, 1964.
Resorption currents of macromolecular substances (gum lac and methyl phenyl polysiloxane) whose slow polarization phenomena satisfied the equations of Cole and Cole were analyzed at long times (40 - 5000 sec.) using the equation: complex $\epsilon = \epsilon_\infty + (\epsilon_0 - \epsilon_\infty)/[1 + (j\omega\tau_0)^{1-\alpha}]$ where symbols have the usual meanings. The principal parameters of the slow relaxation spectrum were determined and the method gives rapid results for measurements at low frequency.

Hara, T. and Okamoto, S., J. Appl. Phys. Japan 3, 499-500, 1964.
Dielectric measurements on poly(bisphenol-A carbonate) and poly(tetrachloro bisphenol-A carbonate) at temperatures from -170° to 250°C are reported. The positions of three kinds of dielectric loss peaks are determined and their origins discussed.

Veselovskii, P. F. and Matveev, V. K., Vysokomolekul. Soedin. 6, 1221-7, 1964.
The temperature dependence of ϵ' and tan δ was determined in poly(methyl methacrylate) (1) in toluene at temperatures ranging from -150 to 200° for frequencies from 50 to 1.8×10^6 cps. At 400 cps, maxima are observed and some differences in the tan δ vs. temperature curves for the atactic (1) in comparison with the curves of isotactic (1). Similar maxima were observed in the ϵ' vs. temperature curves. The apparent activation energies were calculated.

Adamec, V., Nature 200, 1196, 1963.
Measurements of increase in ϵ'' of Teflon caused by X-ray dose rates between 0.01-100 r/sec are reported. ϵ' is only slightly affected by exposure to radiation.

I. Mixtures and Suspensions

Swarup, P. and Arora, R. P., Nature 201, 1018, 1964.
ϵ's of powdered S and $BaCl_2$ packed to various densities were measured at 9200 Mc. It was found that $\frac{\epsilon-1}{\epsilon+2}$ was proportional to the density.

Pradhan, B. P. and Gupta, R. C., Dielectrics 1, 195-200, 1964.
The validity of three formulas, derived for a dielectric mixture of 2 components having different particle shapes and for one component imbedded in a continuous medium of the other, was tested at 3090 Mc and at radio frequencies.

Heywang, W. and Winstel, G., Z. Naturforsch. 19a, 156-7, 1964.
The Lichtenecker logarithmic rule for calculating the ϵ of a mixture from the ϵ's of the components is formally extended to a mixture of a dielectric and a conducting substance by using the 'J' operator. The result, a frequency-independent loss angle, and ϵ which drops with the rising frequency, represents the behavior of many practical dielectrics and is shown to be consistent with the Kramers-Kronig relations.

Rabinovitch, M., Compt. Rend. 258, 4663-5, 1964.
It is shown that for various types of powders, the variation of ϵ can be expressed in the form $\log \epsilon = p \log \epsilon_i + k$ where p is the proportion of volume occupies by the grains of the solid and ϵ_i the intrinsic ϵ of the material. For mixtures of powders the relation can be generalized.

Finkel'berg, V. M., Zh. Tekhn. Fiz. 34, 509-518, 1964. (Russian).
Translation: Soviet Phys.-Tech. Phys. 9, No. 3, 1964.
For calculating ϵ_{eff} of mixtures it is necessary to know the spatial distribution of the components and their dielectric properties. In the first case, a statistical mixture is considered when the difference between the ϵ's of the components is small and in the second case an emulsion with a small concentration of droplets. The method for the first case can be applied to polycrystals, when ϵ is a tensor, and the method for the second case can be used for matrix mixtures in which the particles have a non-spherical form.

VI. Static Dielectric Constants

A. Theory

Glueckauf, E., Trans. Faraday Soc. 60, 1637-45, 1964.
ϵ's of aqueous electrolyte solutions have been calculated by integrating over the spatial distribution of the local dielectric constant in a manner appropriate to disperse systems. Calculated values agree with those of Hasted et al. (J. Chem. Phys. 16, 1, 1948). If the ϵ change of the water molecules is taken as a rough measure of their immobolization a mean hydration number may be calculated which lies between those obtained from activity coefficients and those from entropies.

Hollins, G. T., Proc. Phys. Soc. 84, 1001-16, 1964.
Expressions for ϵ_0 of ice can be derived using either the Kirkwood-Fröhlich theory of dipolar dielectrics or the large-assembly method of Slater's ferroelectric theory. The two theories are extended and brought into equivalence. The Slater theory is shown to be correct to the well-known first approximation in the theory of regular assemblies, and an alternative derivation of his combinatory formula is given which reveals more clearly the basis of the approximation. The Kirkwood correlation factor for ice is calculated on the same basis. Both methods indicate that the error due to the first approximation is of the order of 1%. The problem of the local electric field in ice is critically examined, and reasons are given for thinking that Fröhlich's cavity theory is not appropriate, and that the local field differs little from the externally applied field. The difficulty of estimating μ of a molecule in the crystal leaves any appeal to experiment inconclusive.

Stein, R. S., NSF Progr. Report No. 3, and ONR Tech. Report No. 71, 1964.
The value of effective field in a n-paraffin crystal has been evaluated considering that a particular chain molecule resides in a cylindrical cavity in the crystal, surrounded by its neighbors, with a length, ℓ, and a radius, R, of the order of half the interchain distance in the crystal. The calculation includes the effects of internal field of intramolecular origin.

Decrocq, D., Bull. Soc. Chim. France, 1964, 127-36.
The appropriate expression relating static ϵ with composition of liquid mixtures is an Onsager-Kirkwood equation linear in volume fraction of the components, but containing coefficients proportional to $g_i\mu_i'^2$, which involve the generally unknown Kirkwood correlation factor g_i and intrinsic dipole μ_i' of molecules of species i in the mixture. For a "dielectrically-ideal" mixture, $g_i\mu_i'^2$ is treated as a constant property of molecule i, independent of its concentration in the mixture and the volume change on mixing is taken to be 0. In the equation for ideal behavior, ϵ of the mixture depends on the ϵ's and n's of the pure components and linearly on the volume fractions Y_i. For many of the usual solvents a simplified equation $\epsilon = \sum_i \epsilon_i Y_i$ may, within about 0.5% error, be substituted for the accurate one. If one of the components is apolar or only slightly polar, the theory predicts a slight negative deviation from linearity. An analysis of the data for some 200 binary mixtures showed 50 to agree with the ideal behavior to within 0.5%; the rest showed departures from ideality in both dielectric and other physical chemical properties.

Barriol, J. and Weissbecker, A., Compt. Rend. 259, 2831-3, 1964.
The Onsager equation permits calculation with good approximation of the μ of non-associated liquids. A simple adaptation, using classical dielectric theory, permits the calculation of the μ's of molecules in mixtures, in the absence of specific interaction between the components. The treatment is valid for solutions of ether and carbon tetrachloride. Deviations observed in the acetone-chloroform system are attributed to association of the two molecules.

Barriol, J. and Weisbecker, A., Compt. Rend. 259, 4643-5, 1964.
In the equation of Onsager for liquid mixtures the sum $\sum N_r\mu_r^2$, where N_r is the number density of molecules of dipole moment μ_r, is replaced by $N\mu_0^2$, where

N is the total number of molecules associated to form a variety of complexes such that $\mu_r^2 = r\,\mu_0^2$, for liquids capable of hydrogen-bonding to form chains about which free rotation is possible. Values of μ_0 calculated for this assumption from the experimental ϵ_0's are about 3 D for water and a number of alcohols. This moment is ascribed to the sum of the moment of the OH group and that induced by OH in the O atom to which it is hydrogen-bonded.

Lutskii, A. E. and Mikhailenko, S. A., Zh. Fiz. Khim. 38, 1414-20, 1964.
Equations for the theoretical correlation factor g_T of Kirkwood for intermolecular hydrogen bonds X-H....Y were developed for better comparison with the experimental values G_E. Good agreement was obtained with g_E obtained from application of Fröhlich's equation to ϵ data for water and cyclohexanol. Resorcinol and N-methylacetamide were also treated. Considerable changes in μ's of liquids due to formation of hydrogen bonds can occur only in non-symmetrical hydrogen bonds.

B. Gases

Dunn, A. F., Can. J. Phys. 42, 1489-98, 1964.
Permittivities of Ar, CO_2, N_2, and O_2 were measured at 1592 cps with an accuracy comparable to microwave and optical methods. The method is based on the computable cross-capacitance configuration which permits accurate calculation of capacitance changes arising from dimensional changes. The results for Ar, N_2, and O_2 verify the extrapolation of optical refractivity data to zero frequency. For CO_2 the audio-frequency permittivity is higher because of the strong infrared spectrum.

Leidenfrost, W., Intern. J. Heat Mass Transfer 7, 447-78, 1964.
Using a capacitance bridge, measurements were made of ϵ of Ar, CO_2, and toluene. ϵ values agree within 6 parts per million of recommended values. The cell was designed primarily for thermal conductivity measurements.

Lawley, K. P. and Sutton, L. E., Trans. Faraday Soc. 59, 2680-92, 1963.
Gas densities and ϵ's were measured for the binary mixtures of NO and BF_3, SO_2 and BF_3, $(CH_3)_2O$ and SO_2, $(CH_3)_2O$ and CHF_3, and $(CH_3)_2O$ and HCl. From these the second virial coefficients for the compressibility and dielectric constant (for the Clausius-Mossotti function expressed as a power series in the reciprocal of the molar volume) were evaluated. There were no anomalies in the first two systems. In the last three systems, however, the contribution to the dielectric virial coefficient arising from binary interaction of unlike molecules was of the order of ten times the virial coefficients specifying the interactions between like molecules. A mean pair dipole moment and an internal energy of pairing are derived. These values are much larger than predicted by the Stockmayer interaction potential. An explanation in terms of off-center dimer dipoles seems reasonably adequate for the $(CH_3)_2O$-SO_2 and $(CH_3)_2O$-CHF_3 systems, but the presence in mixtures of $(CH_3)_2O$ and HCl of ion pairs is indicated.

C. Pure Liquids

Munson, R. A., J. Chem. Phys. 40, 2044-5, 1964.
The bridge method used by Gillespie and Cole was modified to determine ϵ_0 of

phosphoric acid at 25° from measurements between 4.89 and 19.32 Mc. The average value was 61 ± 12, the high value confirming the hydrogen-bonded character of the liquid. Results of measurements of the H_3PO_4 - H_2O system revealed a minimum in the ϵ_0 vs. composition curve, as found previously for H_2SO_4 - H_2O solutions.

Dannhauser, W. and Flueckinger, A. F., J. Phys. Chem. 68, 1814-19, 1964.
Densities and equilibrium ϵ's of propio-, acrylo-, pivalo-, benzo-, and 2,6-dimethyl benzonitrile were measured from near their melting points to ~ 200°. The Kirkwood-Fröhlich correlation factor is less than 1 and generally increases with increasing temperature. The dielectric data are analyzed on the basis of an equilibrium between monomer and an antiparallel dipole pair dimer. The nature of their association is discussed.

Dannhauser, W. and Bahe, L. W., J. Chem. Phys. 40, 3058-66, 1964.
ϵ's of the 8 lowest aliphatic alcohols were determined from room temperature to their respective critical temperatures. An analysis of the data was made in terms of Kirkwood's correlation factor based on a model of linear, hydrogen-bonded chains with restricted rotation about the H-bond and variable degree of polymerization. The equilibrium constants are strongly dependent on the size and shape of the alkyl group.

Vaughn, J. W., J. Chem. Eng. Data 9, 427, 1964.
ϵ_0 of dimethyldisulfide (CH_3SSCH_3) is reported at 5° intervals between 25 and 50°.

Mellon, E. K., Jr. and Lagowski, J. J., Inorg. Chem. 3, 1694-8, 1964.
ϵ of hexamethylborazine was measured between 30° and 105°, as well as the ϵ's of its solutions in n-heptane, benzene, p-zylene, and hexafluorobenzene. The molecule is nonpolar; the apparent μ arises from a large atomic polarization.

Gouw, T. H. and Vlugter, J-C., J. Am. Oil Chemists' Soc. 41, 142-5, 1964.
Methyl esters of saturated fatty acid from methyl acetate to methyl archidate, and methyl oleate, linoleate, linolenate and erucate were prepared in high purity. ϵ's were measured in the liquid state between 20° and 40°C.

Breusch, F. L. and Ulusoy, E., Fette, Seifen, Anstrichmittel 66, 169-73, 1964. (German).
n's, d's, viscosities, and ϵ's at 20° of 14 homologous series, including several alkyl ester series, are given. For all series, with increasing C content, d converged to 0.82 to 0.86, n_D to 1.48, and ϵ to 3.

Breusch, F. L. and Ulusoy, E., Fette, Seifen, Anstrichmittel 66, 739-42, 1964.
The homologous series of n - alkyl alcohols, α,ω-dicarboxylic acids and phenylalkyl methyl carbinols show alternation of melting points and solubilities, but not of d of ϵ.

Hilczer, T., Poznan. Towarz. Przyjaciol Nauk, Wydzial Mat. Przyrod. Prace Komisji Mat. Przyrod. 11, 137-48, 1964.
ϵ's of several dipolar liquids were measured with a heterodyne beat apparatus at pressures between 0 and 700 atm. The liquids studied were benzene,

nitrobenzene, o-nitrotoluene, o-nitroanisole, and 1,2-dibromoethane, for all of which ϵ increased with increasing pressure. Dipolar molar polarizations were calculated for the assumption that molar refraction was independent of pressure. With increase of pressure the dipolar polarization of o-nitrotoluene and nitrobenzene increased, that of 1,2-dibromoethane decreased, and that of o-nitroanisole remained constant.

Chelkowski, A., Acta Phys. Polon. 24, 165-89, 1963.
The values of the dielectric saturation effect $\Delta\epsilon$ in ethyl ether, nitrobenzene, o-nitrotoluene, m-nitrotoluene, o-nitroanisole, 1,2-dibromoethane, 1,2-dichloroethane, and 1,2-dichloroethylene were measured by a heterodyne method. For different concentrations, the saturation effect was found to present three patterns. The temperature dependence of $\Delta\epsilon$ in an electric field was measured for nitrobenzene, m-nitrotoluene, and 1,2-dibromoethane. The theoretical derivation of the saturation effect in Piekara's theory, which predicts both positive and negative values of $\Delta\epsilon$, is discussed.

D. Non-aqueous Solutions

Brot, C., J. Chim. Phys. 61, 139-45, 1964.
ϵ_0's are discussed in terms of the Kirkwood correlation parameter g. When g is 1 there is neither auto-association of the solute nor complexing with the solvent (alkyl halides). For association complexes (alcohols in alkanes) g passes through a minimum and finally approaches 1 in the pure solvent. In solutions of the complexes the last behavior is modified more or less completely according to the complexing power of the solvent. The systems studied were 1-hexanol at 25° in n-heptane, n-hexane, n-dodecane, benzene, and dioxane; phenyl chloride in hexane; tert-butyl chloride in heptane; heptyl bromide in heptane.

Raczy, L., Compt. Rend. 257, 2272-5, 1963.
Static polarization measurements were made at temperatures of 0, 25, and 50°, and at phenol concentrations of 0.002 - 0.10 M in carbon tetrachloride. The variations of the Kirkwood g factor with the concentration are found to be very different for each temperature. The Hertzian spectrum of a dilute solution at 25° confirms that monomers are in the majority. Even at low concentration the monomers appear to associate to form open dimers. The behavior at 0° is attributed to the presence of cyclic trimers.

Runikis, J. O., Dissertation Abstr. 24, 4417, 1964.
Use of dielectric measurements to detect micellar associations of surface-active agents in benzene is studied for a number of detergents, the monomeric μ's being reported.

Vakalov, I. A. and Shakhparonov, M. I., Zh. Strukt. Khim. 5, 620-1, 1964.
ϵ's of acetone-pyridine solutions of different concentrations were determined at 800 kc for a range of temperatures. The linearity between ϵ and 1/T indicates random orientation of the molecules.

Michalczyk, J., Roczniki Chem. 38, 697-701, 1964. (Polish).
ϵ's of tributyl phosphate solutions in benzene, carbon tetrachloride, and dioxane were measured. The ratio of the molar orientational polarization in

benzene to that in the gaseous state is plotted vs. mole fraction and applied as an indicator of self-association and of interaction with the solvent. The μ in benzene is 3.05 D.

Michalczyk, J., Roczniki Chem. 37, 1519-24, 1963. (Polish).
ε's of solutions of ethyl alcohol and tributyl phosphate were measured at 30°. The deviations of molar orientational polarizations from additive values are attributed to interruption of chains of alcohol molecules with rising phosphate concentration and the formation of hydrogen bonds between alcohol and phosphate molecules involving one or more ethanol molecules per molecule of phosphate.

Dolling, O. W., O'Hara, K. K., and Stevens, T. L., Trans. Kansas Acad. Sci. 66, 435-42, 1963.
Dielectric constants were measured of solutions of acetic acid with acetic anhydride and nitromethane. No pronounced anomalies occurred in the curves of polarization vs. mole fraction.

Kolling, O. W. and McMillan, D. J., Trans. Kansas Acad. Sci. 67, 470-80, 1964.
Curves of ε vs. mole fraction are given for numerous binary solutions over the complete concentration ranges. Deviations from linearity for some systems are discussed in terms of solvent interactions.

Gur'yanova, E. N., Vodorodnaya Svyaz, Akad, Nauk SSSR, Inst. Khim. Fiz., Sb. Statei, 1964, 281-9. (Russian).
The process of complex formation was studied using dielectrometric titration of chloracetic acid and β-naphthol with diethyl-, di-n-butyl-, and heptylamine and pyridine. ε increases sharply with formation of complex. Complex formation proceeded in two stages, in which the acid to amine ratio was first 1:0.5 and finally 1:1.

Moelwyn-Hughes, E. A. and Thorpe, P. L., Proc. Roy. Soc. (London) A 277, 423-36, 1964.
ε's of liquid mixtures piperidine-tetrahydropyran, piperidine-cyclohexane, and tetrahydropyran-cyclohexane were determined from 20° to 60°C. The results were used to calculate Kirkwood's g-factor for the last 2 systems. The heats of mixing of the above systems were determined at 20°C to compare the strengths of the various molecular interaction involved. The mixtures were formed endothermally. This suggested that N—H...O hydrogen bonds formed in the first system are weaker than the N—H...N bonds in the second, which has the largest excess enthalpy of the three systems.

Shadskii, S. V. and Mishchenko, K. P., Dokl. Akad. Nauk SSSR 158, 1180-2, 1964.
Heats of solution of NaI in methanol, acetone, and water are compared with the heats of solution in dioxane-water mixtures of the same ε. The dependence of heat of solution at infinite dilution on ε is linear for dioxane-water solutions and has an irregular form for the other solvents.

Paruta, A. N., Dissertation Abstr. 24, 2701-2, 1964.
A linear empirical relationship between ε and Hildebrand solubility parameter is discussed and an attempt made to extend it to mixtures. Measurements of

solubility of salicylic acid in solvents of varying dielectric constant tended to show peak solubilities at ϵ's between 14 and 17.

E. Aqueous Solutions

Baturin, A. N., Nauchn. Zap. Dnepropetr. Gos. Univ. 77, 170-5, 1962. (Russian).
Using a device based on the Drude-Coolidge method, ϵ of the dioxane-water system at 20° in all intervals of concentration was measured for the frequency range 150-440 Mc. ϵ of the mixture was not additive. This is attributed to the destruction of the associates of the molecules of dioxane with a rise of the water concentration. The energy of the intermolecular interaction in the system was calculated.

Le Huerou, M. L. and Guerillot, C. R., Compt. Rend. 258, 2549-51, 1964.
ϵ of water-ethanol mixtures was measured at 25, 35, and 45°. No definite compound between water and ethanol seems to exist in the liquid. The nature and the statistical composition of the association aggregates must vary as a function of mole fraction, two distinct regions being distinguished, one below and the other above an ethanol mole fraction of ca. 0.25.

Miles, J. H., J. Inorg. Nucl. Chem. 26, 2308-9, 1964.
ϵ's of solutions of water in tri-n-butyl phosphate at 18° and 600 kc increased linearly with water concentration to a value of 10.0 at saturation (3.68 molar). ϵ's of solutions of anhydrous sulfuric, hydrochloric, and nitric acids in the phosphate are given for concentrations near 1 molar.

Campbell, A. N. and Gieskes, J. M. T. M., Can. J. Chem. 42, 1379-87, 1964.
ϵ's at 5 Mc and 25° are reported of mixtures of acetic acid (A) and water (W), of chloroform (C) and A, of C, A, and carbon tetrachloride, and of C, A, and W. Molar polarizations of A were calculated from the Debye equation and their concentration dependence interpreted by dimerization of A and hydrogen-bonding between A and C and between A and W.

Sorby, D. L., Bitter, R. G., and Webb, J. G., J. Pharm. Sci. 52, 1149-53, 1963.
Measured ϵ's of the systems water-ethanol-glycerol and water-ethanol-propylene glycol are reported to show large deviations from the values calculated from the Onsager-Kirkwood equation regardless of whether weight or volume per cent is used.

F. Solids

Simhony, M., J. Phys. Chem. Solids 24, 1297-1300, 1963.
Measurements at room temperature yield for ϵ of iodine along the principal crystallographic directions: $\epsilon_a = 6 \pm 0.5$, $\epsilon_b = 3 \pm 0.3$, $\epsilon_c = 40 \pm 2$, by a liquid immersion method. Between 180 and 330°K, ϵ(T) at first decreases with increasing temperature and, after passing through a minimum (at ca. 260, 290, and 310°K for the a, b, and c directions), increases.

Sicha, M., Studnicka, J., Prosser, V., and Gruber, B., Phys. Status Solidi 7, 1045-50, 1964.
Relative ϵ of hexagonal Se single crystals prepared from the vapor phase was measured by a resonance method. In the 3.3-cm region, $\epsilon_{\parallel}$ and $\epsilon_{\perp}$ were 9.3 and 8.1 respectively. These values agree with those obtained by optical methods and expected from theory.

Panchenko, V. V., Fiz. Tverd. Tela 6, 584-9, 1964. (Russian). Translation: Soviet Phys.-Solid State 6, 457-61, 1964.
Temperature dependence of ϵ of a number of alkali halide single crystals is investigated. It is shown that ϵ is a nonlinear function of temperature. Crystals with the NaCl-type lattice have the largest temperature dependence of the temperature coefficient of dielectric susceptibility.

Watanabe, N., J. Appl. Phys. Japan 3, 166, 1964.
Cavity surface impedance measurements at 24 Gc indicate that the ϵ of PbTe is less than 400 and is probably smaller than 200.

Cochran, W., Phys. Letters 13, 193, 1964.
Measurement of the high ϵ_0 of lead telluride by electrical methods is difficult because of its high conductivity. In view of the simple NaCl type of crystal structure of PbTe, ϵ_0 may be calculated from the lattice dynamical properties. Neutron scattering measurements on single crystals gave the frequency of the longitudinal optic mode of zero wave number $\nu_L = 3.24 \pm 0.05 \times 10^{12}$ cps and that of the corresponding transverse optic mode $\nu_T = 0.98 \pm 0.02 \times 10^{12}$ cps. From $\epsilon_0/\epsilon_\infty = (\nu_L/\nu_T)^2$ and Moss's $\epsilon_\infty = 28.4$, ϵ_0 was 310 to within a standard error of $\sim 6\%$.

Whalen, J. J., J. Electrochem. Soc. 110, 1015-18, 1963.
A method of graphical analysis for determination of ϵ in the microwave region is described and applied to measurements of two nitrates. ϵ of $TlNO_3$ was 13.5 ± 0.1 at frequencies between 27 and 37 kMc. For $Pb(NO_3)_2$, ϵ ranged from 14.1 to 14.8, the variation being attributed to non-uniformity of the crystals.

Gilletta, F., Compt. Rend. 259, 4653-5, 1964.
ϵ of glycine sulfate parallel to its ferroelectric axis decreases slowly with time, as does also the surface area of the domain walls. ϵ is a linear function of this area and its measurement is suggested as a convenient method of following the growth of the domains.

Servant, R., J. Phys. 24, 405-6, 1963.
The dielectric anisotropy of $CaSO_4 \cdot 2H_2O$ (gypsum) in the 3 cm band was determined. The reported values of principal ϵ's are $\epsilon_{1} = 5.10$, $\epsilon_{11} = 5.24$ and $\epsilon_{111} = 10.30$.

Syrkin, Ya. K. and Ezuchevskaya, V. M., Zh. Strukt. Khim. 5, 864-72, 1964.
ϵ's of some crystal hydrates and the corresponding anhydrous salts were measured by the immersion method. Data on several Pt, Pd, Co, and Fe complexes, $CuSO_4$ and $CaSO_4$, containing various amounts of water of crystallization, are given. If the water is in crystal lattice vacancies, its contribution to the polarization is 15 ± 2 cm_3/mole. In most cases, water which is H-bonded to the anion with its O linked to the cation contributes 9 ± 1 cm_3/mole. Structural and enthalpy changes accompanying hydration changes are considered.

Ezuchevskaya, V. M., Syrkin, Ya. K., and Deichman, E. N., Zh. Neorgan. Khim. 9, 1495, 1964. (Russian).
The total polarization of $RbIn(SO_4)_2 \cdot xH_2O$ was 102.4, 89.0, and 76.2 cm^3/mole for x = 4, 2, and 0, respectively. The change in polarization per mole of water was 6.5 ± 0.2 cm^3, a value appreciably smaller than 9 ± 1 cm^3, as found for other crystal hydrates. Apparently the water molecules are able to undergo less complete orientation in the present hydrates.

Ezuchevskaya, V. M., Syrkin, Ya. K., and Shchelokov, R. N., Ibid. 1758-9.
The dielectric polarization of uranyl complexes of the type $M_2UO_2(C_2O_4)_2 \cdot xH_2O$, where M is Na and NH_4 and x = 1, 2, 2.7, 3, 4, and 5, is tabulated. Polarization is decreased by 12.5 cm^3 by loss of 1 mole of water when x = 5. Further loss of water almost to the formation of the anhydrous salt brings about a decrease of 8.25 ± 1.25 cm^3 per mole of water lost, a value characteristic of water of crystallization. Replacement of Na by NH_4 brings about a significant decrease in polarization, showing an absence of orientational polarization for water in the crystal.

Krajewski, T. and Blaszkiewicz, B., Poznan. Towarz. Przyjaciol Nauk, Wydzial Mat. Przyrod. Prace Komisji Mat. Przyrod. 11, 213-26, 1964.
Results are given of measurements of the dielectric and piezoelectric properties of potassium pentaborate $(KH_4B_5O_{10} \cdot 2H_2O)$. The piezoelectric properties are associated with the water of crystallization, which is lost at 160° where the piezoelectric character disappears. ϵ increases slowly from -60 to +160°, then decreases with time.

Sawaguchi, E. and Kikuchi, A., J. Phys. Soc. Japan 19, 579, 1964. (English).
Results of crystal structure and dielectric studies of $K_2O \cdot 2Ta_2O_5$ are given. ϵ at 1 kc was ~ 50 at temperatures of 4 to 500°K and there was no evidence of ferroelectricity.

Daniel, V., Trans. Faraday Soc. 60, 1299-1309, 1964.
The variation in ϵ_0 at high dc fields was studied in 12,20-dihydroxydotriacontane, an easily purified example of the secondary long-chain alcohols with anomalously high permittivities. The results are correlated with the predicted dielectric saturation in long chains of hydrogen bonds (see next paper). A hydrogen-bond chain length of 3 to 200 OH units is suggested by different experiments. Most of the samples showed negligible saturation, but several showed positive saturation in the sense that ϵ_0 increased with field strength, in agreement with prediction if some longer chains containing 200 to 2000 units are present. A consistent interpretation assumes a texture involving rings as well as chains of hydrogen bonds.

Daniel, V. and Vein, P. R., Trans. Faraday Soc. 60, 1310-18, 1964.
A model of Sack (ibid., 59, 1672, 1963) to explain the large permittivities of secondary long-chain alcohols is extended to high fields. A discontinuity in a linear chain of hydrogen-bonded OH groups is considered to move along the chain by rotation of neighboring OH groups from one potential minimum to another, there being 2n such minima in the chain of 2n-1 dipoles. The end minima may be deeper than the others, all of which are assumed equivalent. For certain cases the permittivity may increase by a factor of more than 3 upon application of a dc field because of reduction of the population of the

deeper wells. The model may be used either for chains of dipoles which reverse serially or for movements of charges along limited paths. In some cases there may be negligible saturation.

G. Mixtures and Suspensions

Nakano, K., Satuka, A., and Saruvatari, K., Nippon Kagaku Zasshi 84, 902-9, 1963.
From the measured values of ϵ of compressed powders of 1 Mc the intrinsic ϵ's were calculated. For NaCl and $[Co(NH_3)_6]Cl_3$ ϵ's were 5.91 and 7.31 respectively.

Yu-Pin Wang, Hua Hsuech T'ung Pao 1964, 57-9.
An apparatus is described for determining the ϵ of crystalline materials by an immersion method. ϵ of KCl powder has been measured by using mixtures of toluene and benzoyl chloride. The result agrees well with literature values.

Schmidt, M. and Sand, T., J. Inorg. Nucl. Chem. 26, 1189-90, 1964. (German).
By a method of immersion of the powders in solutions of cyclohexane and acetone, ϵ's of the following potassium sulfane disulfonates were determined: $K_2S_3O_6$, $K_2S_4O_6$, $K_2S_5O_6 \cdot H_2O$, and $K_2S_6O_6$. These may be useful for identification purposes. ϵ of the hydrate of the trisulfane disulfonate was anomalously high, indicating some mobility of the water molecule.

VII. Dielectric Properties of Surfaces and Sorbed Molecules

A. Theory

Macdonald, J. R. and Barlow, C. A., Jr., J. Phys. Chem. 68, 2737-40, 1964.
Discreteness-of-charge effects are not only important for any property which depends on more than the average potential. They also affect indirectly the average potential, since the effective dielectric constant depends on the local field and hence on discreteness of charge. A reasonable fit to Grahame's differential capacitance data for aqueous NaF solutions at a variety of temperatures, concentrations and electrode charges may be obtained, without assuming adsorption other than the water monolayer, simply by properly taking into account discreteness of charge and its effect on the ϵ of the inner layer. A procedure for determining the effective ϵ and the work function for adsorption of ions is outlined. An improved method is suggested for summing the Coulomb terms in the expression for the local field potential in a form sufficiently general for wide application.

Shurr, J. M., J. Phys. Chem. 68, 2407-13, 1964.
The theory of the low-frequency dielectric dispersion of spherical colloidal particles in electrolytic solution is treated. The theory of Schwarz rests on an objectionable boundary condition - that free charge on the surface of the sphere may not respond to tangential electric fields. Moreover, in the Schwarz treatment the counterion layer is a nonconductor in a constant field since the electric and diffusion currents cancel each other. It is necessary to distinguish between bound charge current which is cancelled by diffusion current and true or dc current which obeys Ohm's law in the steady state. The latter is the current considered by O'Konski, whose boundary conditions

appear to be most suitable. The treatments of O'Konski and Schwarz are combined by assuming conditions based on analogy with the steady state, with the objectionable features of Schwarz's theory removed. The agreement with experiment appears to be more complete than for either individual theory. The use of dielectrophoretic flow to distinguish between this theory and that of Schwarz is suggested.

Sanfeld, A., Bull. Classe Sci., Acad. Roy. Belg. 50, 339-57, 1964. (French).
Various methods are given to calculate the distribution of pressures in charged and polarized liquid surfaces at uniform temperatures, where ϵ is a function of temperature, concentration, and electric field. Simple expressions are obtained for phase surfaces at mechanical equilibrium. The final results depend on the use of Kelvin or Helmholtz pressure in the equations and on which expression is being used for ϵ.

Bass, L., Trans. Faraday Soc. 60, 1656-63, 1964.
A rigorous treatment is given of the electric field and potential distributions at interfaces in the presence of a steady electric current. A non-linear equation for the field in deposition, dissolution, and discharge of ions is derived from migration-diffusion balance. An improved approximation for the field of concentration polarization is obtained.

B. Films and Adsorbed Molecules

Ida, M., Hirata, M., and Kawada, S., J. Phys. Soc. Japan 19, 417-18, 1964.
Changes in capacitance with time were measured in a glass plate under conditions of adsorption and desorption of water. The peak observed at the initial stage is due mainly to orientation polarization of water molecules. This peak is more pronounced in a thin layer than in a thick, amorphous layer.

Feldman, U. and Folman, M., Trans. Faraday Soc. 60, 440-448, 1964.
Dielectric absorption in the microwave region (23,500 Mc) has been studied on ammonia adsorbed on porous Vycor glass. Tan δ values were measured with an accuracy of 10^{-5}. Using a solution-like model for the composite adsorbate + adsorbent system, τ's and potential barriers for orientation of the adsorbate have been calculated from the experimental results. It has been shown that tan δ against surface coverage dependence may be explained in terms of existence of distribution of τ. The lower limit of μ of adsorbed NH_3 molecule was estimated from $(\partial \tan \delta/\partial V)_{max}$ as 1.2 D.

Plumb, R. C., J. Phys. 25, 69-73, 1964.
It is shown that there is anomalous absorption in thin (< 100 Å) dielectric films on metal surfaces. This absorption is explained in terms of the electric double layer.

Wales, R. D., J. Electrochem. Soc. 111, 478-89, 1964.
Resistivity and ϵ of GeO_2 films at 1 kc are reported to be 3.3×10^{12} ohm cm and 6.4 respectively. The variation of capacitance with thickness of the film and with frequency is also given.

Bertulis, K. and Tolutis, V., Lietuvos Fiz. Rinkinys, Lietuvos TSR Mokslu Akad. Lietuvos TSR Aukstosios Mokyklos 4, 381-7, 1964. (Russian).
The effective ϵ (ϵ_{eff}) and tan δ of praseodymium fluoride films were determined for a frequency range from 20 to 10^5 cps and for a temperature range from -50° to 250°. Increasing the thickness of the film from 0.2 to 2.0 micron increased ϵ_{eff} from 40 to 700, but heating or aging reduced it to $\leq$ 200. The plot ϵ_{eff} vs. temperature indicated a relaxation mechanism of polarization.

Harrop, P. J. and Wanklyn, J. N., J. Electrochem. Soc. 111, 1133-6, 1964.
A technique for examining bulk electrical properties of ZrO_2 films was developed and used to determine the loss spectra of the film formed by steam corrosion and by anodization of Van Arkel Zr. The activation energy of dipole relaxation was 0.72 ± 0.04 eV.

C. Clathrates and Molecules Occluded in Solids

Syrkin, Ya. K. and Ezuchevskaya, V. M., Zh. Strukt. Khim. 5, 387-91, 1964.
The dielectric polarization of clathrates formed by nickel cyanide-ammonia -$Ni(CN)_2 \cdot NH_3$ - with water, benzene, aniline, and thiophene was determined by the immersion method. The orientational polarization for water in the clathrate is greater than that for liquid water, since orientation is more inhibited by hydrogen bonds in the latter than by the walls of the crystal lattice. The polarization of the benzene clathrate exceeds the sum of the polarizations of the components, whereas for aniline it is somewhat less. With thiophene, the clathrate has a greater orientational polarization than gaseous thiophene. This is either connected with environmental factors affecting the orientation of the encaged molecule or with interaction with the Ni so as to contribute the additional μ of the weak Ni-S bond.

Davidson, D. W., Davies, M. M., and Williams K., J. Chem. Phys. 40, 3449-50, 1964.
In addition to a disperson-absorption region at kilocycle frequencies attributed to relaxation of water molecules forming the solid lattice, the gas hydrates of ethylene oxide (EO) and tetrahydrofuran (THF) show absorption in the Gc region at low temperatures attributed to slightly restricted orientation of the encaged EO and THF molecules. For the latter τ's at -185° were ca 30 and 10 x 10^{-12} sec. and the corresponding activation energies ca 0.5 and 0.3 kcal/mole respectively.

Chihara, H., Okawa, S., and Seki, S., Bull. Chem. Soc. Japan 37, 1373-8, 1964.
Measurements were made between -150° and room temperature and between 40 cps and 3 Mc on single crystals of the DL-$[Co(ethylene\ diamine)_3]Cl_3 \cdot nH_2O$ complex. The practical limit of hydration was n = 3.6 at room temperature. Crystals of smaller n were obtained by controlled dehydration in the dielectric apparatus. Quick dehydration rendered the crystal surface opaque, transparency being regained by conditioning for about one week. ϵ' and ϵ'' were measured for nτ' between 0.27 and 3.6 and found to be strongly dependent on n and on crystal orientation. Activation energies varied from 4.7 to 8.3 kcal mole^{-1}. A mechanism of absorption is based on the orientation of water molecules held in the zeolite-like crystal.

Fedorov, V. M., Glazun, B. A., Zhilenkov, I. V., and Dubinin, M. M., Izv. Akad. Nauk SSSR, Ser. Khim. 1964, 1930-4.
ϵ' and ϵ'' were measured between -20 and 20° at frequencies between 1 kc and 10 Mc of crystalline zeolite type NaA with low water primings. Hydration lowers the already low conductivity which is therefore inferred to be of ionic character. τ of water adsorbed by the zeolite is 5 to 6 orders larger than of water adsorbed by SiO_2 gel. The relaxing units consist of complexes of water molecules localized on ions or molecules occupying vacancies of the crystal. Activation parameters for conductivity and relaxation were evaluated for different water contents.

Ebert, G., Kolloid Z. 198, 65-76, 1964.
A dielectric study was made of water sorbed on α-AlOOH, silica gel, and Na-Al silicate at temperatures to -60°. Results are given for τ's and activation energies of rotation of water molecules. Other sorbates studied were n- and t-butyl alcohols, methyl alcohol, acetone, and nitrobenzene. The role of hydrogen bonding is discussed.

Lovell, S. P., Firth, P., and Hasted, J. B., Brit. J. Appl. Phys. 15, 1439-40, 1964.
Measurements of the temperature dependence of 3.33 cm wavelength ϵ of water-loaded brick and hardened cement paste show discontinuity around 0° only for the brick. This supports the view that the water adsorbed in cement paste is bound or chemically adsorbed, being unable to undergo phase-change at this temperature.

VIII. Electrets

Asch, G., Compt. Rend. 256, 5302-4, 1963.
An expression for the variation of charge on electrets is derived, and shown to be consistent with the variation of homocharge and heterocharge observed under various experimental conditions.

Davies, D. K., Nature 203, 290-1, 1964.
The release of trapped charge on a series of dielectrics has been measured by an electrometer technique. In all cases a single activation energy was observed.

Bogoroditskii, N. P., Tairova, D. A., and Sorokin, V. S., Fiz. Tverd. Tela 6, 2301-6, 1964. (Russian).
The physical processes taking place in ceramic materials polarized in strong fields and high temperatures are discussed, including the role of free charge carriers in the formation of a stable electret homocharge. There is a relation between color centers at Schottky defects and the surface charge of the electret. A new model is given for the electret state in nonpolar dielectrics.

Lambert, V. L. and Weik, H., Phys. Letters 9, 15-17, 1964.
Lattice distortion resulting from the electric field in single crystal $SrTiO_3$ electrets is an important feature of their behavior and a study of the internal field in the crystal provides a model for explaining the behavior of ceramic electrets.

Cross, J. D. and Hart, J., Dielectrics 1, 225-8, 1964.
Purified carnauba wax electrets were studied by measuring the discharge current and by direct measurement of μ. The maximum μ determined by the torque produced on a sample in a homogeneous field was equivalent to a surface charge of ~ 2 esu cm^{-2}. The results agree with the theory proposed by Gross.

Bhatnagar, C. S., Indian J. Pure Appl. Phys. 2, 57-61, 1964.
Surface charge and its decay with time of laminar carnauba wax electrets prepared at 74°, 76°, and 78°C and with different polarizing fields have been studied. The electrets prepared above 74°C show both homo and hetero charges while those prepared at and below 74°C show only homocharge. The inequality of charge observed on the two surfaces of the electret was interpreted on the basis of Gross' theory.

Murphy, P. V., Ribeiro, S. C., Milanez, F., and deMoraes, R. J., J. Appl. Phys. 34, 3138-9, 1963.
Using an improved technique for polarization measurement, carnauba wax of different thicknesses were examined and three γ-ray irradiation series were carried out at room temperature and at the temperature of dry ice. The results now obtained differed from those already published in that the relation between residual polarization and radiation dose cannot be approximated by a simple exponential; they indicate that depolarization results from a direct interaction of radiation with the dipolar units.

Polovikov, E. I., Fiz. Tverd. Tela 5, 1830-2, 1963. (Russian). Translation: Soviet Phys.-Solid State 5, 1336-7, 1964.
Polycrystalline naphthalene electrets were prepared using 14 different values of electric field intensity in the range 2.0 - 12.5 kv/cm, and then irradiated with infrared rays having a maximum at $\lambda = 3$ microns. The irradiation increased the magnitude and stability of the heterocharge.

Antonov, A., Compt. Rend. Acad. Bulgare Sci. 15, 470, 1964. (Russian).
An attempt is made to explain the phenomena occurring in a photoelectret, assuming that the free electrons are secured in close vicinity to the atoms from which they have been removed, so that they form peculiar dipoles - photodipoles. The polarization of the photoelectret is examined as a dipole polarization which is homogeneous all along the specimen. The laws of photopolarization and photodepolarization of photoelectrets are obtained under certain assumptions.

Lyubin, V. M. and Fomina, V. I., Fiz. Tverd. Tela 5, 3367-72, 1963. (Russian). Translation: Soviet Physics-Solid State 5, 2472-6, 1964.
Formation, persistence, failure characteristics and results of a study of the photoelectret state of several photoelectret materials including thin amorphous $Tl_2Se \cdot As_2Se_3$ prepared by evaporation in vacuum, are described. High sensitivity is noted in the photoelectrets studied. The electret state was observed and studied when the samples were irradiated with a beam of fast neutrons (cathode electret state).

IX. Electrical Conductance

A. Liquids

Glueckauf, E., Trans. Faraday Soc. 60, 776-82, 1964.
The theory of Debye and Hückel is extended to include the changes of ϵ in the vicinity of an ion. The effect is normally small, but becomes more pronounced with increase of ionic charge and temperature.

Passeron, E. J., J. Am. Chem. Soc. 68, 2728-30, 1964.
The relationship $r = f/(6\pi u\eta)$ has been used to express deviations from Stokes' Law relating the radius r of an ion to its mobility u and solvent viscosity η. The correction factor f is normally derived in terms of dielectric relaxation of the medium (cf. Zwanzig, J. Chem. Phys. 38, 1603, 1963). An alternative derivation of f, not directly involving relaxation, is proposed. Solvent molecules near the moving ion slip around it in an oriented position because of the ionic field, and revert to a normal position of no preferred orientation after passage of the ion. The total work done by the field in this case is compared with that done on an ideal, uncharged, Stokes' Law sphere of larger radius. The resulting expression for f includes an adjustable parameter which is fixed from the experimental f values of the tetramethyl ammonium ion. Values for other tetraalkyl ammonium ions are then calculated.

Pickard, W. F., J. Electrochem. Soc. 111, 1234-8, 1964.
The effect of ionic space charge on dielectrophoretic forces in dielectric fluids is examined theoretically and experimentally. Two new theoretical results are presented. The effect of a space charge on the dielectrophoretic force is shown by the frequency dependences in the Pellat-Greiracher method of determining electric susceptibility of liquids. A new method is given for measuring electrical conductance of liquids.

Briere, G. B., Brit. J. Appl. Phys. 15, 413-7, 1964.
Modern ion exchangers make it possible to reduce the conductivities of polar liquids like ethanol by several orders of magnitude to the extent that, as in pure water, they are determined by the ionic concentrations resulting from self-dissociation of the liquid. The increase of conductivity of highly pure water (5×10^{-8} ohm^{-1} cm^{-1} at low fields) with applied pulsed field agrees at all fields up to breakdown with the theory of the Wien effect given by Plumley but not with Onsager's theory. Values of tan δ at 50 cps in pure ethanol (1.4×10^{-11} ohm^{-1} cm^{-1}), measured with rapidly rotating cylindrical electrodes to reduce polarization, lead to the same conclusion.

Gavis, J., J. Chem. Phys. 41, 3787-93, 1964.
Conductivities of electrolytes in low ϵ liquids are commonly so low that they must be measured by dc methods. A linearized differential equation developed by the author (Chem. Eng. Sci. 19, 237, 1964) for charge transport is applied. Boundary conditions are formulated in terms of charge densities near electrode surfaces and potentials at the surfaces. Expressions are found for formation of the equilibrium double layer at the surface and of the nonequilibrium double layer when the potential is raised to cause current flow. The current consists of a transient polarization current which decays to a steady-state

value which obeys Ohm's Law if the electrode spacing is large enough. Otherwise, small diffusion-enhanced transport leads to erroneously high conductivities.

Malecki, J. and Krowarsch, A., Poznan. Towarz. Przyjaciol. Nauk, Wydzial Mat. Przyrod. Prace Komisji Mat. Przyrod. 11, 113-24, 1964.
The effect of time on the conductivity σ of anhydrous 3-methyl-1-butanol, benzene, carbon tetrachloride, and nitrobenzene was studied by a pulse technique with adjustable electrode separation ℓ. At $t = 0$, σ_0 was constant and independent of field strength. For solutions of the alcohol in benzene, σ decreased with dilution and t and showed a weak maximum at a mole fraction of 0.83. With addition of carbon tetrachloride to the alcohol σ rises steeply with t and dilution to a maximum at 0.995 mole fraction of alcohol. Theory. Malecki, J., Ibid. 125-136. An equation relates σ to t, electric field, and ℓ. As $t \to \infty$, $\sigma \to \sigma_\infty$; $\sigma_\infty \to \sigma_0$ as the field $\to 0$ and $\ell \to \infty$ in agreement with the experimental data for 3-methyl-1-butanol.

Iverson, A., J. Phys. Chem. 68, 515-21, 1964.
The resistivity of water purified by recirculation in an all glass and Teflon system for removing contaminants was measured between 5 and 55°. The value at 25.00° was 18.36 ± 0.02 megohm-cm. Experimental values agreed to within 1.4% with resistivity values calculated from the dissociation constant of water and the limiting mobilities of the H^+ and OH^- ions.

Dannhauser, W., J. Phys. Chem. 68, 2007-9, 1964.
Conductivities (σ) of MeOH, EtOH, iso-BuOH were measured as a function of temperature (25-227°). Graphs of log σ_T/σ_{298} vs. $1/T$ and $1/\epsilon T$ are given. The maxima observed are attributed to the decrease in effective ion concentration as a result of decrease in ϵ with increasing temperature.

B. Solids

Bogoroditskii, N. P. and Fridberg, I. D., Fiz. Tverd. Tela 6, 680-3, 1964. (Russian). Translation: Soviet Phys. Solid State 6, 533-5, 1964.
The existing views on the nature of continuous electrical conductivity in solid dielectrics are inadequate. A summary of existing experimental data is given.

Jaffe, B. M. and Kallmann, H. P., J. Am. Chem. Soc. 86, 3428-33, 1964.
The theory of the ac impedance or of the apparent ϵ of poor conductors has been revised taking into account the diffusion of the charges inside the poor conductor. The equation for the capacity of the whole system is augmented by effective penetration depths of the field into the conductor, closely connected to the Debye lengths.

Eigen, M., de Maeyer, L., and Spatz, H. Ch., Ber. Bunsen Ges. Phys. Chem. 68, 19-29, 1964. (German).
Three quantities are needed for complete determination of the kinetic and thermodynamic parameters of the proton processes in ice. These are (1) the equilibrium dc conductivity, (2) the saturation current at High fields, and (3) the dissociation field effect. In the reaction $H^+ + OH^- \rightleftharpoons H_2O$ in ice the rate constant for dissociation (K_D) is determined from (2), and the one

(K_R) for diffusion-controlled recombination calculated from (1) and an effective dielectric constant for interaction of two ions. (3) also depends on the effective dielectric constant as defined by Onsager. New values for the conductivities of H_2O and D_2O ice are 1.0×10^{-9} and 3.6×10^{-11} ohm^{-1} cm^{-1}, respectively, with corresponding activation energies of 11 and 13 kcal mole^{-1}. K_D's are 3.2×10^{-9} and 2.7×10^{-11} sec^{-1}, K_R's 0.86 and 0.13×10^{13} mole^{-1} liter sec^{-1}, and equilibrium constants 3.8 and 0.20×10^{-22} mole liter^{-1}. Thermodynamic properties are evaluated. There is a large difference in mobility of protons ($\sim$ 0.08) and deuterons ($\sim$ 0.01 cm^2/v sec). The proton jump in the hydrogen bridge is the rate-determining step for charge transport.

Gosar, P. and Pintar, M., Phys. Status Solidi 4, 675-83, 1964.
A theory of the lattice energy bands and mobility of H_3O^+ ions in ice is given. The mobility is determined by second-order processes involving 1-phonon emission and absorption. The variational principle is applied to the Boltzman equation to derive the mobility.

Levi, L. and Arias, D., J. Chim. Phys. 61, 668-73, 1964.
The dc conductivities of ice crystals grown in the presence of HF, HCl, HBr, and HI showed similar behavior and were also similar to those grown with HNO_3. This behavior indicates that the different univalent anions play a similar role, despite the rapid increase of ionic radius in the order given, only the F^- ion being similar to O^{--} in size. Curves show conductivity as a function of acid concentration and indicate that the concentration of the H_3O^+, the charge carrier, does not follow the mass action law for acid dissociation. If the existence of ion traps is postulated, dissociation constants for the acids and for the ion traps may be estimated.

van Beek, L. K. H., Physica 29, 1323-8, 1963.
Study of the proton conductor $Li_2SO_4 \cdot H_2O$ shows two dispersion regions similar to those in borax and doped ice. A low-frequency dispersion around 0.26 cps, with limiting ϵ's of 380 and 105 is attributed to mobile protons. The mobility given by Macdonald's theory of space charge is 2.6×10^{-6} m^2/v sec and the concentration of mobile protons 1 in 10^{12}. A second dispersion near 700 cps, limiting ϵ's 80 and 4.75, is ascribed to rotation of protons around O atoms.

van Beek, L. K. H., Physica 30, 1682-8, 1964.
Proton mobilities in single crystals of $Li_2SO_4 \cdot H_2O$ are derived from its dielectric behavior between 0.01 and 10 cps and from dc transients. Space-charge effects were appreciable only in samples cut perpendicular to the crystallographic b- axis. The dielectric effects of space charge are discussed for a simple model, in which the sample with space charge layer is considered as a capacitance in series with a resistance. The mobilities calculated are of the order 6×10^{-7}m^2/v sec.

van Beek, L. K. H., Physica 30, 1907-8, 1964.
Dielectric loss data were obtained during studies of space-charge polarization in single crystal $Li_2SO_4 \cdot H_2O$ at 20°.

Ibid. 30, 1925-6, 1964.
Dielectric measurements with single crystals of borax $Na_2(B_4O_5(OH)_4) \cdot 8H_2O$ were carried out at 0.1 - 10 cps and 0.06 - 300 kc. At low frequencies ϵ was proportional to crystal thickness.

Herrington, T. M. and Staveley, L. A. K., J. Phys. Chem. Solids 25, 921-30, 1964.
Conductivity measurements were made on single crystals of NH_4Cl, CsCl, and KCl and, in less detail, on various other salts. The conductivity of NH_4Cl is significantly greater than comparable alkali chlorides which suggests a mechanism of conductance for ammonium salts not possible for alkali salts. A 3-step mechanism is proposed involving (1) a proton transfer from NH_4^+ to a Cl^- ion adjacent to a vacancy to form NH_3 and HCl molecules, (2) the migration of one of these molecules into the vacancy, and (3) reformation of NH_4^+ and Cl^- ions. The mechanism is consistent with the formation of a significant number of molecules at room temperature and below, as suggested by the thermodynamic properties of NH_4Cl.

Jaffrain, M., Compt. Rend. 259, 2223-6, 1964.
The introduction of small amounts of organic acids into frozen organic solvents, and, in oxygenated polar solvents, to a dipolar relaxation characterized by an increased activation energy.

Kepler, R. G., Am. Chem. Soc., Div. Polymers Chem., Preprints 4, 199-201, 1963.
Salts of tetracyanoquinodimethane exhibit very high electronic conductivity, as high as 100 ohm^{-1} cm^{-1}.

Popov, V., Comp. Rend. Acad. Bulgare Sci. 15, 821-4, 1962.
Conductivity of paraffin, beeswax, and ceresin was studied in the region of melting at fields of 3.3×10^3 to 2.8×10^4 v/cm. Different behaviors at melting for the three substances were attributed to differences in the melting processes.

X. Miscellaneous Electrical and Related Properties

Coyle, P. J., Dainton, F. S., and Logan, S. R., Proc. Chem. Soc. 1964, 219.
This paper deals with the τ of the ionic atmosphere of the hydrated electrons which were generated by the photodetachment from I^- and allowed to react competitively with I_3^- and N_2O.

Debye, P. J. and Kleboth, K., Defense Documentation Center - Clearing House for Federal Science and Technical Information Report No. AD 604494, 32 pp., 1964.
The free energy involved in the concentration fluctuations of a liquid mixture is charged by an electric field. The effect increases with decreasing distance from the critical temperature of solution and is proportional to E^2 and to dE/dc, where E = field strength and c = concentration. The effect may be interpreted as a shift of critical temperature. An experimental shift of 0.015° for E = 45,000 volts per cm in the nitrobenzene-2,2,4-trimethylpentane system compared with a theoretical shift of 0.010°.

Tukhvatullin, F. Kh. and Vuks, M. F., Ukr. Fiz. Zh. 9, 537-40, 1964. (Russian).
Changes in the line contours of light scattered anisotropically by the quasi-spherical molecules carbon disulfide, benzene, thiophene, acetonitrile, acetone, chloroform, methyl chloride, cyclohexane, cyclopentane, and carbon tetrachloride were studied in the liquids at 20, 120, 180, and 220°C. The

orientational τ was calculated from a dispersion formula. For carbon disulfide and benzene the line became broader with increasing temperature to 180° and τ decreased according to $\tau = \tau_0 \exp (u_0/RT)$ where u_0 is the energy of orientational interaction. At higher temperatures the line contours changed. Acetone exhibits the same behavior at 100° and the contours of the other liquids are already disturbed at room temperature. This change in contour corresponds to a transition from the hindered rotational motion in the liquid to a more free molecular rotation which occurs when RT is approximately equal to u_0.

Moriamez, C., J. Chim. Phys. 61, 298-302, 1964.
The velocity of propagation and the absorption coefficients of ultrasonic waves in liquid 2-ethyl-1,3-hexanediol and 1,5-pentanediol were determined at -30° to 20° at frequencies 1 - 12 Mc. ε's were calculated and compared with dielectric τ's.

Sakharov, V. M., Gaz. Khromatogr. Akad. Nauk SSSR, Tr. Vtoroi Vses. Knof., Moscow, 1962, 346-7 (Pub. 1964). (Russian).
Since the logarithm of the retention volume of a substance for a given solvent varies linearly with its molar refraction and with the square of its μ, for two substances having the same molar refraction one should have $RT\Delta \log V = (2/9)(\Delta\mu^2/r^3)(1-1/\epsilon)$, where $\Delta\mu^2$ is the difference between the squares of μ's and r the molecular radius. The equation was tested for its validity and it is suggested that the chromatographic method of measuring μ's may prove valuable with nonvolatile materials, such as natural products and polymers.

Anvaer, B. I., Zhukovitskii, A. A., Litovtseva, I. I., Sakharov, V. M., and Turkel'taub, N. M., Zh. Analit. Khim. 19, 178-83, 1964. (Russian).
Translation: J. Anal. Chem. (USSR) 19, 162-6, 1964.
The logarithm of the retention volume of different substances is a linear function of 1/ε of the solvent for most liquids used as the stationary phase in gas-liquid chromatography. The slope varies with the polarity of the material analyzed. The relation is of use in choice of solvent and in identification of an analyzed components.

Johnson, S. L. and Rumon, K. A., J. Phys. Chem. 68, 3149-54, 1964.
It was found from n.m.r., infrared, ultraviolet, and conductivity measurements that the ionic adduct formed from dimethylcarbamoyl chloride and pyridine tends to decompose into its component parts in nonhydroxylic solvents whose ε's lie between 5 and 95 but not in hydroxylic solvents with ε ranging from 11 to 80. The nucleophilic characters of the chloride and pyridine are strongly affected by the chemical nature of the solvent.

Krasnopevtsev, V. V., Fiz. Tverd. Tela 5, 2261-9, 1963. (Russian).
Translation: Soviet Phys.-Solid State 5, 1645-50, 1964.
Single crystals of KBr were irradiated with fast electrons and their dielectric properties and optical absorption studied. The F^- and V_2^- centers and other defects produced give rise to dielectric relaxation which is described satisfactorily by the Cole-Cole diagram.

MacChesney, J. B. and Johnson, G. E., J. Appl. Phys. 35, 2784-5, 1964.
ε and tan δ at 1 Mc were measured, as well as d, of fused silica and

polycrystalline alumina, for radiation up to 5×10^{19} fast neutrons per cm^2. Tan δ is more sensitive than ϵ to irradiation. The results are related to previously reported changes in optical and structural properties of fused silica.

Gesi, K. and Takagi, Y., J. Phys. Soc. Japan 19, 632-9, 1964.
Single crystals of sodium nitrite were irradiated with Co^{60} γ-rays and the radiation-induced changes in dielectric properties were measured. Depression of the Curie temperature, decrease of the max. ϵ, increase of the coercive field, appearance of a weak double hysteresis loop, increase of the electrical conductivity, and a change in its activation energy were observed as a result of the irradiation.

Brian, H. H. and Gutmann, F., Electrochim. Acta 9, 1587-98, 1964.
Current harmonics were studied in benzene, n-hexane and cyclohexane in relation to harmonics present in the voltage wave. The dielectric behaves not merely as a nonlinear impedance but has some of the characteristics of a source. Analysis at the 80% confidence level establishes the significance of this behavior and of the differences between the harmonic spectra of the three liquids studied. These must reflect some physical process occurring in the electrically stressed liquids.

Frenkel, L., J. Res. Nat'l. Bur. Std. 68A, 185-8, 1964.
Errors due to surface conductivity are treated for the case of dielectric measurements in plane parallel plate capacitors. A general theory reduces the system to an assembly of lumped elements superimposed on distributed transmission lines. Surface effects in the presence of air gaps cannot be eliminated by guarding and many of the published data describing losses in mica must be reexamined.

XI. Reviews

Ionic conductivity is reviewed in the chapter Solutions of Electrolytes by J. N. Agar in volume 15 of the Annual Review of Physical Chemistry (Annual Reviews, Inc., Palo Alto, Cal., 1964).

Volume VI of Advances in Chemical Physics (edited by I. Progogine, Interscience Publishers, New York, 1964) includes a chapter on the many-electron theory of atoms, molecules, and their interactions by O. Sinanoglu, and one on the statistical mechanics of ionic solvation by J. Stecki.

A comprehensive review of theoretical aspects of matter transport in solids is given by R. E. Howard and A. B. Lidiard in volume XXVII of Reports in Progress in Physics (edited by A. C. Stickland, published by The Institute of Physics and The Physical Society, London, 1964, pp. 161-240). Among the topics treated are defects in metals, ionic crystals, semiconductors, and insulators; irreversible thermodynamics of transport processes; and ionic and thermal diffusion.

M. A. Lampert (ibid. pp. 329-67) discusses volume-controlled current injection as a method of studying space-charge and trapping effects in the conduction of insulators and semiconductors.

Vigoureux, P., Contemp. Phys. 6, 15-25, 1964.
A review of electric units and atomic constants.

Suffczynski, M., Phys. Status Solidi 4, 1-29, 1964.
The article deals with the optical properties of Cu, Ag, and Au and their interpretation in terms of band structure. The theory of the dielectric constant of metals (composed additively of the contributions of free electrons (essentially a collective effect, i.e. a plasma effect) and interband transitions) is summarized and a considerable number of references and experimental data are given.

Lutskii, A. E. and Mikhailenko, S. A., Vodorodnaya Svyza, Akad. Nauk SSSR, Inst. Khim. Fiz., Sb. Statei 1964, 272-80.
A review of the dielectric properties of hydrogen-bonded liquids.

Van Belle, C., Nachrichtentech. Fachber (NTF) 29, 7-10, 1964.
The classical theory of polarization and internal field effects in a homogeneous dielectric containing permanent dipoles is described.

van Heteren, P. J. M., Ibid. 29, 11-19, 1964.
The theory of structure relaxation is reviewed, including the general theory, the superposition integral, the complex ϵ and the Kronig-Kramers equations.

Müser, A., Ibid. 29, 30-37, 1964.
An outline is given of the principal theories of dielectric behavior of gases and solids with a brief qualitative review of the coupling of μ's in solids, the frequency dependence of dielectric losses, and the effect of crystal imperfections on ϵ.

XII. Books, Journals, and Conferences

Books bearing on the contents of the present chapter which were published or became generally available in 1964 include the following:

Tables of Experimental Dipole Moments by A. L. McClennan (W. H. Freeman and Company, San Francisco, 1963) collects practically all measured dipole moments published to the end of 1961 and lists recommended values for many common molecules.

Charge Storage in Solid Dielectrics by B. Gross (Elsevier Publishing Company, New York, 1964) is a bibliographical review of the electret and related effects. After an introductory survey in which terms are defined and trends are discussed, abstracts, prepared by the author, of pertinent papers published to September 1963 are presented.

Dielectrics by J. C. Anderson (Chapman and Hall, Ltd., London 1964) is a textbook designed for electrical engineering and physics students. It provides a useful, if elementary, introduction to the concepts and theories of dielectrics and uses the m.k.s. system throughout.

Methods of Studying the Thermal Motion of Molecules and the Structure of Liquids (in Russian) by M. I. Shakhparonov (Izdatel'stvo Moskovskogo

Universiteta, 1963, 280 pp.) is mainly concerned with the author's interesting studies of dielectric properties and Rayleigh scattering of solutions of non-hydrogen-bonded molecules. There are three chapters, of which the first describes the dielectric methods and static and relaxation dielectric theory, the second the methods, theory, and results of measurements of intensity and depolarization of scattered light, and the third the information obtained by combining both techniques regarding fluctuations of density, concentration, and orientation of molecules and molecular complexes. Solutions of acetone and nitrobenzene in carbon tetrachloride, benzene, and saturated hydrocarbons, and of nitrobenzene in acetone are treated in detail.

The title General Chemistry of Dielectrics (in Russian) by I. M. Maiofis (Gosudarstvennoe Izdatel'stvo Vysshaya Shkola, Moscow, 1963) might be more accurately rendered as General Chemistry of Polymers since it describes the chemical structures, methods of preparation, and some of the mechanical and electrical properties of polymers, at an elementary level.

The Study of Dielectrics at Ultrahigh Frequencies by A. A. Brandt (Gosudarstvennoe Izdatel'stvo Fiziko-Matematicheskoe Literatury, Moscow, 1963) provides, in Russian, a survey of the principles of the different experimental methods of studying dielectric properties at high frequencies, including resonant, wave guide, optical, calorimetric, and ponderomotive techniques.

The proceedings of the 12th Ampere Colloquium (Bordeaux, 1963) have been published as Electromagnetic Resonance and Solid Dielectrics (North-Holland Publishing Company, Amsterdam, 1964). Included are the following: Tensor representation of polarization in homogeneous anisotropic dielectrics (J. F. Nye), Activation energy of the low- and high-frequency relaxation regions of zeolites (A. Lebrun, R. Liebaert, and A. Risbourg), Activation energy of the low- and high-frequency relaxation regions of silica gels (J. Fontaine and A. Chapoton), Dielectric properties of emulsions with dispersed aqueous phase (C. Lafargue and L. Babin), A dielectric anomaly for water absorbed on the surface of ionic crystals (J. Lajzerowicz and B. Humbert), Influence of small amounts of impurity on the Debye dipolar absorption of frozen organic compounds (M. Jaffrain), Study of the praseodymium-oxygen system by the dielectric method (G. Grosvald), Dipolar defects and dielectric dispersion in lithium fluoride (J. Petiau and H. Curien), Measurement of the dielectric constants of some powders at 9275 Mc (R. Sardos), Organic semi-conductors and dielectric properties; organo-phosphorus compounds (M. Freymann and R. Freymann), The Hertzian spectrum and changes of phase of poly-substituted phenols (J. Meinnel, Y. Balcou, and P. Gregoire), Structure and Hertzian spectrum of n-alkyl halides (G. Martin and J. Meinnel), Dielectric properties of triglycine sulfate and the domain structure (P. Lauginie), The existence of a double transition in lead zirconate (L. Goulpeau and S. Le-Montagner), On the distribution functions of relaxation times and activation energies (P. H. Fang), Dielectric properties of a rigid system of hydrogen bonds (A. Piekara), Coupling between dipoles-short and long range order (J. Lajzerowicz), The permittivity tensor of gypsum in the microwave region (R. Servant), High field effects for linear chains of dipoles and limited conducting paths (V. Daniel and P. R. Vein), Radio wave spectra of sorbed dipole molecules (G. Ebert), Coupling between lattice vibrations and millimeter dielectric absorption (R. Desbrandes), and numerous other papers mainly dealing with magnetic studies.

The 1964 Annual Report of the Conference on Electrical Insulation includes a summary of papers presented at the 33rd annual meeting (Cleveland, 1964). The following are relevant to this chapter:
A method of simultaneous measurement of dielectric constant and volume of liquids to 2000 atm was outlined (p. 36) by N. L. Brown, and illustrated by results for cyclohexane and carbon tetrachloride.

A. J. Bur (p. 70) provided experimental verification of the Williams, Landel, and Ferry technique for the superposition of dispersion curves obtained at different temperatures for poly(vinyl decanoate) at frequencies between 10 and 2.5×10^8 cps.

M. M. Perlman (P. 73) developed a model for the surface charge behavior of an absorptive dielectric and applied it to results obtained for a carnauba wax electret.

M. G. Broadhurst (p. 129) proposed a dumbbell model for dielectric dispersion in paraffin-like solids.

The proceedings of the 13th annual meeting (1963) of the Societe de Chimie Physique appear in J. Chim. Phys. <u>61</u>, 3-270, 1964. The topic "Molecular Interactions in the Liquid Phase" included papers on dielectric dispersion (which have been individually adstracted) as well as papers on intermolecular interaction theory (by Longuet-Higgins, Mulliken, Barriol, and Katelaar) and on thermodynamic, nuclear magnetic resonance, infrared, and ultrasonic properties.

CHAPTER IV

CONDUCTION PHENOMENA IN DIELECTRIC SOLIDS

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I. Introduction

One of the prerogatives of the authors of any review is the choice of emphasis on those subjects in which the authors are particularly interested. The material covered here reflects, to some extent, just such a preference. The sheer quantity of literature published during the year 1964 which could be included under this general title precludes any completely general coverage in a reasonable-sized review. Hence, a selection was based upon a supposition on the interests of the readers of this volume. On this basis, the strongest interest was centered on materials generally considered as dielectrics and on theory most applicable to dielectric materials. The metals, as well as some other materials exhibiting metallic-like behavior, were in general not included. Likewise, no coverage was extended to the so-called wide-band semiconductors such as silicon and germanium on the assumption that adequate coverage of this subject is a separate work to be found in other sources. The intermetallic semiconductors were excluded on the same principle.

It will be noticed that there is a strong emphasis on organic materials. This concentration is a result of both the long-standing interests of the authors and of a world-wide increase in the amount of attention being given to the electrical properties of organic materials. There is considerably more novel, exploration work in the recent literature concerning the molecular-crystal and polymeric organic compounds than for any other single class of dielectric material. Where possible, all journals were covered from January to December, inclusive, except for those foreign-language journals for which English translations are available; here the date of the translated version was considered as the date of availability.

Research on the conductance properties of dielectric materials is definitely becoming more sophisticated. It is being realized that the description (experimental and theoretical) of electron transport in most dielectric materials is a quite complicated process and that naive interpretations contribute very little to our understanding.

The year was marked by a continuing development of theories for narrow-band and polaron transport descriptions of electron motion. These models have been shown to be particularly useful in many dielectric materials; for example, in some of the crystalline metal oxides and in organic molecular solids. Wide-band semiconductors usually exhibit a small temperature dependence in the Hall and drift mobilities, which are essentially equivalent. For the narrow-band systems, however, the temperature dependences are complex and often the mobilities derived from Hall or drift experiments are quite different. A detailed theory of these phenomena is lacking. Clearly, further progress will depend largely on the accumulation of data on the several kinds of dielectric phenomena for the same sample.

A fair amount of work is continuing on the study of induced currents in insulators. This property depends on the ionizing power of some form of external irradiation, X-rays, gamma rays, and neutrons are among the high-energy sources studied. Light and electron bombardment are more common ionizing media. These studies are particularly useful when the ionizing source is pulsed; the transient induced current is more susceptible to analysis than steady-state currents induced by continued illumination.

The transition metal oxides continued to be the subject of considerable interest. Of particular note were several papers concerned with the metal-to-semiconductor transition in the vanadium oxides. Adler and Feinleib suggest that the relationship between energy gap at 0°K and the transition temperature which describes the metal-to-semiconductor transition in antiferromagnets is also applicable to solids where the gap results from a crystal structure distortion. This is crystal structure distortion. This is consistent with the data for V_2O_3, which displays no magnetic ordering. Minomura and Nagasaki have studied the effect of pressure on the transition in V_2O_3 and V_2O_4, and Neuman, Lawson, and Brown have done the same for VO_2. In the latter case the phenomena are entirely consistent with Mott's theory of the metal-to-semiconductor transition.

A substantial fraction of the publications concerned with organic conductors is devoted to polymers. Electrical measurements on polymers were mainly done on powders with only a few exceptions where the samples could be obtained in film form. Sophisticated measurements are mainly reported on compounds which can be obtained in the form of single crystals of high purity. Examples are found among derivatives of aromatic hydrocarbons, phthalocyanines, charge transfer complexes and ion-radical salts. Anthracene is the most extensively studied compound.

II. General

A. Theory

1. Moorjani, K. and Feldman, C., Rev. Modern Phys. 36, 1042, 1964.
This article constitutes a good review of existing theory concerning the electrical properties of amorphous semiconductors. Many of the properties of the highly-regular crystalline compounds carry over into the glassy or amorphous phase.

2. Toombs, G. A., Proc. Phys. Soc. 84, 451, 1964.
Some previous treatments of electronic conductivity are inconsistent because factors of the conductivity tensor are evaluated by different expansion techniques. A unified technique, avoiding these inconsistencies, is expressed in terms of only three parameters: the energy shift and two relaxation time factors.

3. Kohn, W., Phys. Rev. 133, A171, 1964.
A new and more comprehensive characterization of the insulating state is presented, including the conventional insulators with energy gaps as well as systems discussed by Mott which, in band theory, would be metals. An appendix deals with a soluble model exhibiting a transition between an insulating and a conducting state.

4. Bogoroditskii, N. F. and Fridberg, I. D., Fiz. Tverd. Tela 6, 680, 1964. (Russian).
It is shown that existing views of the nature of continuous electrical conductivity in solid dielectrics are insufficient. A classification of possible mechanisms of continuous electrical conductivity is given, based on distinguishing the current carriers.

5. Bhagavantam, S. and Pantulu, P. V., Proc. Indian Acad. Sci. A 60, 1, 1964.
A group-theoretical method for studying the effect of crystal symmetry on physical properties is now extended to cover the galvanomagnetic, thermomagnetic and piezo-galvanomagnetic effects in single crystals. Such studies are of current interest and are expected to yield valuable new information.

6. Hubbard, J., Proc. Roy. Soc. A 277, 237, 1964.
A theory of correlation effects in narrow bands is generalized to apply to

narrow degenerate electron bands. The solution obtained has the important property of going over into the ordinary band theory solution in the appropriate limit (no interaction) and the exact atomic (Heitler-London) solution in the opposite limit (zero band width). The general properties of the solution are discussed in terms of some simple models.

7. Bordure, G., Lecoy, G., and Savelli, M., Cahiers Phys. 17, 1, 1963.
The authors review various methods for the determination of the characters of the irreducible representations of the group which leaves invariant the Hamiltonian for one-electron in a crystalline potential. An application is given for the case of Cu_2O.

8. Mandel, G., Morehead, F. F., and Wagner, P. R., Phys. Rev. 136, A826, 1964.
A calculation of the degree of self-compensation in a binary semiconductor is used to obtain a useful correlation between the degree of self-compensation by singly ionized natural defects and the ratio of the electronic energy gap to certain generally known thermodynamic quantities. It is shown that the gross electrical properties of the II-VI compounds can be completely correlated with a single parameter, the ratio of the tetrahedral covalent radii of the elements.

9. Lorenz, M. R., Phys. Letters 12, 161, 1964.
On the basis of the known electrical properties it now appears possible to make some predictions of the sign of the majority carriers in some groups of compounds based on the valence state of the more metallic of the constituent atoms.

10. Kahn, A. H. and Leyendecker, A. J., Phys. Rev. 135, A1321, 1964.
A theoretical examination of the electronic energy bands of cubic strontium titanate has been performed by application of the LCAO method. Comparison is made with experimental data on conductivity, Hall effects, and related phenomena.

11. Allnatt, A. R., J. Phys. Chem. 68, 1763, 1964.
An expression is derived for the ratio of the surface layer concentration to the bulk concentration for a substitutional divalent cation impurity in a univalent ionic conducting crystal at thermodynamic equilibrium.

12. Cohen, J., J. Appl. Phys. 35, 3056, 1964.
It is proposed that previous data on the conduction in thin films of BeO is best explained in terms of tunneling as opposed to Schottky emission. The Fowler-Nordheim treatment of the data is only applicable at high voltage; at low voltages, the tunneling current is Ohmic.

13. Tantraporn, W., Solid-State Electronics 7, 81, 1964.
A straight-forward numerical calculation is carried out for the energy distribution of the electron current from a metal into an insulator using the Sommerfeld and Bethe model, or a rectangular barrier modified by the image force. Formulae are developed for the total current density as a function of the electric field and temperature over a wide range. Specified conclusions, useful in the study of other solid-state thin-film devices, are made from the total current calculation.

14. Gundlach, K. H., Phys. Status Solidi 4, 527, 1964.
An equation is derived, applicable for all voltages, for the thermal-electron current through a thin dielectric layer. For high voltages, this equation tends to the known formula of Schottky, and for low voltages, it tends to a linear dependence. Intermediate voltages are discussed by example.

B. Polarons

15. Larsen, D. M., Phys. Rev. 133, A860, 1964.
Wave functions for a polaron in a uniform external electric field are calculated in the weak coupling approximation to first order in the electron-phonon interaction at zero temperature. The distortion of the wave function due to the field in typical crystals is small for reasonable values of the applied field.

16. Lang, I. G. and Firsov, Y. A., Fiz. Tverd. Tela 5, 2799, 1963. (Russian). Soviet Phys.-Solid State 5, 2049, 1964.
The mobility of small-radius polarons at low temperatures is calculated using methods previously described. The limits of applicability of the theory are established and the role of other scattering mechanisms is discussed. The mobility may be much lower than the minimum value obtained from the standard transport theory in the case of narrow bands.

17, Lang, I. G. and Firsov, Y. A., Zh. Eksper. Teor. Fiz. 45, 378, 1963. (Russian). Soviet Phys.-JETP 18, 262L, 1964.
A method introduced previously is used to show that the mobility has a minimum and then increases with decreasing temperature according to the law exp $(h\omega/kT)$.

18. Langreth, D. C. and Kadanoff, L. P., Phys. Rev. 133, A1070, 1964.
The low-temperature drift mobility of the polaron is calculated in perturbation theory with the aid of the Kubo formula. The result is compared with previous values.

19. Friedman, L., Phys. Rev. 135, A233, 1964.
A density-matrix treatment of small-polaron motion is presented for the case in which the electronic overlap term of the total Hamiltonian is a small perturbation. The principal result is that the mobility can be expressed as the sum of a band part, characteristic of the low-temperature regime, plus a part describing the hopping motion dominant at high temperatures.

20. Nagaev, E. L., Fiz. Tverd. Tela 5, 2380, 1963. (Russian). Soviet Phys.-Solid State 6, 1734, 1964.
The author discusses the small-radius polaron for two conduction mechanisms: a nearly-pure Einstein phonon spectrum and a phonon spectrum very different than Einsteinian.

21. Siebrand, W., J. Chem. Phys. 41, 3574, 1964.
The author considers the interaction of intramolecular vibrations with carrier transport in crystals of several diatomic molecules and some condensed aromatic hydrocarbons. He predicts correctly that the hole will be much more

mobile than the electron in iodine. He also shows that polaron considerations are necessary to reconcile the experimental mobility data for iodine, anthracene, naphthalene, and pyrene with their respective band structures.

22. Friedman, L., Phys. Rev. 133, A1668, 1964.
The electrical and thermal-transport coefficients of a large class of organic crystals are calculated from a Boltzmann equation treatment of narrow-band semiconduction. The latter, in turn, is based on the known tight-binding band structure of these crystals. Among other parameters, the Hall constant is found to be anomalous both in magnitude and sign.

23. Choi, S. I., J. Chem. Phys. 40, 1691, 1964.
As a result of theoretical comparisons of rates of exciton ionization by photon absorption and ionization through double exciton interactions, it is concluded that the double exciton process was very dominant in some high-intensity photoconduction studies on anthracene.

24. Taylor, P. L., Phys. Rev. 135, A1333, 1964.
A small proportion of the events in which a conduction electron is scattered by an impurity atom involve the emission or absorption of a phonon. The effect of such processes on the electrical resistivity is found to be too small to be observable.

C. Photoconduction and Space-charge Effects

25. Keating, P. N., Phys. Rev. 135, A1413, 1964.
Further understanding of the double-injection mechanism of current flow in insulators has been obtained by a theoretical treatment, largely based on a theory by Lampert, which allows an arbitrary thermal-equilibrium occupancy of the recombination centers and also shallow trapping of both carriers.

26. Lee, V. J. and Mason, D. R., J. Appl. Phys. 35, 1557, 1964.
Analytical expressions are derived which relate the incremental electrical conductivity in an accumulation layer on a semiconductor to the concentration of surface ions. The theory is checked by comparing the predicted results with published graphs.

27. Shumka, A. and Nicolet, M. A., Solid-State Elec. 7, 106, 1964.
The analysis of space-charge-limited currents assuming that the field velocity is proportional to $\mu E^{(1/n)}$ where $n \geq 1$. The cases of $n = 1$ and $n = 2$ lead to results obtained previously by other workers.

28. Ward, A. L., J. Appl. Phys. 35, 469, 1964.
Numerical machine calculations have been made on the effect that space charge, composed of mobile charge carriers, has on the drift and diffusion of those carriers in an electric field. An apparent diffusion of carriers arises from the different equations used to solve the transport problem, even though no diffusion term is included in the transport equations.

29. Rose, A., J. Appl. Phys. 35, 2664, 1964.
The several models for double injection of electrons and holes into solids

are shown to fall into three groups: field-dominated, diffusion-dominated, and hybrid models. For all of the models reviewed, solutions for the current-voltage relations are obtained within a factor of two by relatively simple physical arguments.

30. Lampert, M. A. and Edelman, F., J. Appl. Phys. 35, 2971, 1964.
The theoretical problem of a one-carrier, space-charge-limited current flow is beyond the reach of analytical solutions when trapping and diffusion are included in the analysis. However, the problem for the semi-infinite solid very generally lends itself to rather simple numerical solution on a digital computer. Detailed solutions are obtained for several special cases of the trap-filled insulator.

31. Litovchenko, V. G., Ukrayin. Fiz. Zh. 8, 1117, 1963. (Russian).
Theoretical relations are derived for the kinetics of monopolar non-equilibrium conductivity. The specific effect of the surface space charge on the free carrier lifetime is discussed.

32. Fridkin, V. M. and Tikhomirova, N. A., Phys. Status Solidi 6, K73, 1964.
On the basis of a simple phenomenological model, an expression is derived for the relationship between the hydrostatic pressure, electron-lifetime, the band gap, and the photoconductivity of semiconductors.

33. Stöckmann, F., Z. Physik 180, 184, 1964.
The current-voltage characteristics of trap-free photoconductors with ohmic contacts are calculated for large applied voltages. It is shown that under the assumed general conditions one obtains essentially the same expressions for the saturated parts of the photocurrent as were found earlier for low excitation rates and neutral contacts.

34. Titov, R. A., Fiz. Tverd. Tela 5, 3480, 1963. (Russian). Soviet Phys.-Solid State 5, 2553, 1964.
For the case of a simple semiconductor model, an analytical expression was obtained for the spectral distribution of photoconductivity in the presence of two independent absorption mechanisms not contributing similarly to the internal photo effect. The form of the photoconductivity spectrum is calculated for a number of characteristic cases.

35. Hole, W. L., J. Opt. Soc. Amer. 54, 1380, 1964.
The author lists, and very briefly reviews, a dozen papers, some of which are half a century old, which were concerned with variations in the conductance of a photoconductive cell with changes in the light distribution.

36. See reference 315.

37. Rosenberg, B., Heck, R. J., and Aziz, K., J. Opt. Soc. Amer. 54, 1018, 1964.
A photovoltaic effect and photoconductivity, each with its own spectral response curve, occur simultaneously in a β-carotene cell. The two effects produce currents in opposite directions and with different response times.

D. Experimental

38. Freeman, G. R., J. Chem. Phys. 39, 3537, 1964.
The X-ray-induced conductance in solids is proportional to the z-th power of the beam intensity, where $0.5 \leq z \leq 1.0$. Some previously reported measurements in solids were probably spurious and due to leakage currents.

39. Harrison, S. E., Coppage, F. N., and Snyder, A. W., IEEE Trans. Nuclear Sci. NS-10, 118, 1963.
The time dependent relationships between electrical conductivity of insulators are discussed for steady irradiation with gamma rays and for pulsed neutrons and gamma rays. The theory of the effect is discussed with graphical and tabular presentation of the results.

40. Veith, H., Nachrichtentech. Fachber. 29, 83, 1964.
The absorption of moisture in insulators is considered for equilibrium conditions. The effects on diffusion, changes in dielectric constant and loss, and their time dependences are considered.

41. Fridrikhov, S. A., Smirnov, P. V., and Serebrov, L. A., Fiz. Tverd. Tela 6, 1343, 1964.
The specific pecularities of two basic experimental methods for studying the longitudinal electron-excited conductivity in dielectric materials were investigated. Electron-excited conductivity was studied in thin films of NaCl and mica by the electric contact methods, thereby determining the intensity of the internal space charge, the trap concentration, and the lifetime-mobility product of the carriers.

42. Watson, P. K. and Sharbaugh, A. H., Rev. Sci. Inst. 35, 1310, 1964.
A new technique was developed for measuring small conduction currents due to microsecond voltage pulses. It uses a charge-storing technique in which the conduction current through a sample is integrated on a capacitor whose voltage is measured after the high-voltage pulse is terminated.

43. Mircea, A., J. Sci. Instr. 41, 679, 1964.
The conformal transformation of a square into a circle is used to solve the problem of the electric field distribution arising from four-point resistivity measurements on square wafers. Some previously reported results are shown to be incorrect.

44. Krempasky, J., Czech. J. Phys. B 14, 533, 1964.
A new method of measuring the thermal and thermoelectric characteristics of materials, especially semiconductors, is elaborated theoretically and experimentally. A special advantage claimed for the methods is that they are quick.

45. Dorcas, D. S. and Scott, R. N., Rev. Sci. Instr. 35, 1175, 1964.
Instrumentation for measuring the dc conductivity of alkali halide crystals and other high-resistivity materials in the temperature range 20-200°C is described. Conductivity as low as 2×10^{-18} ohm^{-1}cm^{-1} was measured with an estimated accuracy of five percent.

46. LaFlamme, P. M., Rev. Sci. Instr. 35, 1193, 1964.
Describes the construction, calibration, and performance of a simple electrical conductivity cell for use in measuring the electrical conductivity-temperature relationship of organic semiconductors and related materials. The cell allows operation is a vacuum or inert gas atmosphere over a considerable temperature range.

47. Kon'kov, V. L., Fiz. Tverd. Tela 6, 304, 1964. (Russian). Soviet Phys.-Solid State 6, 244, 1964.
Presents equations for the bulk conductivity derived from measurements using four surface probes.

48. Kon'kov, V. L., Fiz. Tverd. Tela 6, 308, 1964. (Russian). Soviet Phys.-Solid State 6, 247, 1964.
Equations are derived relating voltages measured on surface probes to the Hall effect.

49. Lange, J., J. Appl. Phys. 35, 2659, 1964.
A method for measuring Hall mobility and resistivity in thin layers of semiconducting materials uses four contacts near the center of a sample that is large in comparison to the contact spacing. Other arrangements are discussed.

50. Firsov, Y. A., Fiz. Tverd. Tela 5, 2149, 1963. (Russian). Soviet Phys.-Solid State 5, 1566, 1964.
The Hall effect in semiconductors having low mobility is treated in some detail. In particular, the relationships between the Hall mobility and the drift mobility are considered. It is shown that there is a maximum in the Hall mobility at a temperature near the point of minimum drift mobility.

51. Green, M., J. Appl. Phys. 35, 2689, 1964.
A pressure theory of the thermoelectric and photovoltaic effects are developed, in which the free charge carriers and phonons exert a pressure inside the solid. The results of this theory are not directly expressible in terms of conventional electrical parameters so that it is difficult to evaluate its usefulness.

52. Nadjakov, G. and Andreichin, R., Izv. Fiz. Inst. ANEB 8, 5, 1960.
A contact potential photovoltaic-effect was discovered by the authors. If two ohmic contacts of different materials are deposited onto a uniformly illuminated semiconductor, then an e.m.f. and a current flow is observed due to the contact potential difference between the electrodes.

53. Chetkarov, M. L., Izv. Fiz. ANEB 8, 33, 1960.
In a theory of the photoelectret-effect, the author assumes that a part of the electrons generated in the conduction band gradually fall in the surface traps and create a space volume electric charge inside the dielectric. The theory is compared with measurements on a rhombic sulfur photoelectret.

54. Khanderek, Y. I., Fiz. Tverd. Tela 5, 2517, 1963. (Russian). Soviet Phys.-Solid State 5, 1839, 1964.
In a treatment of the problem of electret polarity reversal, the author shows that the time taken for the heterocharge in a beeswax electret to transform

into the homocharge depends on the conditions of polarization as well as the conditions of storage. The results of several experiments are well explained by the developments of this hypothesis.

55. Abe, R., Progr. Theoret. Phys. 31, 957, 1964.
A nonlinear theoretical treatment of current saturation observed in a piezoelectric semiconductor such as CdS or ZnO is discussed. The resultant current-voltage relation is shown to have a kink character consistent with experimental results.

56. Penn, A. W., J. Sci. Instr. 41, 626, 1964.
A dc current flowing in a thermoelectric material produces a potential and a thermal gradient. It is shown that the use of probes inset from the sample ends allows quick and accurate determination of the pertinent parameters of the effect.

57. Dieleman, J., Ned. Tijdschr. Natuurk. 30, 25, 1964.
The applications of electron-spin resonance (ERP) to the study of photoconductors and phosphors is discussed in some detail.

58. Eckstein, S. G., J. Appl. Phys. 35, 2702, 1964.
General expressions for the acoustoelectric current in the presence of external electric and magnetic fields have been derived. The Weinreich relations are valid for carriers of only one sign, but are not valid for semimetals.

59. Jaffe, B. M. and Kallmann, H. P., J. Amer. Chem. Soc. 86, 3428, 1964.
The theory of the ac impedance or of the apparent dielectric constant of poor conductors has been revised, taking into account the diffusion of charges inside the conductor. The equation for the capacity of the whole system is augmented by terms which contain the effective penetration depths of the field into the conductor, which is closely connected to the Debye lengths.

60. Pollack, M., Phys. Rev. 133, A564, 1964.
A previous approximation of the ac impurity hopping conduction in the high-temperature, low-concentration limit is extended to low temperatures and high concentrations.

61. Lacam, A. and Lallemand, M., J. Physique 25, 402, 1964.
The authors present a review of various treatments of the influence of hydrostatic pressure on the electrical conductivity of solids. The characteristic effect of the pressure is dependent on the nature of the solid (metal, semiconductor, or ionic crystals).

62. Drickamer, H. G., Science 142, 1429, 1963.
In this review article the use of the pressure (of up to 500 atmospheres) in elucidating the electronic structure of solids is discussed. Data on the optical absorption and electrical resistivity combine to illustrate the mechanisms whereby an insulator or a semiconductor becomes metallic.

63. See reference 97.

III. Inorganic Materials

A. Elements

1. Sulphur

64. Mead, C. A., Phys. Letters (Netherlands) 11, 212, 1964.
From photoconductivity measurements on a solution-grown crystal, an energy gap of 3.82 ± 0.02 eV was deduced. Both holes and electrons are mobile.

65. Admans, A. R. and Spear, W. E., J. Phys. Chem. Solids 25, 1113, 1964.
Drift mobility measurements were made on solution-grown crystals (composed of S_8 rings) which yielded a hole mobility of 10 cm^2/volt-sec at 300°K. The electron lifetime was estimated to less than five nanoseconds.

66. Adams, A. R., Gibbons, D. J., and Spear, W. E., Solid State Communications 2, 387, 1964.
Electron transport studies in orthorhombic sulfur crystals gave a drift mobility of $5.5 \times 10^{-4} cm^2$/volt-sec at 19°C. An interpretation in terms of an intermolecular hopping mechanism is given.

67. Nadzhakov, G., Antonov, A., and Zadorozhnyi, G., C. R. Acad. Bulg. Sci. 15, 723, 1962.
The assumption that the application of high electric fields to monocrystalline sulfur produces an ion absorption on the crystal surface, and the ions are transformed into peculiar shallow traps, is confirmed.

68. Tikhomirova, N. A. and Fridkin, V. M., Fiz. Tverd. Tela 5, 2709, 1963. (Russian). Sov. Phys.-Solid State 5, 1980, 1964.
Application of pressures up to 10,000 atm raised the photoconductivity of sulfur single crystals in a superlinear manner. The results are interpreted in terms of an increase in the carrier lifetime.

69. Ribeiro, S. C. and Murphy, P. V., Ann. Acad. Brasil. Cienc. 35, 159, 1963.
Single crystals of rhombic sulfur (dark conductivity less than 5×10^{-18} ohm cm^{-1}) were exposed to Sr^{90} beta rays. The induced conductivity was proportional to beta-ray dose rate and to electric field; the induced conductivity was 3×10^{-13} ohm cm^{-1} at 590 rad-mm^{-1}.

70. Nadzhakov, G., Antonov, A., Zadarozhnyi, G., Konova, A., Pakeva, S., and Yuskeselieva, L., C. R. Acad. Bulg. Sci. 17, 365, 1964.
Small plates of artificial single-crystal sulfur were subjected to fields of up to 4000 V and illuminated for periods of a few minutes. After illumination, the current decay was measured and the results interpreted in relation to the photo-electret properties of sulfur and the sulfur-mica combination.

2. Selenium

71. Korsunskii, M. I. and Pastushuk, N. S., Fiz. Tverd. Tela 6, 254, 1964. (Russian). Soviet Phys.-Solid State 6, 202, 1964.
It is shown that the anomalous photoconductivity in a selenium layer, illuminated with strongly absorbed light, is uniform throughout the layer's thickness.

72. Stuke, J., Phys. Status Solidi 6, 441, 1964.
Changes in the temperature and voltage dependence of conductivity, induced by plastic deformation, are investigated for hexagonal selenium single crystals. From thermal e.m.f. measurements, the hole concentration is found to be essentially constant down to -180°C.

73. Dresner, J., J. Phys. Chem. Solids 25, 505, 1964.
The photo-Hall effect has been measured in the insulating vitreous form of selenium. The mobility for electrons $\mu_{on} = 0.32$ cm^2/volt-sec at 20°C, for holes $\mu_{op} = \mu_{Dp} = 0.15$.

74. Lottahammer, R., Polke, M., and Stockman, F., Z. Phys. 176, 429, 1963.
Evaporated layers of hexagonal selenium were excited with modulated light and the alternating photocurrent studied as a function of the saturation applied field. The results show the effects of charge carrier trapping on the photocurrent.

75. Regel, A. R. and Tagiev, B. G., Fiz. Tverd. Tela USSR 5, 2914, 1963. (Russian). Soviet Phys.-Solid State 5, 2135, 1964.
The electrical conductivity of pressed selenium samples of 99.99999% purity was investigated in strong electric fields up to 30,000 V/cm from 77-293°K. The results are well represented by $\sigma = \sigma_0 \exp(\beta \sqrt{E})$, where $\beta \approx 1/T$.

76. Abdullaev, G. B., Aliev, G. M., Barkinkhoev, K. G., Askerov, C. M., and Larionkina, L. S., Fiz. Tverd. Tela 6, 1018, 1964. (Russian).
The electrical conductivity and thermal e.m.f. of ordinary and deoxygenated selenium (both crystal and liquid) were measured from 293-773°K. Different discontinuities in the conductivity were determined in ordinary selenium during melting. The activation energy of conduction for liquid selenium is 2.05 eV.

77. Regel, A. R. and Tagiev, G. B., Fiz. Tverd. Tela 6, 1001, 1964. (Russian).
The electrical conductivity of polycrystalline selenium was investigated by a pulse technique in fields up to 40,000 V/cm from -130 to 20°C. The introduction of bismuth up to 0.1% increases the conductivity but further amounts decreases the conductivity.

78. Regel, A. R. and Tagiev, B. G., Fiz. Tverd. Tela 6, 1424, 1964. (Russian).
In a continuation of the work described in the preceding reference, the addition of cadmium, tellurium, sulfur, and iodine effected similar results.

79. Khodosevich, P. K. and Kolomiets, B. T., Fiz. Tverd. Tela 6, 1325, 1964. (Russian).
Photoconductivity measurements on polycrystalline selenium were interpreted in terms of shallow and deep traps in the forbidden band of selenium.

3. Tellurium

80. Chapotovich, E. E., Soviet Phys.-Solid State 6, 495, 1964. (Russian).
Measurements of changes in the energy gap in tellurium with hydrostatic

pressure gave -1.0 to -1.3 x 10^{-5} eV/atm for annealed single crystals and -1.6 x 10^{-5} eV/atm without annealing.

81. Vis, V. A., J. Appl. Phys. 35, 365, 1964.
The electrical noise of carefully-prepared single crystals was measured in the extrinsic temperature range. The effect of temperature variations on the noise power spectrum is interpreted quantitatively as the result of transitions between the valence band and four species of traps lying 0.045 eV above it.

82. Vis, V. A., J. Appl. Phys. 35, 360, 1964.
Measurements of the steady-state and transient photoconductive behavior of single-crystal tellurium in the extrinsic range are presented and interpreted in terms of a simple trapping model. Details of the sample preparation process are given.

83. Schwartz, M., Hockensmith, D., and Eisenberg, L., Phys. Letters 11, 11, 1964.
A modulated electric field was applied across capacitors formed of 1000-angstrom tellurium films on mica substrates. Its effect on the conductivity and Hall voltage in the tellurium film was observed--for each, about a 10% change was generated by a 1380-volt potential.

4. Other Elements

84. Wolff, P. A., J. Phys. Chem. Solids 25, 1057, 1964.
A two-band model is used to investigate the wave functions and matrix elements for electrons in bismuth. The results are in agreement with some magnetooptic experiments.

85. Ivanov, G. A., Fiz. Tverd. Tela 5, 3173, 1963. (Russian). Soviet Phys.-Solid State 5, 2322, 1964.
This paper presents experimental data on the Hall effect and resistivity of single crystals of solid solutions of tellurium in bismuth in the temperature range 77-300°K. The concentration and mobility of electrons in these alloys were determined.

86. Ursu, I., Weissmann, E., and Szentgyörgyi, P., Rev. Roumaine Phys. 9, 447, 1964.
The electrical properties of the nickel-chromia system and their correlation with catalytic activity were studied.

87. Many, A., Simhony, M., Weisz, S. Z., and Teucher, Y., J. Phys. Chem. Solids 25, 721, 1964.
Transient space-charge-limited photocurrents in iodine single crystals were studied along the three principal axes. The room-temperature mobilities are $\mu_a = 2.3$, $\mu_b = 0.72$, and $\mu_c = 2.1$ cm^2/volt-sec; the temperature dependence is as $1/T^n$, where n = 1.5, 1.3, and 2.1, respectively.

88. Gerstenberg, D. and Calbick, C. J., J. Appl. Phys. 35, 402, 1964.
A thorough investigation of the electrical properties was made for tantalum films sputtered in argon containing small amounts of nitrogen, methane or oxygen.

89. Warschauer, D. M., J. Appl. Phys. 35, 3516, 1964.
The electrical and mechanical properties of polycrystalline black phosphorus make it potentially useful for strain and hydrostatic gauges, and other transducer uses. The advantages and disadvantages are discussed briefly.

90. Mattheiss, L. F., Phys. Rev. 133, A1399, 1964.
Energy bands are calculated for argon using the augmented plane-wave method. The present calculation yields a band gap of 13.3 eV, which is in fair agreement with the experimental value of 14.3 eV.

91. Brungs, R. A. and Jacobsmeyer, V. P., J. Phys. Chem. Solids 25, 701, 1964.
Electrical and optical experiments were performed on relatively large but impure single crystals of the beta-rhombohedral form of boron. All samples had a high resistivity (about 10^8 ohm-cm) and room temperature was decreased by a factor of 10^8 at 750°K.

B. Oxides

Except for the first two references, which are general, the listing for the oxides is ordered according to the position of the cation in the periodic table. The column of the periodic table is given in parentheses after the reference number, with the rare earth and actinide oxides listed separately at the end of the section. Mixed oxide systems are cross-referenced.

92. Hannay, N. B., Semiconductors (Academic Press, New York and London, 1963). pp. 409-423.
A review paper concerned with the state of the art in the study of the transition metal oxides. Band formation and crystal field theory are discussed. A classification of oxides into metals, semiconductors, and insulators is presented. A review of the electrical behavior of metallic 3d oxides is given both for materials with formation of an energy band and for materials without energy band formation.

93. Kevane, C. J., Phys. Rev. 133, A1431, 1964.
Oxygen vacancies and their effects on conduction in some metal oxides are considered through an exact solution of the equilibrium relations between O_2 partial pressure and concentrations of oxygen vacancies and conduction electrons in the solid. The results, which possess considerably complexity not contained in the usual limiting-case solutions, are compared with pertinent experiments.

94. (I) Vorob'ev, Yu. V., Soviet Phys.-Solid State 6, 1391, 1964.
The excitation of nonlinear photoconductivity in Cu_2O was studied in various regions of the spectrum. The phenomenon is attributed to a change in recombination cross section with illumination.

95. (I) Peka, G. P., Soviet Phys.-Solid State 5, 1473, 1964.
Considerable reversible reduction in luminescence and resistivity occurs upon absorption of air on Cu_2O. Moist air is more effective than dry.

96. (I) Fortin, E. and Weichman, F. L., Phys. Status Solidi 5, 515, 1964.
The spectral distribution of photoconductivity in Ag_2O depends upon the mode of sample preparation and previous illumination.

97. (II) Mitoff, S. P., J. Chem. Phys. 41, 2561, 1964.
A method was devised for transport number measurements which is similar to the guard ring technique for conductivity. The electronic component of conductivity in MgO, which dominates above 1000°C, is a bulk phenomenon.

98. (II) Surplice, N. A. and Jones, R. P., Brit. J. Appl. Phys. 15, 639, 1964.
Conductivity and thermoelectric power of CaO and MgO was measured. The sign of the thermoelectric power for both corresponded to n-type conductivity.

99. (II) Zirkin, P. and Freeman, E. S., J. Chem. Phys. 41, 906, 1964.
Upon gamma irradiation of MgO the conductivity increases but the activation energy is unchanged, suggesting that the radiation increases the number of carriers without changing the conduction mechanism.

100. (II) Strickler, D. W. and Carlson, W. G., J. Amer. Ceram. Soc. 47, 122, 1964.
The ionic conductivity of cubic solid solutions in the system $CaO\text{-}Y_2O_3\text{-}ZrO_2$ was examined.

101. (II) Johansen, H. A. and Cleary, J. G., J. Electrochem. Soc. 111, 100, 1964.
The ac conductivity of the systems $CaO\text{-}ZrO_2$ and $CaO\text{-}Hf_2O$ are similar, both showing conductivity maxima near 12 mole % CaO.

102. (II) Dudkowski, S. J. and Grossweiner, L. I., J. Opt. Soc. Amer. 54, 486, 1964.
The conductivity in a ZnO thin film is increased by light absorption in an adjacent layer of cosin (Na), and measurements with voltaic couples show that charge transfer occurs across the interface.

103. (II) Hotchkiss, D. R., J. Appl. Phys. 35, 2455, 1964.
Photoconductivity in ZnO was excited with a 6935A laser and attributed to bulk phenomena.

104. (II) Mesnard, G. and Eyman, C., Compt. Rend. 258, 3672, 1964.
ZnO crystals were doped with Na, Li, and Cu. Conductivity, optical and IR absorption, and dielectric properties were studied.

105. (II) Watanabe, H., Wada, M., and Takahashi, T., J. Appl. Phys. (Japan) 10, 617, 1964.
Transmission in the region of the absorption edge as a function of temperature was investigated for ZnO. An effective mass of (0.06 to 0.14) m_0 resulted using the classical expression for the free carrier absorption. An electron affinity of 1.3 eV was deduced from the photoelectric threshold.

106. (II) Mazelsky, R. and Kramer, W. E., J. Electrochem. Soc. 111, 528, 1964.
$Cd_2Nb_2O_7$ has a large ionic contribution to its conductivity while the conductivity in $Pb_{1.5}Nb_2O_{6.5}$ is almost exclusively electronic. Mass action equations describing the generation of electronic carriers are derived, and equilibrium constants and the energies involved in the conduction process are calculated.

107. (III) Champion, J. A., Brit. J. Appl. Phys. 6, 633, 1964.
The electrical conductivity of Al_2O_3 crystals with varying Cr content has an activation energy of about 0.5 eV in the range 200°-450°C and about 1.7 eV in the range 450°-850°C.

108. (III) Hickmott, T. W., J. Appl. Phys. 35, 2118, 1964.
The conductivity of Al-Al_2O_3-metal diodes depends upon the impurities in the oxide and on the metal used as the counterelectrode.

109. (III) Hochuli, U. E., Phys. Rev. 133, A468, 1964.
Weak photoconductivity was observed in Al_2O_3 and attributed to the excitation of electrons from occupied impurity levels to the conduction band.

110. (III) Nakai, J. and Miyazaki, T., Technol. Rep. Osaka Univ. 13, 321, 1964.
Tunneling was observed in metal-Al_2O_3-metal diodes.

111. (III) Nakai, J. and Miyazaki, T., J. Appl. Phys. (Japan) 3, 677, 1964.
Tunneling in metal-Al_2O_3-metal diodes was studied. The barrier height of the diode was estimated as 2.2 eV from a photosensitization measurement. The surface potential of the insulator was found to be 3.6 eV.

112. (III) See reference 72.

113. (III) Remeika, J. P. and Spencer, E. G., J. Appl. Phys. 35, 2803, 1964.
The conductivity of In_2O_3 was measured down to 4.2°K. An anomaly was observed at about 100°K.

114. (III) Weiher, R. L. and Dick, B. G., Jr., J. Appl. Phys. 35, 3511, 1964.
The magnetoresistance of n-type In_2O_3 is consistent with the "warped-spherical" or the "many-valley" model for the conduction band structure.

115. (III) See reference 100.

116. (III) See reference 101.

117. (III) See reference 120.

118. (IV) Hickmott, T. W., J. Appl. Phys. 35, 2679, 1964.
Al-SiO_2-Al-SiO_2-Au triodes with SiO_2 thicknesses between 150 and 500 Å were used to measure the potential distribution in thin oxide films before, during,

and after the development of voltage-controlled negative resistance in the current-voltage characteristics.

119. (IV) Hirose, H. and Wada, Y., J. Appl. Phys. (Japan) 3, 179, 1964.
The conductivity of vacuum-deposited SiO_2 films increases with increasing oxidation. The dc conductivity is attributed to diffusion of free Si ions.

120. (IV) MacChesney, J. B. and Johnson, G. E., J. Appl. Phys. 35, 2784, 1964.
The room temperature dielectric properties of fast-neutron-irradiated fused SiO_2 and α-Al_2O_3.

121. (IV) Wales, R. D., J. Electrochem. Soc. 111, 478, 1964.
Measurements were made of the capacitance, dielectric loss, and resistivity of GeO_2 films prepared by anodic oxidation of Ge.

122. (IV) Acket, G. A. and Volger, J., Phys. Letters 8, 244, 1964.
Specific resistivity and Hall constant measurements were made on slightly reduced TiO_2 between room and liquid N_2 temperatures. The Hall constant changes from complicated behavior at 10^2 ohm-cm to simpler behavior at higher resistivities.

123. (IV) Acket, G. A. and Volger, J., Physica 30, 1667, 1964.
The conductivity and Hall constant of reduced TiO_2 doped with 100 p.p.m. Al_2O_3 were measured from 80° to 300°K. The effective mass of the charge carriers was estimated to lie in the range 3-5 m_0, much lower than previous values.

124. (IV) Bogomolov, V. N. and Shavkunov, P. M., Soviet Phys.-Solid State 5, 1481, 1964.
The mobility anisotropy in partially reduced TiO_2 is shown to be independent of the amount of reduction.

125. (IV) Bogomolov, V. N. and Zhuze, V. P., Soviet Phys.-Solid State 5, 2404, 1964.
Conductivity and Hall constant were measured parallel and perpendicular to the c-axis of oriented single crystals of slightly reduced TiO_2 in the range 78°-700°K. The conductivity anisotropy is due to the anisotropy of carrier mobility. The ratio of Hall to drift mobilities is different in magnitude and has a different temperature dependence in the different crystal orientations, indicating that TiO_2 has a complex energy spectrum.

126. (IV) Denker, S. P., J. Phys. Chem. Solids 25, 1397, 1964.
The relationship between bonding and the electronic band structure is examined theoretically and it is found that a high equilibrium lattice vacancy concentration is energetically favorable for TiO_2.

127. (IV) Dorin, V. A. and Patrakova, A. Ya., Soviet Phys.-Solid State 5, 1506, 1964.
The electrical properties of Ag contacts to partially reduced TiO_2 are unchanged when a thin insulating layer intervenes between the semiconductor and the metal.

128. (IV) Hasiguti, R. R., Kawamiya, N., and Yagi, E., J. Phys. Soc. (Japan) 19, 573, 1964.
Reduced TiO_2 has four distinct conductivity regions each with a different activation energy between 3° and 30°K.

129. (IV) Ishikura, O. and Sakata, T., J. Appl. Phys. (Japan) 3, 498, 1964.
Room temperature values of resistivity, carrier concentration, and Hall mobility were determined for hot-pressed TiO_2 specimens doped with Nb_2O_5 and Ta_2O_5 in concentrations varying from 0.1 to 1%.

130. (IV) Keezer, R., J. Appl. Phys. 35, 1866, 1964.
Absorbed O_2 increases both the response and the response time for the photovoltaic effect in TiO_2. A model is given for the effect of chemisorbed oxygen on the photoconductivity which takes into account the effect of oxygen pressure.

131. (IV) Keezer, R., Mudar, J., and Brown, D. E., J. Appl. Phys. 35, 1868, 1964.
The ultraviolet photovoltaic response of barrier layer cells formed from single-crystal TiO_2 was investigated. The effect of surface treatment on cell characteristics is discussed.

132. (IV) Kunin, V. Ya., Sedunov, Yu. N., and Tsikin, A. N., Soviet Phys.-Solid State 5, 2028, 1964.
Upon electrical aging the conductivity type in ceramic TiO_2 changed from p- to n-type.

133. (IV) Lal, H. B. and Srivastava, K. G., Phys. Letters 10, 258, 1964.
Discussed conduction in reduced TiO_2.

134. (IV) Yahia, J., J. Phys. Chem. Solids 25, 881, 1964.
A combination of thermogravimetric and conductivity data can yield a value of carrier mobility, and values were calculated in this way for TiO_2 from 860° to 1050°C and for Nb_2O_5 from 900° to 1400°C. The mobilities for both substances are low, 5×10^{-5} for TiO_2 and 7×10^{-3} cm^2/V-sec for Nb_2O_5 (at 1200°K), and for both the mobility increases with increasing temperature.

135. (IV) Anthony, A. M., Cabannes, F., and Renon, J., Ann. Phys. 9, 1, 1964.
Conduction in the system $ZrO_2 - La_2O_3$ with 5-33% La_2O_3 was studied as a function of temperature, frequency, time, and oxygen pressure. Three distinct conduction mechanisms are postulated to account for the results.

136. (IV) Tien, T. Y., J. Appl. Phys 35, 122, 1964.
The effect of microstructure on the ionic conductivity of $Zr_{0.84}Ca_{0.16}O_{1.84}$ ceramics was investigated. At low temperatures the specimens with smaller grain size exhibited a higher conductivity, whereas at temperatures greater than 1000°C the effect of grain size is insignificant.

137. (IV) See reference 101.

138. (IV) See reference 106.

139. (IV) See reference 71.

140. (V) Zolyan, T. S. and Regel, A. R., Soviet Phys.-Solid State 5, 1762, 1964.
Conductivity and thermoelectric power of Bi_2O_3 were measured in the solid and liquid up to 1000°C. The conductivity increased by three powers of ten on transformation from the alpha to the beta phase, while melting resulted in only a two-fold increase. An ionic component contributes to the conductivity of the beta phase.

141. (V) Adler, D. and Feinleib, J., Phys. Rev. Letters 12, 700, 1964.
It is suggested that the relation (energy gap at 0°K/kx transition temperature) = 7.1, which describes the semiconductor-to-metal transition in antiferromagnets, also is applicable to materials where the gap results from a crystal structure distortion. This is checked for V_2O_3, which does not display magnetic ordering. It is shown that the observed energy gap and transsition temperature are consistent with a reasonable band model for V_2O_3.

142. (V) Gemus, D. M., Ukrayin. Fiz. Zh. 8, 954, 1963. (Russian).
Band theoretical investigation shows that the maximum of the valence band probably occurs at high symmetry points, Γ or Z, for V_2O_5.

143. (V) Haemers, J., Compt. Rend. 259, 3740, 1964.
Measured conductivity of V_2O_5 with evaporated Ag electrodes. At high temperatures Ag diffuses into the crystal giving additional impurity conduction.

144. (V) Kachi, S., Takada, T., and Kosuge, K., J. Phys. Soc. Japan 18, 1839, 1964.
Conductivities of several phases of the V_2O_3 - V_2O_5 system were measured in the vicinity of their Neel temperatures. Three classes are distinguished, showing either a discontinuous change in conductivity, an abrupt change, or no significant change.

145. (V) Minomura, S. and Nagasaki, H., J. Phys. Soc. Japan 19, 131, 1964.
From the effect of pressure on the metal-to-semiconductor transition it is concluded that the transition in V_2O_4 is second order, that in V_2O_3 is first order.

146. (V) Neuman, C. H., Lawson, A. W., and Brown, R. F., J. Chem. Phys. 41, 1591, 1964.
The resistance of VO_2 through the metal-to-semiconductor transition was measured as a function of pressure. The relation between the pressure dependence of the energy gap in the semiconducting state and the pressure dependence of the transition temperature is consistent with Mott's mechanism.

147. (V) Zoylan, T. S. and Regel, A. R., Soviet Phys.-Solid State 6, 1189, 1964.
Conductivity and thermoelectric power was measured in V_2O_5 in the solid and liquid at temperatures up to 1100°C. Effect of impurities (Al, Cu, Sn, Te, and In) on the electrical properties was also investigated.

148. (V) Ornatskaya, Z. I., Soviet Phys.-Solid State 6, 978, 1964.
Conductivity, thermoelectric power, and Hall effect were measured for vanadium oxide bronzes $M_xV_2O_5$, where M = Na, Li, Cu, and Ag.

149. (V) Smyth, D. M., Shirn, G. A., and Tripp, T. B., J. Electrochem. Soc. 110, 1264, 1963.
When anodized Ta is subjected to temperatures in excess of 200°C, the equivalent series capacitance and resistance change. This is interpreted as extraction of oxygen from the oxide dielectric by the Ta substrate.

150. (V) Standley, C. L. and Maissel, L. I., J. Appl. Phys. 35, 1530, 1964.
The electrical properties of several Ta_2O_5 diodes with various metal counter-electrodes were studied.

151. (V) See reference 40.

152. (V) See reference 162.

153. (VI) Crawford, J. A. and Vest, R. W., J. Appl. Phys. 35, 2413, 1964.
Conductivity of Cr_2O_3 was measured from 600° to 1400°C and as a function of O_2 pressure from 10^{-6} to 1 atm. At high temperatures the conductivity is intrinsic and independent of O_2 pressure, at low temperatures it is defect controlled and varies with O_2 pressure. The low mobility deduced from the intrinsic conductivity suggests interpretation in terms of the theory of small polarons. The model proposed involves carrier formation and transport in localized 3d levels of the cations.

154. (VI) Fischer, W. A. and Dietrich, H., Z. Phys. Chem. 41, 205, 1964.
The thermal EMF against Pt and the resistance of Cr_2O_3 were measured between 900° and 1750°C, for pure specimens and for specimens doped with Al_2O_3, MgO, Cr, and Nb.

155. (VII) Lancon, P., Chevillot, J. P., and Breult, J., Compt. Rend. 258, 6411, 1964.
Studied variations in low-temperature semiconductivity of MnO_2 samples containing extraneous ions.

156. (VII) Rosenberg, M., Nicolau, P., and Bunget, I., Phys. Status Solidi 4, K121, 1964.
The temperature dependence of conductivity and Seebeck coefficient was studied in $Fe_xMn_{3-x}O_4$ for x between 1 and 2, through the ordering transition from ferrimagnetic to paramagnetic.

157. (VII) Wiley, J. S. and Knight, H. T., J. Electrochem. Soc. 111, 656, 1964.
A method was developed to produce samples of Pyrolytic beta-MnO_2 to be used for conductivity measurements without the necessity of grinding and pressing into pellets. Samples were prepared by repeatedly filling a test tube with $Mn(NO_3)_2$ solution and pyrolyzing it.

157. (VIII) Ariya, S. M. and Brach, B. Ya., Soviet Phys.-Solid State 5, 2565, 1964.
An investigation of the high-temperature conductivity of FeO_{1+x} yields results in agreement with the idea that conductivity results from electron exchange between cations of different valence.

159. (VIII) Tanner, D. W., Sweet, F., and Gardner, R. F. G., Brit. J. Appl. Phys. 15, 1041, 1964.
Results are reported for the conductivity of natural and synthetic alpha-Fe_2O_3 between 20° and 1300°C. The effect of firing temperature is consistent with the introduction of carriers by oxygen loss. Comparison with data for polycrystalline materials indicates that the presence of grain boundaries does not significantly affect carrier mobility.

160. (VIII) Tannhauser, D. S., Phys. kondens. Materie 3, 146, 1964.
A detailed model for the transport of charge through the Fe_3O_4 lattice is presented. It is shown that only a fairly complicated defect can transfer charge. The implications of the model are compared with experimental data.

161. (VIII) See reference 156.

162. (VIII) Rogers, D. B., Goodenough, J. B., and Wold, A., J. Appl. Phys. 35, 1069, 1964.
Conductivity in the spinel system $Co_{1-x}Li_xV_2O_4$ was investigated to obtain information about the physical properties manifested by d electrons in the region of a transition from a localized to a collective state.

163. (VIII) Roilos, M. and Nagels, P., Solid State Commun. 2, 285, 1964.
Resistivity was determined for pure CoO and Li-doped CoO. A change in activation energy was observed for the doped CoO at 20°C (Neel point). Resistivity and Hall measurements were performed also on Li-doped NiO. The Hall mobility increases with temperature in the region 100° to 300°K; its value at room temperature is 0.25 cm^2/V-sec.

164. (VIII) Gibbons, J. F. and Beadle, W. E., Solid State Electronics 7, 785, 1964.
A two-terminal solid-state switch made from a thin film of NiO is described. The switching action is thought to be due to the formation and rupture of a Ni filament in the NiO matrix.

165. (VIII) Koide, S., J. Phys. Soc. Japan 18, 1699, 1964.
Resistance measurements are reported between room temperature and 700°C on doped NiO epitaxially grown on MgO.

166. (VIII) Snowden, D. P., Saltsburg, H., and Pereue, J. H., J. Phys. Chem. Solids 25, 1099, 1964.
The frequency dependent conductivity of powdered NiO, both undoped and doped with Cr^{+3}, was studied. A qualitative discussion is given of the causes of conductivity dispersion in powdered materials.

167. (Rare earth) Anthony, A. M., Cabannes, F., and Renon, J., Ann. Phys. 9, 1, 1964.
The conductivity of films of the mixed oxides La_2O_3 - ZrO_2 was determined. Three carrier generation mechanisms are postulated to explain the results, each involving anion vacancies and trapped electrons.

168. (Rare earth) Forrat, F., Dauge, G., Trevoux, P., Danner, G., and Christen, M., Compt. Rend. 259, 2813, 1964.
Describe the oxidation-reduction properties, conductivity, and ionic diffusion due to the presence of color centers in $AlLaO_3$.

169. (Rare earth) Heikes, R. R., Miller, R. C., and Maxelsky, R., Physica 30, 1600, 1964.
The conductivity and Seebeck coefficient of $LaCoO_3$ drop rapidly with increasing temperature in the vicinity of 500°K. The magnetic moment per Co atom also changes by about one Bohr magneton in the same temperature range. These results are explained by a model in which an electron is thermally excited from one 3d level to another with an accompanying change in spin, and in which the difference in energy of the two levels decreases with increasing population of the upper level because of electrostatic interaction.

170. (Rare earth) See reference 135.

171. (Rare earth) Tare, V. B. and Schmaalzried, H., Z. Physik. Chem. 43, 30, 1964.
Determination of ionic and electronic conductivity in several rare earth oxides.

172. (Actinide) Duquesnoy, A. and Marion, F., Compt. Rend. 258, 4072, 1964.
The conductivity of UO_2 at high temperatures was studied as a function of the O_2 partial pressure at equilibrium and of the chemical composition.

173. (Actinide) Myers, H. P., Jonsson, T., and Westin, R., Solid State Commun. 2, 321, 1964.
Conductivity and Seebeck coefficient measurements show UO_2 to be an n-type intrinsic semiconductor with an activation energy of 1.3 eV in the temperature range 1100°-2000°C.

174. (Actinide) Murat, M., Chevreton, M., Berodias, G., and Eyraud, C., J. Chim. Phys. 61, 812, 1964.
Samples of U_3O_8 were reduced in H_2 at a series of temperatures from 400° to 900°C, and the conductivity determined in vacuum as a function of temperature.

175. (Actinide) Nagels, P., Degreese, J., and Denayer, M., J. Appl. Phys. 35, 1175, 1964.
Conductivity was determined for single crystals in the composition range $UO_{2.000}$-$UO_{2.007}$. The activation energy decreased with increasing oxygen content. Hall effect measurements yielded no detectable response indicating a Hall mobility smaller than 10^{-2} cm^2/V-sec at room temperature. The results suggest interpretation by the small polaron theory.

176. (Actinide) Tkachenko, E. V., Neuimin, A. D., Vlasov, V. G., and Strekalovskii, V. N., Phys. Metals Metallography 16, No. 2, p. 30, 1964. Measured conductivity of UO_3 and U_3O_8 at 80°-900°C. Structural changes associated with the decomposition of UO_3 at higher temperatures were investigated.

177. (Actinide) McNeilly, C. E., J. Nuclear Materials 11, 53, 1964. Conductivity and thermoelectric power measurements were made in PuO_{2-x}. The composition resulting from vacuum sintering is p-type at room temperature and changes on heating to n-type, characteristic of an oxygen deficiency. Room temperature resistivity and low temperature activation energy both vary directly with oxygen content.

C. Halides

Reference for the halides are given in the general order: fluorides, chlorides, bromides, and iodides. The name of the compound studied is listed in parentheses after the reference number.

178. (LiF) Moment, R. L. and Gordon, R. B., J. Appl. Phys. 35, 2489, 1964. Tilt boundaries in LiF were doped with Na + ions and the resulting enhanced conductivity studied. The results are interpreted in terms of a disordered boundary structure containing a high vacancy concentration.

179. (LiF) Berge, P., Benveniste, M., Blanc, G., and Dubois, M., Compt. Rend. 258, 5839, 1964.
Electron spin resonance at variable temperature was used to study the mechanism of conductivity in Mn-doped LiF.

180. (LiF) Collings, P. R. and Hirsch, J., Brit. J. Appl. Phys. 15, 797, 1964.
Electron bombardment induced conductivity was studied in LiF and RbBr. The current gain was unity in the former, higher in the latter. There appeared to be no primary voltage threshold for the effect.

181. (CaF_2, BaF_2) Robin-Kandare, S., Robin, J., and Quema, Y., Compt. Rend. 259, 549, 1964.
Determined band gaps from reflectivity and photoelectric measurements.

182. (CsF) Knox, R. S., Phys. Rev. 133, A498, 1964.
A model of the conduction band structure of the Cs halides is presented.

183. (NaCl, KCl) Ahrenkiel, R. K. and Brown, F. C., Phys. Rev. 136, A223, 1964.
New results are presented on the Hall mobility of electrons down to the temperature of liquid He for NaCl, KCl, KBr, and KI. Optical-mode scattering was generally observed above 40°K.

184. (NaCl) Evseev, Z. Ya., Soviet Phys.-Solid State 5, 1705, 1964.
Band theoretical treatment of the wave function and energy of a NaCl crystal containing an excess electron.

185. (NaCl) Jain, S. C. and Dahake, S. L., Indian J. Pure Appl. Phys. 2, 71, 1964.
The conductivity of NaCl doped with divalent metal impurities was investigated theoretically and experimentally.

186. (NaCl) Murmylo, H. L. and Tolpyho, K. B., Ukrayin. Fiz. Zh. 8, 42, 1964. (Russian).
Band theoretical treatment of the wave function and energy of a NaCl crystal containing an excess electron.

187. (NaCl) Tolpyho, K. B. and Sheka, D. I., Societ Phys.-Solid State 5, 1905, 1964.
A qualitative theory of the hole band structure in the alkali chlorides is given with allowance for spin-orbit splitting and correlation.

188. (NaCl) Williams, R., J. Phys. Chem. Solids 25, 853, 1964.
Electric fields of the order of 10^6 V/cm are observed near blocking contacts to a NaCl crystal made photoconducting through F centers. In some cases these fields can be several times the dielectric breakdown field without the onset of field emission.

189. (KCl) Beltrami, M., Cappelletti, R., and Fieschi, R., Phys. Letters 10, 279, 1964.
The conductivity of KCl doped with $SrCl_2$ is lowered upon irradiation with X-rays. This is said to support the idea that ionizing radiation converts positive ion vacancies into negative ones.

190. (KCl) Hirai, M. and Scott, A. B., J. Chem. Phys. 40, 2864, 1964.
An increase in the photocurrent sensitivity in additively colored KCl is observed during the bleaching of the F bands at -30° to -15°C. This indicates the presence of electron traps of large cross-section which are unstable at room temperature.

191. (KCl) Melik-Gaikazyan, I. Ya., Zavadovskaya, E. K., and Ignat'eva, M. I., Soviet Phys.-Solid State 6, 967, 1964.
Studied change in conductivity in KCl doped with Pb^{+2} and Sr^{+2} upon X-irradiation.

192. (CuCl) Goto, T. and Ueta, M., J. Phys. Soc. Japan 19, 774, 1964.
Measured the photoconduction action spectrum and the fluorescence exitation spectrum in the exciton absorption region of CuCl.

193. (AgCl) Bellomonte, L., Palma-Vittorelli, M. B., and Palma, M. U., Paramagnetic Resonance (Academic Press, New York and London, 1963), Vol. 2, pp. 790-794.
Experimental results and a simple analysis are given for the first stages of the complex processes of trapping of photoliberated holes in Cu^+-doped AgCl.

194. (NH_4Cl, KCl, $[NH_4]_2SnCl_6$, K_2SnCl_6) Herrington, T. M. and Staveley, L. A. K., J. Phys. Chem. Solids 26, 921, 1964.
Conductivity measurements were made in pure and doped NH_4Cl and in CsCl and KCl. Less detailed studies were made of NH_4Br, NH_4I, KBr, KI, $(CH_3)_4NI$,

$(NH_4)_2SnCl_6$, K_2SnCl_6. The conductivity of NH_4Cl is significantly greater than that of a comparable alkali chloride. A conductivity mechanism, operative in the ammonium salts but not in the alkali salts, is suggested.

195. (AgBr) Bobrov, Yu. V., Soviet Phys. Acoustics 9, 331, 1964.
It is found experimentally that the conductivity of AgBr is increased in an ultrasonic field. It is presumed that the conductivity mechanism in this case is ionic.

196. (AgBr) Brady, L. E. and Hamilton, J. F., J. Appl. Phys. 35, 1565, 1964.
Ionic conductance and electron lifetime measurements were made on photographic emulsion grains containing Cd. The reduction in the concentration of interstitial Ag ions because of divalent Cd impurity decreases the conductance and increases the electron lifetime. These results confirm the conclusion that Ag ions are the dominant carriers of ionic current and that they play a major role in the initial trapping of photoelectrons during the latent image formation.

197. (AgBr) Malinowski, J. and Platikanowa, W., Phys. Status Solidi 6, 885, 1964.
A new experimental method is used for the determination of the lifetimes of photoproduced holes in AgBr. The value found from initial decay curves is 10^{-4} sec, but a small fraction of the holes remain mobile up to about 10^{-2} sec after their generation. Thus, the concentration decay cannot be described by a simple recombination mechanism.

198. (Ag_2HgI_4) Weil, R. and Lawson, A. W., J. Chem. Phys. 41, 832, 1964.
Studied the pressure dependence of the conductivity. The conductivity is primarily ionic above the order-disorder transition at 50°C, but below this temperature there is an appreciable electronic component. The effect of pressure at all temperatures is initially to increase the conductivity, which then passes through a maximum between 4000 and 6000 kg/cm^2.

199. (KBr) See references 183 and 194.

200. (NH_4Br) See reference 194.

201. (KI) Forbes, H. L. and Lynch, D. W., J. Phys. Chem. Solids 25, 621, 1964.
KI crystals additively colored with I_2 have an enhanced ionic conductivity in the region 90°-200°C, but with an unchanged activation energy. The excess I_2 presumably gives rise to two cation vacancies and two holes per molecule of I_2. The enhanced conductivity indicates that not all the vacancies are bound in V centers but that some are free.

202. (KI) See reference 194.

203. (KI, CsI) Ecklin, D., Nadler, C., and Rossel, J., Helv. Phys. Acta 37, 692, 1964.
The presence of divalent cation impurities reduces the ionic conductivity in KI and CsI through the association of cation vacancies with the impurities.

204. (NH_4I, (CH_3) NI) See reference 194.

205. (TlI) Akimov, I. A., Doklady Akad. Nauk. 151, 310, 1963. (Russian). Photo and dark conductivity was studied in dye-sensitized vacuum-deposited films of TlI. The dye-sensitization causes an increase in the long-wave photosensitivity but results in no change in the temperature dependence of either the dark or photoconductivity. I_2 vapor also causes an increase in conductivity showing that hole conductivity is predominant.

D. Titanates

206. (Ba) Brown, F. and Taylor, C. E., J. Appl. Phys. 35, 2554, 1964. A positive temperature coefficient of resistivity is observed near the Curie temperature in Nb-doped, single-domain crystals of $BaTiO_3$. It is argued that a similar effect observed in ceramics must therefore be due, at least in part, to a fundamental property of the crystal and not to intergranular processes.

207. (Ba) Cox, G. A. and Tredgold, R. W., Phys. Letters 11, 22, 1964. Hole drift mobility in $BaTiO_3$ was measured by a transient photocurrent technique. The low values obtained, about 10^{-4} cm^2/V-sec, indicate trapping.

208. (Ba) Glower, D. D. and Heckman, R. C., J. Chem. Phys. 41, 877, 1964. Determined cell EMF in concentration cell $Pt, O_2(p_1)/BaTiO_3/O_2(p_2)$, Pt, and measured Ba ion transference number by radioactive isotope techniques. Conclude that pure single crystals are electronic conductors between 100° and 535°C, ceramic pure $BaTiO_3$ is electronic at 600° but ionic in the region 100°-300°C and single crystals containing 0.1% Fe^{++} are electronic at 600° but have significant ionic conduction at 100°C.

209. (Ba) Goodman, G., J. Appl. Phys. (Japan) 3, 123, 1964. The positive temperature coefficient anomaly in the resistivity of H_2 reduced $BaTiO_3$ is attributed to a surface phenomenon.

210. (Ba) Ikegami, S. and Ueda, I., J. Phys. Soc. Japan 19, 159, 1964. Measured resistivity, transmission, Hall effect, thermoelectric power, and electron spin resonance in single crystals of $BaTiO_3$ reduced at temperatures from 400° to 1000°C by H_2. The resistivity changes abruptly at the three transition temperatures. The sign of the Hall effect and of the thermoelectric power indicate that the carriers are electrons.

211. (Ba) Schoijet, M., Brit. J. Appl. Phys. 15, 1124, 1964. Space-charge-limited currents were observed in hexagonal $BaPt_{0.25}Ti_{0.75}O_3$ crystals.

212. (Ba,Sr) Tekster-Proskuryakova, G. N. and Sheftel', I. T., Soviet Phys.-Solid State 5, 2542, 1964. An investigation of the properties and structures of $BaTiO_3$ and of solid solutions $(Ba,Sr)TiO_3$ containing La, Ce, and Bi impurities in the concentration range 0.1-0.3 atom %. It is suggested that the anomalous increase in resistivity with temperature in the neighborhood of the tetragonal-cubic phase transition is related to a decrease in mobility.

213. (Sr) Frederikse, H. P. R., Thurber, W. R., and Hosler, E. R., Phys. Rev. 134, A442, 1964.
Conductivity, Hall effect, and Seebeck coefficient of reduced and doped $SrTiO_3$ were measured from 4.2° to 300°K. An average effective mass of about $10m_0$ was deduced from these experiments, a value which is in agreement with an energy band calculation.

214. (Sr) See reference 10.

215. (Pb, La) Matsuo, Y. and Sasaki, H., J. Appl. Phys. (Japan) 3, 799, 1964.
Resistivity was measured as a function of temperature for N_2 fired samples of $PbTiO_3$-$xLa_{2/3}TiO_3$ ceramics.

E. Ferrites

216. (Ni) Hughes, D. O., Brit. J. Appl. Phys. 15, 1250, 1964.
The thermoelectric power of $Ni_{1.00}Mn_{0.02}Fe_{1.98}O_4$ and of $NiFe_2O_4$ containing Mn were measured over the range 100°-500°C.

217. (Mn) Lotgering, F. K., J. Phys. Chem. Solids 25, 95, 1964.
Conductivity and Seebeck coefficients were measured on single crystals and on polycrystalline specimens of the mixed crystals Fe_3O_4-$MnFe_2O_4$-Mn_2FeO_4. The data can be interpreted by assuming that the conductivity is wholly due to the Fe^{+2} and Fe^{+3} ions on octahedral sites according to the Verwey mechanism.

218. (Mn) Rosenberg, M., Nicolau, P., and Bunget, I., Phys. Status Solidi 4, K125, 1964.
The anomaly in the resistance of $MnFe_2O_4$ near the Curie point was studied through resistance and Seebeck coefficient measurements in single crystals. The results are analyzed in terms of a hopping model.

219. (Ni-Zn) Samokhalov, A. A. and Rustamov, A. G., Soviet Phys.-Solid State 6, 749, 1964.
Conductivity, thermo-EMF, Hall effect, and magnetoresistance were measured in $NiZnFeO_4$ specimens. The samples were p-type, the drift mobility was 10^{-3} cm^2/V-sec at 50°C, decreased as the temperature increased, reached a minimum value, and began to increase. The Hall mobility near room temperature also decreased with increasing temperature, and it was one or two orders of magnitude higher than the drift mobility.

220. (Ni, Cu) Sinha, J. K. and Kishan, P., Indian J. Pure Appl. Phys. 2, 200, 1964.
The resistivity of a sample of composition $Ni_{0.2}Cu_{0.8}Fe_{1.9}Mn_{0.02}O_4$ was measured from room temperature to 300°K. The results are consistent with hole conduction in a narrow d band.

F. Miscellaneous Inorganic Compounds

221. ($Li_2SO_4 \cdot H_2O$) VanBeek, L. K. H., Physica 29, 1323, 1963.
A dielectric dispersion around 0.26 cps is attributed to mobile protons. Application of MacDonald's theory of space-charge polarization leads to a

proton mobility of 2.6 x 10^{-1} cm^2/V-sec and a concentration of 1:10^{12} of mobile protons.

222. ($Li_2SO_4 \cdot H_2O$) VanBeek, L. K. H., Physica 30, 1682, 1964.
From dielectric loss data and dc transients a value of approximately 6 x 10^{-3} cm^2/V-sec was derived for the proton mobility.

223. ($NH_4H_2PO_4$) Murphy, E. J., J. Appl. Phys. 35, 2609, 1964.
It is inferred from conductivity data that the proton is the mobile carrier, and the activation energy for proton motion is found to be 10.5 kcal/mole.

224. (DyN, ErN, HoN, ScN, YN) Sclar, N., J. Appl. Phys. 35, 1534, 1964.
Optical and electrical properties were measured. Whereas all compounds appeared to have an optical band gap of about 2 eV, they all exhibited metallic conduction. This is interpreted to indicate that all samples were N-deficient and were high energy gap defect type degenerate semiconductors.

225. (AgN_3) Zakharov, Yu. A. and Kabanov, A. A., Zhur. Fiz. Khim. 38, 2882, 1964.
The effect of Pb^{+2} and CO_3^{-2} ions added during crystallization on its electrical properties was investigated.

226. (AgN_3) Young, D. A., Brit. J. Appl. Phys. 15, 499, 1964.
A study was made of the changes in coloration, conductivity, and thermoelectric power upon thermal cycling between room temperature and 210°C. It is concluded that in partially decomposed AgN_3 the predominant carriers are interstitial cations and electrons.

227. (KNO_3) Weidenthaler, P., J. Phys. Chem. Solids 25, 1491, 1964.
Followed the changes in conductivity accompanying the polymorphic transitions in KNO_3 at 1 atmosphere.

228. ($MgMn_2O_4$) Rosenberg, M. and Nicolau, P., Phys. Status Solidi 6, 101, 1964.
The temperature dependence on the conductivity and the thermoelectric power was measured. Conductivity occurs by a hopping mechanism between octahedral site Mn^{+3} and Mn^{+4} ions, and it involves very low mobilities.

229. ($NaBrO_3$) Ramasastry, C. and Mutri, Y. V. G. S., J. Phys. Chem. Solids 24, 1384, 1964.
Below 455°K the conductivity activation energy is 0.4 eV and is associated with jumps of positive ion vacancies. Between 455° and 590°K the activation energy is 1.1 eV and is associated with intrinsic conduction by the positive ion vacancies. Above 590°K the conductivity increases very rapidly with increasing temperature.

230. (NiH_2) Baranowski, B., Acta Met. 12, 322, 1964.
The resistance of Ni specimens was measured before and after cathodic charging with H_2 at temperatures from 78° to 273°K, from which the resistance of NiH_2 over this temperature range was deduced.

231. (Pb_2CoWO_6) Filip'ev, V. S. and Fesenko, E. G., Soviet Phys. Cryst. 9, 231, 1964.
At the phase transformation from the cubic (T above 20°C) to the perovskite (T below 20°C) there is no discontinuity in the conductivity, but there is a discontinuity in the temperature coefficient such that the activation energy is higher in the low temperature phase.

232. ($[SN]_x$ polymer) Chapman, D., Warn, R. J., Fitzgerald, A. G., and Yoffe, A. D., Trans. Faraday Soc. 60, 294, 1964.
Temperature and pressure dependence of the conductivity was studied. The activation energy is 0.02 eV.

233. ($P_3N_3Cl_6$) Reucroft, P. J., Kronick, P. L., Scott, H., and Labes, M. M., Nature 201, 609A, 1964.
Phosphonitrilic chloride trimer was found to be an extremely good insulator (10^{15} ohm cm) in contrast to previously reported results. Also see reference 318.

G. Glasses

234. Kolmiets, B. T., Phys. Status Solidi 7, 359 and 713, 1964.
A review covering vitreous (glassy) semiconductors. Two parts.

235. Peck, W. F. and Dewald, J. F., J. Electrochem. Soc. 111, 561, 1964.
The Hall effect was measured on semiconducting glasses in the systems As-Te-I and As-Te-Br. The sign of the Hall effect indicates n-type conduction, in apparent contradiction to the sign of the thermoelectric effect which indicates p-type. The carrier mobilities are of the order of 0.05 cm^2/V-sec with only a small temperature dependence.

236. Pearson, A. D., J. Electrochem. Soc. 111, 783, 1964.
The sign anomaly in the Hall and Seebeck effects observed in the preceeding reference is attributed to the presence of a crystalline phase in the glassy material.

237. Chakravorty, D. and Cross, L. E., J. Amer. Ceram. Soc. 47, 370, 1964.
Conduction in an aluminosilicate glass system was investigated at pressures up to 60 k-bars. The activation energy increased rapidly at first with increasing pressure, then exhibited saturation at 30 k-bars.

238. Sutton, P. M., J. Amer. Ceram. Soc. 47, 188 and 219, 1964.
A review of space charge and electrode polarization phenomena in glass. In two parts.

239. Chatterji, A. K., Nature 203, 284, 1964.
Conductivity measurements on kaolin (China clay) either with or without the addition of ZnO show it to be a p-type semiconductor.

240. Hagel, W. C. and Mackenzie, J. D., Phys. Chem. Glasses 5, 113, 1964.
By direct measurements of oxygen diffusion in calcium aluminoborate and aluminosilicate glasses it is shown that a conduction mechanism involving the drift of oxygen ions is highly improbable.

241. Ivanov, A. O., Soviet Phys.-Solid State 5, 1933, 1964.
A minimum was observed in the conductivity of glasses of the system Na_2O-K_2O-GeO_2 as Na was replaced by K.

242. Lengyel, B. and Boksay, Z., Z. Physik. Chem. 223, 49, 1964.
Conductivities of glasses containing various portions of Li, K, and Na ions were measured at temperatures up to 430°C.

243. Lengyel, B., Boksay, Z., and Dobos, S., Z. Physik. Chem. 223, 186, 1964.
The transport numbers of Li-Na-K glasses were determined at various temperatures.

244. Milne, E. L. and Gibbs, P., J. Appl. Phys. 35, 2364, 1964.
Ag ion conduction currents in alpha-quartz were measured in the region 300°-550°C using Ag electrodes. The activation energy for Ag ion conduction is dependent upon the electric field strength. A theory is postulated to explain this behavior in which there is formation of a lattice-bound negative space near the Ag anode.

245. Veltri, R. D., Phys. Chem. Glasses 4, 221, 1964.
The resistivity of fused silica was measured between 1000° and 2480°C.

IV. Organic Materials

A. Hydrocarbons

References 246 - 269 all deal with anthracene.

246. Nakada, I., Ariga, K., and Ichimiya, A., J. Phys. Soc. Japan 19, 1587, 1964.
The activation energy is .4 to .5 eV below 120°C and 2.8 ± .2 eV at temperatures above 120°C.

247. Hasegawa, K., J. Appl. Phys. (Japan) 3, 633, 1964.
The activation energy was found to be isotropic between 80° and 150°C and to have the value .87 ± .8 eV.

248. Kawasaki, K. and Kanon, K., J. Colloid Sci. 18, 886, 1964.
Absorption of water vapor on a clean cleavage surface lowers the contact resistance while absorption of oxygen increases the contact resistance.

249. Chojnacki, H., Acta Phys. Polon 25, 139, 1964.
In the ab plane the conductivity is presumably isotropic while it has a smaller value in the c-direction.

250. Jansen, P., Helfrich, W., and Riehl, N., Phys. Stat. Sol. 1, 851, 1964.
Detrapping of charge carriers by light and the influence on hole currents is discussed and interpreted.

251. Adolph, J., Baldinger, E., and Gränacher, I., Phys. Letters, 8, 224, 1964.
Electrons, optically excited to the triplet level, are supposed to neutralize trapped holes. (See also reference 252).

252. Adolph, J., Baldinger, E., and Gränacher, I., Helv. Phys. Acta. 37, 192, 1964.
The influence of monochromatic light of low intensity on the space charge limited currents has been studied as function of the wavelength to test the model suggested in the previous reference.

253. Gheorghita-Oancea, C., Rev. Roumaine Phys. 9, 23, 1964.
Vacuum sublimed crystals were exposed to air and to iodine vapors in the study of dark- and photoconductivity.

254. Bree, A. and Kydd, R. A., J. Chem. Phys. 40, 1775, 1964.
In the presence of absorbed oxygen there were found to be hole traps of .8 eV at the surface of anthracene crystals.

255. Nakada, I. and Kojima, T., J. Phys. Soc. Japan 19, 1989, 1964.
An oxygen atmosphere decreases the photovoltage by 50%.

256. Nakada, I. and Ishihara, Y., J. Phys. Soc. Japan 19, 695, 1964.
Carrier generation by light is dependent on the temperature and the electric field. Hole mobility decreases with temperature while electron mobility varies only little with temperature.

257. Kearns, D. R., J. Chem. Phys. 40, 1452, 1964.
Because of the low concentration of triplet state excitions it is argued that carrier generation does not occur through spontaneous ionization of such excitons.

258. Kepler, R. G. and Merrifield, R. E., J. Chem. Phys. 40, 1173, 1964.
Although the quantum efficiency of photocarrier generation can be understood by considering hole-electron recombination, the dependence on intensity and extinction coefficient cannot be explained in such terms.

259. Hasegawa, K. and Schneider, W. G., J. Chem. Phys. 40, 2533, 1964.
Photocurrents generated by ruby-laser light are interpreted in terms of excitation of trapped carriers.

260. Raman, R., Azarraga, L., and McGlynn, S. P., J. Chem. Phys. 41, 2516, 1964.
Pulse photoconduction measurements in 50μ thick crystals gave results comparable to data obtained by other scientists working with thick crystals.

261. Sharp, J. H. and Schneider, W. G., J. Chem. Phys. 41, 3657, 1964.
Triplet excitons induce photoconduction as is shown by a study of the absorption spectrum of triplet transitions in the 5000-7000 Å region.

262. Weisz, S. Z., Jarnigan, R. C., Silver, M., Sinhony, M., and Balberg, J., J. Chem. Phys. 40, 3365, 1964.
Carrier trapping in photoconducting anthracene was studied by transient space charge limited photocurrents. The concentration of traps can be reduced by annealing. It is suggested that these traps are molecules in a distorted position in the lattice.

263. Kokado, H. and Schneider, W. G., J. Chem. Phys. 40, 2937, 1964.
Hole traps at .76 eV were found in experiments on thermally stimulated currents and carrier trapping.

264. Gheorghita-Oancea, C., Rev. de Physique (Roumania) 8, 361, 1963.
Previous work is reviewed (112 ref.) and spectra of vacuum deposited thin films are given.

265. Lyons, L. E. and Mackie, J. C., J. Chem. Phys. 40, 2411, 1964.
Criticism of a paper by Choi and Rice (J. Chem. Phys. 38, 366, 1963).

266. Mitskevich, P. and Bashmakova, M. I., Zhurn. Fiz. Khim. 38, 1606, 1964.
A discontinuity in the conductivity as function of temperature was observed while passing the melting point. The conductivity of liquid anthracene is about four orders of magnitude higher than in the solid at the same temperature. See also reference 307.

267. Gränacher, I., Solid State Communications 2, 365, 1964.
Compounds that form solid charge transfer complexes with anthracene are recommended for ohmic contacts and are said to be hole injecting in the dark.

268. Harada, Y., Maruyama, Y., Shirotani, I., and Inokuchi, H., Bull Chem. Soc. Japan 37, 1378, 1964.
The band structure of anthracene was calculated for 1 atm and for 160 k-bars. At 160 k-bars the bandwidth for holes and electrons are 5 to 6 fold the value at 1 atm. Although the mobility of both carriers increases with pressure, the large increase in conductivity might be due to a larger concentration of charge carriers.

269. See reference 23.

270. (Anthracene, Stilbene, and m-terphenyl) Raman, R. and McGlynn, S. P., J. Chem. Phys. 40, 515, 1964.
Hole mobilities in crystals 15-50μ thick were measured with pulsed photocurrents.

271. (Anthracene, Naphthalene, and Pyrene) See reference 21.

272. (Anthracene, Naphthalene) Riehl, N., Nachrichtentech. Fachber. (NTF) 29, 25, 1964.
Details of organic conductors, anthracene and other compounds are discussed. Ice is included as an example of protonic conduction.

273. (Anthracene, Pentacene, Naphthacene) Vilesov, F. I., Zagrubskii, A. A., and Garburov, D. Z., Fiz. Tverd. Tela 5, 2000, 1963.
Photoemission spectra were obtained and for anthracene the results are compared with theoretical values. See also reference 290.

274. (Naphthalene) Kearns, D. R., J. Chem. Phys. 41, 581, 1964.
The energy of resonance states in crystals of aromatic molecules is discussed and evidence for such states, theoretical as well as experimental, is examined.

275. (α-Methylnaphthalene) Kallman, H., Krasnansky, V. T., and Orenstein, A., J. Chem. Phys. 40, 3740, 1964.
From pulse photoconductivity measurements the hole mobility was found to be 10^{-4} cm^2 V^{-1} sec^{-1} and the electron mobility was 5×10^{-5} cm^2 V^{-1} cm^{-1}.

276. (Phenanthrene) Matsumoto, S. and Tsukada, T., Bull. Chem. Soc. Japan 37, 1545, 1964.
The conductivity was measured along the different crystal axes of single crystals.

277. (Pyrene) Ohki, K., Inokuchi, H., and Maruyama, Y., Bull. Chem. Soc. Japan 36, 1512, 1963.
A theoretical estimate was made of the hole and electron mobility in a direction perpendicular to the ab plane. The results are compared with experimental values.

278. (Tetracene, Pentacene, Hexacene, Azulene, Coronene, Violanthrene) Aust, R. B., Bentley, W. H., and Drickamer, H. G., J. Chem. Phys. 41, 1856, 1964.
The electrical conductivity of a number of hydrocarbons increases with pressure. In some samples metallic conduction was observed at high pressures (up to 300 k-bars).

279. (β-Carotene) Chapman, D. and Cherry, R. J., Nature 203, 641, 1964.
Dark- and photocurrents in thin crystals of β-carotene were studied with a pulse technique. In oxygen atmosphere the dark conductivity increases by several orders of magnitude. Upon pumping the conductivity returns to its original value.

280. See reference 37.

B. Phthalocyanines

281. (Metal Free Phthalocyanine) Hamann, C. and Starke, M., Phys. Status Solidi 4, 509, 1964.
Conductivity and thermoelectric properties are shown to depend on sample preparation techniques.

282. Bradley, R. S., Grace, J. D., and Munro, D. C., J. Phys. Chem Solids 25, 725, 1964.
The conductivity of β-phthalocyanine has been measured between 25° and 200°C and 2.5 and 50 k-bar over a frequency range from 1-20 kcs. Some remarks are made about powder samples.

283. Assour, J. M. and Harrison, S. E., J. Phys. Chem. 68, 872, 1964.
Free radicals in phthalocyanine were studied by means of electron spin resonance techniques. Details about the influence of oxygen are given and it is suggested that the absorbed oxygen may be associated with the electronically active centers in phthalocyanine.

284. (Metal-Phthalocyanines) Fielding, P. E. and Mackay, A. G., Aust. J. Chem. 17, 750, 1964.
Spectra of metal free- and a number of metal-phthalocyanines were measured. There seems to be no correlation between optical transition frequencies and activation energies of conduction.

285. Hamann, C., Phys. Status Solidi 4, K97, 1964.
Pressed pellets of mixed metal free- and metal-phthalocyanines provided with various contacts show rectifying properties.

286. Devaux, P., Schott, M., and Lazerges, M., Phys. Status Solidi 4, 43, 1964.
The surface conductivity of single crystals is compared with the results obtained on thin films. Photoconduction spectrum and optical absorption spectrum are similar.

287. Harrison, S. E. and Assour, J. M., J. Chem. Phys. 40, 365, 1964.
In copper-phthalocyanine the electron mobility is two orders of magnitude larger than in metal-free phthalocyanine. This is explained on the basis of results obtained from ESR experiments.

288. Heilmeier, G. N. and Zanoni, L. A., J. Phys. Chem. Solids 25, 603, 1964.
Surface studies of α-copper phthalocyanine reveal a strong influence of adsorbed oxygen resulting in a high density of acceptor-like surface states.

289. Delacote, G. M., Fillard, J. P., and Marco, F. J., Solid State Communications 2, 373, 1964.
The current-voltage characteristic of copper-phthalocyanine between gold electrodes has been measured and is discussed.

290. Vilesov, F. I., Zagrubskii, A. A., and Garburov, D. Z., Fiz. Tverd. Tela 5, 2000, 1963.
The photoemission spectra of metal free phthalocyanine and Mg-, Cu-, Al- and Fe-phthalocyanine are given.

C. Charge Transfer Complexes and Ion Radical Salts

291. (Perylene-fluoranil Complex) Kokado, H., Hasegawa, K., and Schneider, W. G., Can. J. Chem. 42, 1084, 1964.
Report dark- and photoconductivity data on single crystals. The highest conductivity was observed along the c-direction. Carrier mobilities could not be measured.

292. (Diamino-Quinone Complexes) Matsunaga, Y., J. Chem. Phys. 40, 3453, 1964.
Optical absorption edges of these complexes are compared with previously measured activation energies for conductivity. It is concluded that both are essentially of equal value.

293. (1,6-Diaminopyrene-Complexes) Kronick, P. L., Scott, N., and Labes, M. L., J. Chem. Phys. 40, 890, 1964.
Absorption spectra of solid complexes with bromanil, chloranil, and 2,3-dichloro-5,6-dicyanobenzoquinone indicate the presence of ionic components in

concentrations corresponding to the electron affinities of the acceptors. There is no simple relation between the conductivity and the electron affinity of these acceptors.

294. ($Cs_2(TCNQ)_3$) Arthur, P., Acta Cryst., 17, 1176, 1964.
A structure determination indicates that the planar TCNQ units are stacked face to face while the normal directions of these units are tilted away slightly from the b-axis. The highest conductivity is observed in the b-direction.

295. (Triphenylmethylphosphonium-$(TCNQ)_2$) Iida, Y., Kinoshita, M., Sano, M., and Akamatu, H., Bull. Chem. Soc. Japan 37, 428, 1964.
A phase transition in the single crystal has been detected by conductivity and electron spin resonance experiments. The conductivity changes by a factor of five. (See also Y. Iida, M. Kinoshita, A. Kawamori, and Suzuki, K., Bull. Chem. Soc. Japan 37, 764, 1964).

296. (Fluoranil, Chloranil, and Iodine-Complexes) Schwarz, M., Davies, H. W., and Dobriansky, B. J., J. Chem. Phys. 40, 3257, 1964.
The conductivity of complexes with the donors perylene, 1,6-diaminopyrene, tetramethylbenzidine, p-phenylenediamine and 1,5-diaminonaphthalene were studied as a function of pressure between 1 and 15 k-bar. Generally, the conductivity increases exponentially with pressure up to about 6 k-bar.

297. (Triethylammonium-$(TCNQ)_2$, Quinolinium-$(TCNQ)_2$, and K TCNQ) Aust, R. B., Samara, G. A., and Drickamer, H. G., J. Chem. Phys. 41, 2003, 1964.
At room temperature the conductivity increases with pressure. Above 140-150 k-bar, irreversible chemical changes occur, resulting in a decrease in conductivity. However, such changes are absent if the experiment is done at 78°K.

298. (Chloranil and Bromanil Complexes of Aromatic Hydrocarbons and Aromatic Amines) Benderskii, V. A., Blyumenfeld, L. A., Shevchenko, I. B., and Altshuler, T. S, Soviet Phys.-Solid State 6, 1206, 1964.
Activation energies for conductivity are compared with optical absorptions in films of complexes, made from pyrene, stilbene, o-aminnophenol, p-bromaniline, and diphenylamine.

299. (Phenylenediaminechloranil and Benzidine-Iodine Complexes) Benderskii, V. A., Shevchenko, I. B., and Blyumenfeld, L. A., Optics and Spectrosc. 16, 254, 1964.
Visible, infrared, electron spin resonance spectra and dark conductivity of these complexes were investigated. The results are interpreted in terms of a crystal model with low-lying polar states.

300. (p-Phenylenediamine-Chloranil Complex) Meinhard, J. E., J. Appl. Phys. 35, 3059, 1964.
From experiments on thin films, evaporated on a metal substrate it is concluded that conduction is by holes. Rectification has been observed. See also reference 310.

301. (2,3-Dichloro-5,6-dicyanobenzoquinone Complexes) Ottenberg, A., Brandon, R. L., and Browne, M. E., Nature 201, 1119, 1964.
Complexes with p-phenylenediamine, perylene and pyrene were reported to have $\rho = 10^{-6}\ \Omega^{-1}\ cm^{-1}$, $\Delta E = .37$ eV; $\sigma = 3 \times 10^{-7}\ \Omega^{-1}\ cm^{-1}$, $\Delta E = .45$ eV and $\sigma = 10^{-13}\ \Omega^{-1}\ cm^{-1}$, $\Delta E = .9$ eV. The conductivity of the acceptor is strongly dependent upon the solvent from which it is recrystallized.

D. Miscellaneous Monomeric Organic Compounds

302. (Chloranil) Reucroft, P. J., Rudyj, O. N., and Labes, M. M., J. Chem. Phys. 39, 1136, 1963.
Current voltage characteristics were studied on chloranil single crystals. Ohmic behavior was observed below 4×10^{3} V cm^{-1}. At higher voltages the current increases as the square of the voltage. The possibility that the concentration of traps can be derived from these experiments is discussed.

303. (Ferrocene, Triphenylamine, and Transstilbene) Hoesterey, D. C. and Letson, G. M., J. Chem. Phys. 41, 675, 1964.
The hole photoconductivity was measured; for transstilbene it was found to be 2.4 cm^{2} V^{-1} sec^{-1} and varies as T^{-1}. For ferrocene and triphenylamine 2×10^{-2} cm^{2} V^{-1} sec^{-1} was obtained. In these cases the hole photoconductivity is apparently not controlled by impurity traps.

304. (Ferrocene) Eichorn, H. and Voitlander, J., Z. Naturforsch 18a, 1373, 1963.
The dark conductivity and its activation energy were measured. Above 5000 V cm^{-1} Ohms law is no longer followed. Excitation with light of 2025 Å results in photoconductivity.

305. Okamoto, Y., Chang, J. Y., and Kantor, M. A., J. Chem. Phys. 41, 4010, 1964.
Under the influence of pressure (up to 5 k-bar) the conductivity of ferrocene increases. At higher pressures it decreases irreversibly.

306. (p-Nitrophenol) Chojnacki, H., Acta Phys. Polon 24, 289, 1963.
The conductivity was measured on a single crystal in nitrogen atmosphere using a multi-electrode technique. The surface conductivity is discussed in further detail.

307. (Phenazine and Benzanthrone) Mitskevich, P. and Bashmakova, M. I., Zhurn. Fiz. Khim. 38, 1606, 1964.
A discontinuity in the conductivity as function of temperature was observed for both samples while passing the melting point. The conductivity of the liquids is larger than in the solid at approximately the same temperature. See also reference 266.

308. (Fluoridine, Triphenodioxazine, and Pentacene) Inoue, H., Noda, K., and Imoto, E., Bull. Chem. Soc. Japan 37, 332, 1964.
With "sandwich" type cells the following results were obtained: fluoridine, conductivity: $\sigma = 2.5 \times 10^{-16}\ \Omega^{-1}\ cm^{-1}$, $\Delta E = 1.6$ eV; triphenodioxazine $\sigma = 5 \times 10^{-17}\ \Omega^{-1}\ cm^{-1}$, $\Delta E = 1.7$ eV and pentacene: $\sigma = 1.6 \times 10^{-14}\ \Omega^{-1}$, $\Delta E = 1.5$ eV.

309. Inoue, H., Hayashi, S., and Imoto, E., Bull. Chem. Soc. Japan 37, 336, 1964.
A summary and a discussion of the experimental results is given for fluoridine and triphenodioxazine.

310. (Chloranil, Phenazine, and Indigo) Meinhard, J. E., J. Appl. Phys. 35, 3059, 1964.
Experimental results obtained on vacuum deposited thin films indicate that the conductivity in chloranil and indigo is hole type while in phenazine it it n-type. Rectification has also been observed. See also reference 300.

311. (Various Organic Polyiodides) Kusabayashi, S., Mikawa, H., Kawai, S., Uchida, M., and Kiriyama, R., Bull. Chem. Soc., Japan 37, 811, 1964.
The conductivities and activation energies of two ammoniumtriiodides, one ammonium pentaiodides, one ammoniumheptaiodide along with those of N-methylpyridiniumtri- and pentaiodide, and N-methylquinoliniumtri- and pentaiodide were determined. The conductivities range from 1.2×10^{-7} to 4×10^{-11} Ω^{-1} cm^{-1} and the ΔE's are between 1 and 5.2 eV.

312. (α, α'-diphenyl-β-picrylhydrazyl, Quaterrylene, Violanthrone, and Pentacene) Inokuchi, H., Shirotani, I., and Minomura, S., Bull. Chem. Soc. Japan 37, 1234, 1964.
Above mentioned compounds were studied at atmospheric pressure and at 160 k-bar. At high pressures the conductivities are several orders of magnitude higher while the activation energies are smaller than at atmospheric pressure.

313. (Methylchlorophyllide-A) Vartanyan, A. T., Dokl. Akad. Nauk. 153, 70, 1963.
Amorphous layers deposited from chloroform were studied in vacuum and in oxygen atmosphere. The value of the activation energy in oxygen atmosphere is smaller than when measured in vacuum, however, the original value can be obtained by removal of the oxygen in vacuum.

314. (Di- and Triphenylmethane Dyes) Meshkov, A. M. and Zhdanov, G. S., Soviet Phys.-Solid State 6, 1502, 1964.
Amorphous films of the dyes (deposited from solution) showed n-type conduction while layers of a crystalline structure exhibited p-type conduction.

315. (Leucomalachite Green) Mehl, W. and Wolff, N. E., J. Phys. Chem. Solids 25, 1221, 1964.
The photoconductivity of solid solutions of malachite green's leucobase in various organic media was investigated. Carrier transport occurs by interaction between the leucobase molecules; no participation of the matrix in the charge transport was observed.

316. (Triphenylmethane Dyes) Benderskii, V. A., Kogan, B. Y., Abramov, Y. Y., and Kapranova, L. E., Dokl. Akad. Nauk 156, 897, 1964.
The narrow bands in photoconducting dyes are discussed and it is shown that the optical absorption spectrum coincides with the photoconductivity spectrum.

317. (Cyamelurine) Reucroft, P. J., Kronick, P. L., Scott, N., and Labes, M. M., Nature 201, 609A, 1964.
The samples of cyamelurine were found to be "electrically impure." See also reference 233.

318. (Anils) Gooden, E. W., Nature 203, 515, 1964.
The conductivity of anils prepared from salicylaldehyde and various m- and p-substituted anilines was reinvestigated. These new results do not seem to support an earlier suggestion that conduction occurs through a "surface mechanism."

E. Polymers

319. (Review) Baker, W. O., J. Pol. Sci. C4, 1633, 1964.
The structure and electrical properties of a number of synthetic solid polymers are discussed.

1. Synthetic Polymers with Conjugated Chains

320. (Polyvinylchloride and Chlorinated Polyvinylchloride) Berlin, A. A., Kasatochkin, V. I., Aseyeva, R. M., and Finkelshtein, G. B., Polymer Science 5, 378, 1964.
Both types of polymers were dehydrohalogenated and pyrolyzed. The conductivities range between 10^{-5} and 10^{-15} Ω^{-1} cm^{-1}.

321. Tsuchida, E., Shih, C. N., Shinohara, I., and Kambara, S., J. Pol. Sci. A2, 3347, 1964.
After dehydrohalogenation with alkaliamide in liquid ammonia the samples analyzed for a C/H ratio of 1. However they all contain oxygen. The highest conductivity observed is about 4×10^{-10} Ω^{-1} ohm^{-1}.

322. (Polyazophenylenes) Carlton, D. M., McCarthy, D. K., and Genz, R. H., J. Phys. Chem. 68, 2661, 1964.
The influence of substituents on the conductivity was studied on low molecular weight polymers. Conductivities range between 10^{-12} and 10^{-15} Ω^{-1} cm^{-1}.

323. Berlin, A. A., Liogonsky, B. I., and Parini, V. P., Izvest. Akad. Nauk Ser. Khim, p. 705, 1964.
The conductivity of these particular samples is about 10^{-17} Ω^{-1} cm^{-1} while the activation energy is 1.01 ev.

324. (Polyacetylenes, Polybenzimidazoles, and Polyacene-quinones) Pohl, H. A. and Chartoff, R. P., J. Pol. Sci. A2, 2787, 1964.
It is attempted to formulate a relationship between conductivity, unpaired spin concentrations, relaxation time, activation energy and the molecular structure of the polymers.

325. (Polyschiff Bases) Davydov, B. E., Krentsel, B. A., Popov, Y. A., and Prokofeva, L. V., Polymer Sci. (USSR) 4, 970, 1963.
Preparation and some physical properties are described. Using $\sigma = \sigma_0 \exp - \Delta E/2kT$ gives room temperature conductivities between 10^{-11} and 10^{-18} Ω^{-1} cm^{-1} with ΔE's between .82 and 2.40 eV.

326. (Polymeric Tetracyanoethylene-metal Compounds) Boguslavskii, L. I., Sherle, A. I., and Berlin, A. A., Zhurn. Fiz. Khim. 38, 1118, 1964.
The conductivity of films was investigated with ac and dc simultaneously. It was suggested that the conductivity as well as the activation energy are due to activated jumps over the barriers between macromolecules. See also reference 327.

327. Boguslavskii, L. I., Dokl. Akad. Nauk 154, 1145, 1964.

328. (Polymeric Chelates) Gelfman, A. Y., Kvyatkovskaja, Y. F., Luzan, R. G., and Skorobogatov, B. S., Polymer Science USSR 5, 637, 1964.
Films of polyvinylalcohol were treated with metal salt solutions resulting in polymeric chelates. Typical conductivities are from 10^{-13} to 10^{-19} Ω^{-1}cm^{-1} with ΔE between 1.2 and 3.3 eV (using $\sigma = \sigma_0 \exp - \Delta E/2kT$).

329. Dewar, M. J. S. and Talati, A. M., J. Am. Chem. Soc. 86, 1592, 1964.
Coordination polymers were made from transition metal ions and ligands of aromatic nature such as the dioxime of 1,5-diacyl, 2,6-dihydroxynaphthalene. Supposedly the molecular weights are low while the conductivities are between 10^{-5} and 10^{-6} Ω^{-1} cm^{-1} at room temperature with activation energies from .47 to 2.26 eV.

330. Brown, G. P. and Aftergut, S., J. Pol. Sci. A2, 1839, 1964.
The reaction products of imidazole and the sulfates of some transition metals were studied with respect to their thermal stability and conductivity which appears to be between $10^{-15}$and 10^{-17} Ω^{-1} cm^{-1} at temperatures above 100°C.

331. Berlin, A. A., Liogonskii, B. I., and Parini, V. P., Polymer Sci. (USSR) 4, 980, 1963.
Polyazophenylene ferrocenes of molecular weight ranging from 1000 to 1400 are soluble in benzene and give films upon evaporation of the solvent. Their conductivities are from 10^{-10} to 10^{-16} Ω^{-1} cm^{-1} with activation energies from .45 to .86 eV.

332. Dulov, A. A., Slinkin, A. A., and Rubinshtein, A. M., Polymer Sci. (USSR) 5, 535, 1964.
Ferrocene polymers with maximum molecular weight of 2500 are reported to have conductivities of 5×10^{-11} to 5×10^{-13} Ω^{-1} cm^{-1}, after a heat treatment these values become 5×10^{-7} to 5×10^{-13} Ω^{-1} cm^{-1}. The activation energies are from .91 to 1.17 eV.

333. (Polymeric Phthalocyanines) Balabanov, Y. I., Frankevich, Y. L., and Cherkashina, L. G., Polymer Sci. (USSR) 5, 797, 1964.
These insoluble polymers have conductivities from 10^{-7} to 10^{-8} Ω^{-1} cm^{-1} and activation energies of about .3 eV. The conductivity is reported to rise to 10^{-3} Ω^{-1} cm^{-1} under vacuum while gases are given off.

334. (Polyvinylpyridine-iodine Complexes) Mainthia, S. B., Kronick, P. L., and Labes, M. M., J. Chem. Phys. 41, 2206, 1964.
The conductivity depends on the polymer/iodine ratio and varies between 10^{-4} and 10^{-7} Ω^{-1} cm^{-1}. The activation energies are interpreted as representing impurity levels in the band structure of iodine lying between .6 and 1.0 eV.

335. (Polydiphenylamine Complexes with Iodine, Chloranil and Tetracyanoethylene) Kuwata, K., Sato, Y., and Hirota, K., Bull. Chem. Soc. Japan 37, 1391, 1964.
Depending on the polymer/acceptor ratio the following conductivities have been observed: polydiphenylamineiodine from 5×10^{-12} to 3.0×10^{-8} Ω^{-1} cm^{-1}; polydiphenylaminechloranil 4×10^{-9} Ω^{-1} cm^{-1} and polydiphenylaminetetracyanoethylene from 6×10^{-7} to 1.2×10^{-6} Ω^{-1} cm^{-1}. The maximum molecular weight of the starting material is about 3000.

336. (Polyvinylcarbazole- 7,7,8,8, tetracyanoquinodimethan (TCNQ Complex) Taniguchi, A., Kanda, S., Nogaito, T., Kusabayashi, S., Mikawa, H., and Ito, K., Bull. Chem. Soc. Japan 37, 1386, 1964.
Depending on the polymer/TCNQ ratio the conductivity varies between 10^{-13} and 10^{-16} Ω^{-1} cm^{-1} and the activation energy varies between 1.1 and 1.4 eV. It is claimed that films can be obtained from solutions.

337. (Polyvinylpyridinium - TCNQ Derivatives) Hatano, M., Nomori, H., and Kambara, S., Reports on Progress in Polymer Physics in Japan 7, 321, 1964.
Atactic poly-(2-vinylpyridine TCNQ) derivatives also contained neutral TCNQ. The reported conductivities are 8×10^{-6}, 3×10^{-7} and 1.5×10^{-7} Ω^{-1} cm^{-1} while a nonlinear behavior was observed in the current-voltage characteristic of a sample prepared from the isotactic polymer.

338. (Polymeric TCNQ Derivatives) Lupinski, J. H. and Kopple, K. D., Science 146, 1038, 1964.
TCNQ derivatives of six quaternized polyamines are reported to have conductivities ranging from 10^{-10} to 10^{-3} Ω^{-1} cm^{-1}, depending on the incorporation of neutral TCNQ. All products are soluble in dimethylformamide and films can be cast. The polymers had molecular weights between 5×10^{4} and 2.2×10^{6} and the activation energies for conduction are between .1 and .3 eV.

339. ("Internal" Polymeric Charge Transfer Complexes) Yang, M. C. and Gaoni, Y., J. Am. Chem. Soc. 86, 5022, 1964.
Polymers with donors and acceptors build into one chain. Donors: vinylpyridine and dimethylaminostyrene. Acceptor: trinitrostyrene. The electrical conductivity is being investigated; no details available yet.

2. Miscellaneous Polymeric Materials

340. (Polyacenaphthylene and Nitro Derivatives) Inami, A., Morimoto, K., and Hayashi, Y., Bull. Chem. Soc. Japan 37, 842, 1964.
Almost no photoconduction is observed in polyacenaphthylene but there is considerable photoconduction in the nitrated polymer. The photocurrent depends on the degree of nitration.

341. (Polyethyleneterephthalate and Polytrifluorochloroethylene) Sazhin, B. I. and Podosenova, N. G., Vysokomol Soedin, p. 137, 1964.
Upon crystallization the volume conductivity increases 10 to 100 fold.

342. (Poly-p-phenylene and Polyvinylene) Beck, F., Ber. Bunsengesell. Phys. Chem. 68, 558, 1964.
Conductivities are reported to range between 10^{-1} and 10^{-15} Ω^{-1}cm^{-1} with

activation energies 0.25 to .96 eV. In addition, details are given about photoconduction, thermoelectric power and current-voltage characteristics. The mobilities are about .6 cm^2 V^{-1} sec^{-1}.

343. (Polyamides) Hedvig, P., J. Pol. Sci. A2, 4097, 1964.
Radiation induced conductivities of 10^{-12} Ω^{-1} cm^{-1} were found in polyamide copolymers irradiated by X-rays and Co^{60} radiation. The influence of chemicals such as benzophenone and hydroquinone is also discussed.

344. Yu, L. T., J. de Physique 24, 677, 1963.
The influence of temperature and absorbed water on the dc conductivity of nylon type polymers has been investigated. Conductivities of 10^{-8} to 10^{-13} Ω^{-1} cm^{-1} are reported.

345. (Poly [1,3-diphenyl-5-(4-vinylphenyl)-2-pyrazoline]) Morimoto, K., Hayashi, Y., and Inami, A., Bull. Chem. Soc. Japan 36, 1651, 1963.
Photocurrents in this material follow Ohm's law and the ratio of photocurrent over dark current was 34 to 147 depending on the polarity of the illuminated electrode.

346. (Polybutadiene) Bashara, N. M. and Doty, C. T., J. Appl. Phys. 35, 3498, 1964.
Electrical conduction in films 100 to 500 Å thick were studied. Contacts, space charge limited currents, and traps are discussed.

347. (Silicones) Mann, H. T., J. Appl. Phys. 35, 2173, 1964.
Current-voltage characteristics as a function of temperature are given for silicone polymer films 500 to 2500 Å thick. In addition, charge transport, oxygen diffusion, the effect of free radicals, and the diffusion of water are discussed.

348. (Silicones) Christy, R. W., J. Appl. Phys. 35, 2179, 1964.
Currents through 50 to 150 Å thick silicone films were measured as a function of temperature. Current voltage characteristics are discussed and the influence of oxygen diffusion into the film is described.

349. (Polytetrafluoroethylene) Adamec, V., Dielectrics 1, 159, 1963.
Currents flowing through polytetrafluoroethylene as a result of X-ray irradiation are studied and anomalous and steady state conductivity are discussed.

350. (Polyvinylene) Drechsel, L. and Görlich, P., Infrared Phys. 3, 229, 1963.
Darkconductivity, photoconductivity, and optical properties of polyvinylene are discussed.

351. (Photoconductive Thermoplastics) Wolff, N. E., RCA Review 25, 200, 1964.
Optical and electrical properties of systems consisting of organic photoconductors in polymer matrices are discussed in reference to thermoplastic recording systems.

352. (Polyethylene) Vannikov, A. V., Dokl. Akad. Nauk 152, 905, 1963.
Hole type conduction was found in pyrolyzed, irradiated high-density polyethylene. Treatment with iodine resulted in n-type conduction. A rectifier from compacted n- and p-type samples gave a rectification ratio of 10 to 25.

353. Wintle, H. J., Photochemistry and Photobiology 3, 249, 1964.
A study of charge carriers is made by attempting to correlate the photoconductivity with the elementary processes resulting from irradiation. It is suggested that the carriers are released from impurity centers.

354. (Polystyrene) Weinreb, A., Ohana, N., and Braner, A., Phys. Letters 10, 278, 1964.
Current oscillations in a polystyrene plate under influence of a voltage of about 1 kv are described.

355. (Cellulose Acetate) Barker, R. E. and Thomas, C. R., J. Appl. Phys. 35, 87, 1964.
The influence of salts on the glass transition temperature as well as the ionic conductivities were studied in these systems.

356. (Pyrolyzed Polyvinylalcohol) Gelfman, A. J., Bidnaya, D. S., Sigalova, L. V., Buravleva, M. G., and Koba, V. S., Dokl. Akad. Nauk 154, 894, 1964.
Depending on the pyrolysis conditions, the conductivity varies between 10^{-5} and 10^{-13} Ω^{-1} cm^{-1} with ΔE between .3 and 2.5 eV.

357. (Pyrolyzed Pyromellitonitrile Reaction Products) Katon, J. E. and Wildi, B. S., J. Chem. Phys. 40, 2977, 1964.
Several physical properties were studied of samples obtained through pyrolysis of condensation products derived from pyromellitonitrile and methanol or hydrogensulfide. Conductivities of about 10^{-1} Ω^{-1} cm^{-1} are reported.

358. (Polymers Derived from Nitriles) Wildi, B. S. and Katon, J. E., J. Pol. Sci. A2, 4709, 1964.
Some materials of polymeric nature, derived from nitriles, are described. These infusible, insoluble powders have conductivities between 10^{-1} and 10^{-6} Ω^{-1} cm^{-1} and activation energies from .06 to .98 eV.

359. ("Saran Carbon") Dacey, J. R., Frohnsdorff, G. J. C., and Gallagher, J. T., Carbon 2, 41, 1964.
The electrical conductivity in connection with absorbed water was studied on Saran Carbon rods and the results are discussed.

360. (Pyrolized Polyacrylonitrile) Yamaguchi, T., Carbon 2, 95, 1964.
Depending on the pyrolysis conditions, products with different physical properties are obtained. Values of resistivity, magneto-resistivity, and thermoelectric power are given.

361. Airapetyants, A. V., Voitenko, R. M., Davydov, B. E., Krentsel, B. A., and Serebryanikov, V. S., Vysokomol. Soedin, p. 86, 1964.
The electrical conductivity in pyrolyzed polyacrylonitrile fibres depends on the degree of orientation in the initial fibres. Under identical pyrolysis conditions the more oriented fibres result in products with higher conductivity.

362. (Superconducting Polymers) Little, W. A., Phys. Rev. 134, A1416, 1964. The possibility of superconduction in polymers is evaluated theoretically. A possible model, consisting of a polyene chain with cyanine dye-like substituents, is suggested. It is inferred that superconduction may even occur at room temperature.

F. Biopolymers

363. (Polypeptides) Suzuki, H., J. Phys. Soc. Japan 19, 2175, 1964. A one dimensional model for the behavior of a single excess electron or hole through the π-system in polypeptides is formulated taking electron-vibration interactions into account.

364. (Polypeptides and Polynucleotides) Yomosa, S., J. Phys. Soc. Japan 19, 1718, 1964. Two approaches to the calculation of the electronic band structures of hydrogen-bonded polypeptides or homopolynucleotides are discussed; one is the LCAO-MO method, the other uses Bloch wave functions.

365. (Polynucleotides DNA) Ladik, J. and Appel, K., J. Chem. Phys. 40, 2470, 1964. Based on the Watson-Crick model for DNA, the energy band structure was calculated using the Hückel approximation.

366. Beleznay, F. and Biczo, G., J. Chem. Phys. 41, 2351, 1964. In order to determine the energy band structure, a new method for applying the Hückel approximation is critically discussed.

367. Beleznay, F., Biczo, G., and Ladik, J., Phys. Letters 11, 234, 1964. Comparison of experimental conductivity values of DNA with theoretical values, shows that the conduction mechanism in DNA is not well understood.

368. Perakis, N. and Kern, F., Phys. Kondens. Materie 3, 29, 1964. On the basis of a cryomagnetic study some expectations are voiced on extrinsic conductivity in DNA.

369. Snart, R. S., Trans Far. Soc. 60, 1178, 1964. The effect of ultraviolet light on the electrical conductivity is reported. After an initial increase in conductivity by a factor of 10^6 upon radiation with 2600 Å light, the conductivity gradually decreases.

370. (DNA and Derivatives) Mesnard, G. and Vasilescu, D., Compt. Rend. 257, 4177, 1963. The electrical conductivity of three pyrimidine and two purine bases was determined and the results are discussed in terms of the electronic properties of the materials.

371. (DNA Salts) O'Konshi, C. T., Moser, P., and Shirai, M., Biopolymers Symposia 1, 479, 1964. The electrical conductivity and dielectric constant of solid Na-, Li-, and mg-salts of DNA are measured and the results are discussed.

372. Liang, C. Y. and Scalco, E. G., J. Chem. Phys. 40, 919, 1964.
The influence of moisture on the electrical conductivity of the solid Na salt of DNA was investigated.

373. (Protein - Dye Systems) Peersen, E. and Ore, A., Phys. Norveg. 1, 205, 1963.
Addition of dyes such as rhodamine or methylene blue to gelatin increased the conductivity of the latter by factors of 10^4 and 5×10^7. Details about other protein-dye systems are also reported.

CHAPTER V

FERROELECTRIC AND PIEZOELECTRIC MATERIALS

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I. Introduction and Summary

The most prominent feature of this year's literature is the continuing proliferation of papers on optical aspects of piezoelectric crystals for use with coherent light sources. The newest interests are the use of perovskite crystals such as KTN above their Curie point as Kerr-effect modulators (Geusic and co-workers, Appl. Phys. Letters 4, 141-3, 1964), and the application of KTN or KDP in digital light-deflection arrangements (seven papers). Many measurements of second harmonic generation were also made, including two from crystals which are opaque to incident radiation of the second harmonic wavelength. All these papers, while they concern piezoelectric and ferroelectric materials, are somewhat peripheral to the main interests of piezoelectricity and ferroelectricity. With the field growing so rapidly, it may be appropriate in future years to cover the optics separately.

The lattice vibration approach to phase stability has been elaborated by several workers, with attention to specific ferroelectrics and near-far infrared measurements. One interesting use of this is the determination of the dielectric constant of semiconductive PbTe by far-infrared techniques (Cochran, Phys. Letters 13, 193, 1964).

There seem to be few noteworthy developments among the ceramic ferroelectrics. Perhaps the most significant paper is the description of the conversion between ferroelectric and antiferroelectric phases in modified lead zirconate by action of field and/or pressure (Berlincourt and co-workers, J. Phys. Chem. Solids 25, 659-74, 1964). A preliminary report of this work was given last year. The status of $BiFeO_3$ as a ferroelectric is still not clear, in spite of several years' work. More work on discovery of new complex perovskites is reported (Fesenko and co-workers, Izv. Akad. Nauk SSSR, Ser. Fiz.

28, 669-74, 1964; Venevtsev and co-workers, Dokl. Akad. Nauk SSSR 158, 86-8, 1964), but no obviously useful materials have been developed yet.

Renewed work on $LiNbO_3$ and $LiTaO_3$ has shown interesting properties, particularly electro-optic properties in the case of $LiNbO_3$ (Peterson and co-workers, Appl. Phys. Letters 5, 62-4, 1964).

A new piezoelectric crystal has been discovered with high mechanical Q and higher electromechanical coupling than quartz ($LiGaO_2$; Remeika and Ballman, Appl. Phys. Letters 5, 180-1, 1964). The Russians have continued their systematic study of the piezoelectric properties of crystals, including measurements on several silicates and organic crystals.

Buhrer and co-workers and Sliker and co-workers measured the electro-optic properties of a number of crystals. It is probable that the electro-optic constant of hexamethylenetetramine reported last year is a good deal too high.

Another crystal whose status is in doubt is boracite. Several years ago it was investigated as a possible new ferroelectric, but the evidence was inconclusive. A new look has been taken by Tar and co-workers, who were able to observe slow movement of domains with an electric field.

The discovery by White in 1962 of ultrasonic amplification in CdS has resulted in a good deal of interest in the piezoelectric properties of semiconductors, both on a practical and on a theoretical level.

In summary, while the interest in the whole field of ferroelectrics and piezoelectrics has been maintained, particularly in Russia and Japan, the current excitement in this country is being generated in the fields of optical properties and optical uses of crystals, and also in the piezoelectricity of semiconductors.

II. Reviews

Devonshire, A. F., Repts. Progr. Phys. 27, 1-22, 1964.
Ferroelectric materials are reviewed with emphasis on the more recent work.

Sonin, A. S. and Zheludev, I. S., Rost Kristallov, Akad. Nauk SSSR, Inst. Kristallogr. 4, 171-80, 203-8, 1964. (Russian).
Reviews are given of new non-oxide ferroelectrics and antiferroelectrics and of isomorphism and ferroelectric properties.

Frazer, B. C., J. Phys. Soc. Japan, Suppl. B-II 17, 376-82, 1962.
Neutron-diffraction studies of ferroelectrics are reviewed.

Gilman, J. J. (Ed.), The Art and Science of Growing Crystals, John Wiley, New York, 1963, pp. 493.
Review articles are presented by 25 authors covering the theory of crystal growth and state-of-the art with respect to the following growth methods: vapor deposition, growth from solution, hydrothermal growth, growth from the melt (Czochralski, Kyropoulos, Bridgman-Stockbarger, zone melting, floating zone, and Verneuil techniques), and solid-state recrystallization. Growth of many piezoelectric and ferroelectric crystals is included.

Palermo, J. A., Ind. Eng. Chem. 56 (10), 38-52, Oct. 1964.
This is the latest in a periodic series of reviews of recent articles on crystallization, with 741 references. The previous article in the series was published in 1961. Many piezoelectrics and ferroelectrics are covered.

Poplavko, Yu. M., Izv. Kievsk. Politekhn. Inst. 41, 114-21, 1962.
A review is given of the electromechanical coupling coefficient and piezoelectric constants of piezoelectric and ferroelectric crystals and ferroelectric ceramics. The author likes compositions in the system $Ba(Ti,Zr,Sn)O_3$ for low losses and high piezoelectricity.

Cady, W. G., Piezoelectricity, Revised Ed., 2 vol., Dover Publ., Inc., New York, 1964.
A new updated edition has been published of his classic book.

III. Theory and Mathematics

Cochran, W., Repts. Progr. Phys. 26, 1-45, 1963.

Cowley, R. A., "Internat. Conf. Lattice Dynamics Copenhagen, 1963," 52-3.

Dvorsk, V., Phys. Status Solidi 3, 2235-40, 1963.

Silverman, B. D., Phys. Rev. 135 A, 1596-1603, 1964.
The four articles are concerned with analysis of lattice vibrations in cubic or nearly cubic (ferroelectric) crystals.

Sinha, K. P. and Sinha, A. P. B., Indian J. Pure Appl. Phys. 2, 91-4, 1964.
The possible role of Jahn-Teller distortions in the origin of ferroelectricity and the occurrence of ordered phases in ferroelectric perovskites is analyzed.

Kopvillem, U. Kh., Golenishchev-Kutuzov, V. A., and Nagibarov, V. R., Fiz. Tverd. Tela 6, 1251-3, 1964. (Russian). Soviet Phys.-Solid State 6, 974-5.
The possibility of observing nuclear quadrupole resonance in the domain walls of ferro- and antiferroelectrics is considered mathematically.

Kinase, W., Suzuki, K., and Kazami, A., Progr. Theoret. Phys. (Kyoto) 30, 266-8, 1963.
The mechanism of polarization reversal is considered from a quantum-mechanical standpoint.

Ashley, J. C. and Harris, E. G., Bull. Am. Phys. Soc. 8, 559-60, 1963.

Tsu, R., J. Appl. Phys. 35, 125-30, 1964.
Both papers are concerned with the phonons emitted (analogous to Cerenkov radiation) when a charged particle passes through a piezoelectric medium with supersonic velocity.

Seebass, J., Z. Naturforsch. 19a, 284-93, 1964.
Ultrasonic waves resulting from a charged particle moving through a piezoelectric cubic crystal cause an energy loss of 10 to 100 kev/cm.

Gurevich, V. L. and Laikhtman, B. D., Fiz. Tverd. Tela 6, 2884-6, 1964. (Russian). Soviet Phys.-Solid State 6, 2299-2300.
The dependence of a standing acoustic wave on electric field in a piezoelectric crystal is analyzed mathematically.

Joseph, R. I. and Silverman, B. D., Phys. Rev. 133A, 207-10, 1964.
The nonlinear dielectric constant of a paraelectric crystal is analyzed using the dynamic lattice theory of Born and von Karman. The deviations from the Devonshire theory are discussed.

Davis, L., J. Appl. Phys. 35, 2004-10, 1964.
The thermal fluctuations of spontaneous polarization were analyzed by three methods: thermodynamic, using Fröhlich's theorem, and by the method of equivalent circuits.

Müser, H. E., Phys. Verhandl. 4, 84, 1964. (German, abstract).
Equations of state were established for ferroelectric crystals.

Aizu, K., Phys. Rev. 133, A1350-9; 134, A701-12; 136, A753-8, 1964; J. Phys. Soc. Japan 19, 918-23, 1488-9, 1964.
The conditions necessary for ferroelectricity, the classification and characteristics of ferroelectrics and their transformations are considered in a series of articles.

Shuvalov, L. A., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 660-5, 1964. (Russian).
A new classification of ferroelectrics is made which is based upon their types of domain structure.

Zheludev, I. S., Proc. Indian Acad. Sci. 59A, 168-84, 1964.
The changes of symmetry involved in ferroelectric and ferromagnetic transitions were systematized.

Rolov, B. N., Fiz. Tverd. Tela 6, 2128-30, 1964. (Russian). Soviet Phys.-Solid State 6, 1676-8.
The effect of composition fluctuations on the broadening of ferroelectric transitions was studied mathematically. The dependence of spontaneous polarization and permittivity on temperature was obtained for second-order transitions.

Isupov, V. A., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 653-7, 1964. (Russian).
The relation between various types of relaxation polarization mechanisms and diffuse ferroelectric transitions is discussed in detail.

Barker, A. S., Jr., Phys. Rev. 135A, 1732-7, 1964.
A general classical model is proposed to explain the dielectric behavior of $BaTiO_3$, $SrTiO_3$, and $KTaO_3$ in certain infrared-frequency regions near the three infrared-active modes.

Tatarskii, V. B., Kristallografiya 9, 451-4, 1964. (Russian). Soviet Phys.-Cryst. 9, 377-9.
Materials in any of four non-enantiomorphic classes (m, mm2, $\bar{4}$, $\bar{4}2m$) could show optical rotation but only one such has been reported $(C_9H_{12}O_4)_2$. The author shows that this report is wrong, and speculated on possible occurrences.

Shuvalov, L. A. and Ivanov, N. R., Kristallografiya 9, 363-72, 1964. (Russian). Soviet Phys.-Cryst. 9, 291-7.
The possibilities of change of optical activity in ferroelectrics resulting from switching is examined. The various possible changes are tabulated.

Granovskii, V. G., Izv. Vysshikh. Uchebn. Zavedenii, Fiz. 1964, 131-4. (Russian).
The dependence of piezoelectric constants and a second-order transition temperature on elastic stresses in a ferroelectric solid solution is examined theoretically.

IV. Measurement and Processing Techniques

General Electric Co., Ltd. (by John Butcher and E. A. D. White), Brit. Patent 952,385, March 18, 1964; Appl. Aug. 30, 1961.

Centre National de la Recherche Scientifique, Belg. Patent 630,303, Oct. 21, 1963; Fr. Appl. Mar. 29, 1962.

Compagnie Generale d'Electricite (by F. Forrat), Fr. Patent 1,347,015, Dec. 27, 1963; Appl. Aug. 10, 1962.
These three patents are concerned with growing refractory crystals, including perovskites. The methods discussed are molten flux, zone-melting, and modified Verneuil techniques respectively.

Hodge, E. S., Powder Met. 7, 168-201, 1964.
Hot isostatic pressing of a variety of materials including $BaTiO_3$ is described.

N. V. Philips' Gloeilampenfabrieken (by E. C. Munk, J. P. J. Philippart, and A. Rademakers), Ger. Patent 1,151,209, July 4, 1963; Neth. Appl. May 23, 1959.
The manufacture of thin flat ceramic sheets of materials such as $BaTiO_3$ less than 0.5 mm thick is described.

Kamenev, L. V., Novye Mashiny i Pribory dlya Ispytaniya Metal., Sb. Statei 1963, 182-4. (Russian).
An apparatus is described to measure dielectric constant and loss of semiconductive samples.

Aharoni, A. and Sapoznikov, D., Rev. Sci. Instr. 35, 1370-1, 1964.
The circuit diagram is given of a device to plot automatically the piezoelectric resonances over a range of frequencies.

Redwood, M., J. Acoust. Soc. Am. 36, 1872-80, 1964.
The electrical analog of a piezoelectric transducer was built and used to demonstrate the generation and detection of acoustic waves and the electrical characteristics of a piezoelectric resonator.

Tehon, S. W. and Wanuga, S., Proc. IEEE 52, 1113-27, 1964.
The propagation and characteristics of acoustic waves at microwave frequencies is discussed, with emphasis on effects and techniques at cryogenic temperatures.

Kucka, J. and Svehla, S., Czech. Patent 110,047, Feb. 15, 1964; Appl. Nov. 23, 1961.
An enamel coating for preventing loosening of silver electrodes for use on ultrasonic elements is described.

V. Applications

Nekrasov, M. M. and Poplavko, Yu. M., Avtomatika i Priborostr., Nauchn.-Tekhn. Sb. 1963 59-62. (Russian).
The use of ferroelectric materials above their Curie points as sensors for temperature and pressure is described.

Willis, J. and Jimerson, B. D., Proc. IEEE 52, 871-2, 1964.
A design for an accelerometer is suggested using frequency changes of around 100 cps per pound of force for crystals with resonant frequency around 300 kc. The design has not been tested, but should be considerably more sensitive than existing accelerometers.

Rozenberg, L. D. and Sirotyuk, M. G., Akust. Zhur. 9, 61-5, 1963. (Russian). Soviet Phys.-Acoustics 9, 47-50.
A mosaic bowl, with shell radius 183 mm, was made, using lead titanate-zirconate ceramics, which is capable of concentrating energy to 43000 watts/cm^2.

Billeter, T. R., Giarola, A. J., and Bjorkstam, J. L., J. Appl. Phys. 35, 2159-60, 1964.
The conditions required for a dielectric parametric amplifier are calculated and the data applied to $SrTiO_3$.

Schubring, N. W., Nolta, J. P., and Dork, R. A., Rev. Sci. Instr. 35, 1517-21, 1964.
A hysteresis loop tracer is described which features sample grounding and compensation of capacitance and conductance.

Muirhead, J. C. and Fenrick, W. J., J. Sci. Instr. 41, 483-4, 1964.
A warning is given of the anomalous results obtained when a ceramic element in a blast gauge is subjected to fields other than those resulting from the function measured.

Gorshtein, A. E. and Soroko, V. E., Izv. Vysshikh Uchebn. Zavedenii, Khim. i Khim. Tekhnol. 7, 137-40, 1964. (Russian).
Ultrasonic probes using $BaTiO_3$ or Rochelle salt transducers are used in sensing particle motion in a fluidized bed.

Winslow, J. S. and Kazan, B., Proc. IEEE 52, 1381, 1964.
The theoretical performance improvement and the circuit and intensifier designs are considered for a solid state image intensifier with an added ferroelectric amplifying stage.

Orlov, I. N. and Taborko, N. I., Opt. Spectry. 9, 329-31, 1960. (Translation of the Russian Journal Optika i Spektroscopiya).
A circuit is described for an electroluminescent image amplifier using a photoconductor and a ferroelectric material. By using ZnS with green luminescence, a photoconductive CdS powder, and a single crystal of TGS, it is possible to obtain a light flux amplification coefficient of $\sim 5 \times 10^4$ at low input illumination ($\sim$ 0.01 lux).

Stern, M. O. and Dacus, E. N., Rev. Sci. Instr. 32, 140-3, 1961.

Buechl, K., Z. Naturforsch. 19a, 690-6, 1964.
These two papers consider various aspects of the use of a piezoelectric probe for measuring phenomena of short duration to moderately small pressures.

VI. Electro-optics, Indices of Refraction, and Second Harmonic Generation, Including Applications

A. Second Harmonic Generation

Miller, R. C., Phys. Rev. 134A, 1313-19, 1964.
The coefficients of second harmonic generation in single domain $BaTiO_3$ were measured versus temperature. They have the same temperature dependence as the spontaneous polarization. The effect of various domain arrangements on second harmonic generation was also determined.

Boyd, G. D., Miller, R. C., Nassau, K., Bond, W. L., and Savage, A., Appl. Phys. Letters 5, 234-6, 1964.
Large second harmonic generation is reported in single crystals of $LiNbO_3$. Other data are also given, including indices of refraction from 0.42 to 4.00 microns.

Carr, P. H., Phys. Rev. Letters 13, 332-5, 1964.
Second and third harmonic generation of microwave phonons in quartz was measured. The second harmonic power was around 5 orders of magnitude greater in X-cut quartz than in the non-piezoelectric Z-cut.

Van der Ziel, J. P. and Bloembergen, N., Phys. Rev. 135A, 1662-9, 1964.
The second harmonic generation in KH_2PO_4 (KDP) has been measured between 77° and 300°K. Single domain crystals have to be used below the Curie point. Second harmonic generation was also measured for $NH_4H_2PO_4$ from 300°K to the transition point.

Himbarger, R. L. and Bjorkstam, J. L., Appl. Phys. Letters 3, 109-10, 1963.
The second harmonic generation in KDP near the Curie point was investigated. Anomalies observed are due to domain or dimensional effects rather than the fundamental process in second harmonic generation production.

Van der Ziel, J. P., Appl. Phys. Letters 5, 27-9, 1964.
The modulation of second harmonic generation in KDP (not at the index-matched angle) is analyzed.

Johnson, F. M., Proc. IEEE 52, 1351, 1964.
The generation of coherent continuous wave radiation at 3164 Å in KDP was described. The index matching angle (~ 56°) was used.

Miller, R. C., Appl. Phys. Letters 5, 17-19, 1964.
Coefficients describing optical second harmonic generation and electro-optic coefficients are given for Kh_2PO_4,KD_2PO_4, $NH_4H_2PO_4$, KH_2AsO_4, quartz, $AlPO_4$, ZnO, CdS, GaP, GaAs, and $BaTiO_3$. When expressed in terms of polarization, the electro-optical effects in all these crystals are of remarkably uniform magnitudes.

Takatsuji, M., J. Phys. Soc. Japan 19, 1090-1, 1964.
The optical second harmonic generation in ZnS plain and doped with Fe^{3+} was measured as a function of temperature. Second harmonic generation was 20 times the level in CdS and adenosine diphosphate.

Tell, B., Phys. Rev. 136A, 772-5, 1964.
Theoretical relations and experimental data are presented on ultrasonic second harmonic generation in photoconductive CdS. The harmonic power is proportional to the square of the input power.

Soref, R. A. and Moos, H. W., J. Appl. Phys. 35, 2152-8, 1964.
The optical second harmonic generation was measured as a function of composition in (Zn,Cd)Se and Cd(S,Se) single crystals. There is a strong dependence upon the band gap; appreciable second harmonic signals were detected in crystals which are highly absorbing at the harmonic frequency.

Nelson, D. F. and Reinhart, F. K., Appl. Phys. Letters 5, 148-50, 1964.
Phase modulation was observed of light guided through the depletion layer of reverse-biased GaP p-n junctions. The phase modulation is believed to be caused by the Pockels effect arising from the junction electric field.

Peterson, D. G. and Yariv, A., Appl. Phys. Letters 5, 184-6, 1964.
A coherent light beam at a frequency $f_o + f_m$ was generated from an optical wave at f_o and a microwave signal at f_m by a KDP crystal within the laser resonator.

Ward, J. F. and Franken, P. A., Phys. Rev. 133, 183-90, 1964.
The relationship of second harmonic generation and the linear electro-optic effects to electronic (ultraviolet) and ionic (infrared) energy levels is analyzed in the light of recent experimental data.

Rentzepis, P. M. and Pao, Y.-H., Appl. Phys. Letters 5, 156-8, 1964.
Optical second harmonic generation is reported in crystals of 3,4 benzpyrene and 1,2 benzanthracene. Of special interest is the fact that they are opaque to incident radiation at the ruby laser second harmonic wavelength (3470Å).

B. Electro-optic Coefficients and Indices of Refraction

Peterson, G. E., Ballman, A. A., Lenzo, P. V., and Bridenbaugh, P. M., Appl. Phys. Letters 5, 62-4, 1964.
Strong electro-optic effects are observed in $LiNbO_3$, increasing with temperature.

Geusic, J. E., Kurtz, S. K., Van Uitert, L. G., and Wemple, S. H., Appl. Phys. Letters 4, 141-3, 1964.
The dependence of the quadratic electro-optic (Kerr) effect on temperature, wavelength, and frequency of applied field is reported for $KTaO_3$, $KTa_{0.65}Nb_{0.35}O_3$, $BaTiO_3$, and $SrTiO_3$. The polarization-related Kerr coefficients are temperature independent and show little variation among the various perovskites.

Sliker, T. R., J. Opt. Soc. Am. 54, 1348-51, 1964.
Pockels effect constants were determined for a number of piezoelectric crystals: potassium dithionate (class 32, $r_{11} = 0.263 \pm 0.013$), cesium tartrate (class 32, $r_{11} = 1.0 \pm 0.2$), glucose $NaBr \cdot H_2O$ (class 32, $r_{11} = 0.10 \pm 0.01$), Sr dithionate $\cdot\, 4H_2O$ (class 32, $r_{11} < 0.03$), $LiKSO_4$(class 6, $r_{13} - r_{33} = 1.6 \pm 0.16$), $NaLiSO_4$ (class 3m, $r_{22} < 0.02$),all x 10^{-12}m/v.

Gainon, D. J. A., J. Opt. Soc. Am. 54, 270-1, 1964.
Pockels effect constants were measured for CdS, doped with copper to improve resistivity: $r_{51} = 3.7 \pm 0.5$, $|r_{13} - r_{33}| = 4 \pm 1 \times 10^{-12}$m/v.

Sterzer, F., Blattner, D., and Miniter, S., J. Opt. Soc. Am. 54, 62-8, 1964.
Design and theory of CuCl light modulators is discussed in comparison with other materials. Some properties of CuCl are: transparent from 0.4 to 20.5μ, dielectric constant = 7.5 (measured at C band), r_{41} at 5461 Å = 5.6 x 10^{-12}m/v.

Ott, J. H. and Sliker, T. R., J. Opt. Soc. Am. 54, 1442-4, 1964.
New measurements of the Pockels effect in KDP and isomorphs are reported: KH_2PO_4 $r_{63} = 10.3 \pm 0.1$, $r_{41} = 8.77 \pm 0.14$; KD_2PO_4 (~ 90% deuterated) $r_{41} = 8.8 \pm 0.4$; KH_2AsO_4 $r_{63} = 10.9 \pm 0.1$, $r_{41} = 12.5 \pm 0,4$; $RbH_2AsO_4 r_{63} = 13.0 \pm 0.2$; $NH_4H_2PO_4 r_{41} = 24.5 \pm 0.4$, all x 10^{-12}m/v.

Buhrer, C. F. and Ho, L., Appl. Opt. 3, 314, 1964.
The linear electro-optic coefficient $n_0^3 r_{41}$ is given for various wavelengths for the "langbeinites" $(NH_4)_2Cd_2(SO_4)_3$ and $(NH_4)_2Mn_2(SO_4)_3$. The Pockels constants are down an order of magnitude from common electro-optic materials such as ZnS and KDP.

Buhrer, C. F. and Ho, L., Appl. Opt. 3, 1500-1, 1964.

Sliker, T. R., J. Opt. Soc. Am. 54, 1348-51, 1964.

Heilmeier, G. H., Appl. Opt. 3, 1281-7, 1964.

Heilmeier, G. H., Ockman, N., Braunstein, R., and Kramer, D. A., Appl. Phys. Letters 5, 229-30, 1964.
These papers all report electro-optic data on hexamethylenetetramine (HMT).

The first two agree exactly, with $r_{41} = 0.8 \pm 0.1 \times 10^{-12}$m/v. Heilmeier obtained a value of 4.2×10^{-12} m/v. The original McQuaid measurement was 7.3×10^{-12} m/v. In view of the careful work by Buhrer and Ho and by Sliker on crystals grown by a variety of methods, it appears likely that 0.8×10^{-12} is the correct value, and that the higher ones are in error. It is possible, however, that some as yet undiscovered structural variant is affecting the results. Dielectric properties, second harmonic generation, and a theoretical model of HMT were also considered by Heilmeier and co-workers.

Buhrer, C. F., Ho, L., and Zucker, J., Appl. Opt. 3, 517-21, 1964.
The complications in attempting to use the electro-optic effect in an optically active crystal are discussed. The use of Na-thioantimonate crystals for electro-optic modulation is described.

Lawless, W. N. and DeVries, R. C., J. Appl. Phys. 35, 2638-9, 1964.

Shumate, M. S., Appl. Phys. Letters 5, 178-9, 1964.
The first paper reports n_o at 5893 Å versus temperature for $BaTiO_3$. Between 20° and 105°, $n_o = 2.368$; above the Curie point the value is 2.938. No other variation with temperature was found. In the second paper, n_o and n_e are given at seven wavelengths. The value of n_o is significantly larger than for the first paper.

Trifonov, I. A., Kristallografiya 9, 923-5, 1964. (Russian).
The indices of refraction of hexagonal $BaTiO_3$ are $n_o = 2.28 \pm .02$, $n_e = 2.42 \pm .03$.

C. Electro-optic Modulation, Light Beam Deflection, and Other Applications

Gil'varg, A. B. and Kolesov, G. V., Pribory i Tekh. Eksperimenta 3, 123-6, 1961.
A description is given of the use of KDP and ADP ($NH_4H_2PO_4$) as light modulators.

Takasaki, H. and Yochino, Y., J. Opt. Soc. Am. 54, 551, 1964.
A method is given for determining the orientation of ADP crystals in an electro-optic apparatus by means of the elastically induced birefringence.

Stone, S. M., Proc. IEEE 52, 409-10, 1964.
A microwave electro-optic modulator is described using the Pockels effect in KDP.

Wentz, J. L., Proc. IEEE 52, 716-7, 1964.
Two crystals of KDP oriented at 90° to each other are used in a Laser modulator.

Yariv, A., Proc. IEEE 52, 719-20, 1964.
An optical feed-back mechanism was designed for the frequency modulation and frequency stabilization of lasers.

Cohen, M. G. and Gordon, E. I., Appl. Phys. Letters 5, 181-2, 1964.

Chen, F. S., Geusic, J. E., Kurtz, S. K., Skinner, J. G., and Wemple, S. H., Proc. IEEE 52, 1258-9, 1964.

Haas, W., Johannes, R., and Cholet, P., Appl. Opt. 3, 988-9, 1964.

Skinner, J. G., Appl. Opt. 3, 1504, 1964.
Three of the above papers discuss various aspects of the use of $K(Ta_xNb_{1-x})O_3$ (KTN) and other perovskites in beam deflectors and other optical read out systems. Skinner points out that what is important is the spot resolution rather than the maximum angular deflection.

Kulcke, W., Harris, T. J., Kosauke, K., and Max, E., IBM J. Res. Dev. 8, 64-7, 1964.

Nelson, T. J., Bell System Tech. J. 43, 821-45, 1964.

Fowler, V. J., Buhrer, C. F., and Bloom, L. R., Proc. IEEE 52, 193-4, 1964.
The use of KDP in digital light beam deflectors is discussed. The designs described in the first two papers allow random read out of at least 1000 positions using calcite as the deflector and KDP as an electro-optical switch. The maximum measured angular deviation in the third paper was 9 minutes of arc using KDP as the beam deflector.

Harris, S. E. and Siegman, A. E., Appl. Opt. 3, 1089-90, 1964.
The Kerr effect in cubic perovskites is used for optical frequency translation.

Kaminow, I. P., Appl. Opt. 3, 507-10, 511-15, 1964.
The advantages of phase modulation over intensity modulation in optical communication systems are pointed out, particularly in connection with strain effects arising from bulk heating and surface cooling of the modulator.

VII. Miscellaneous Articles

This section is for articles that for one reason or another are not readily classified in the other sections.

Hauser, O. and Schenk, M., Phys. Status Solidi 6, 83-8, 1964.
The change of a number of crystalline materials (including $BaTiO_3$ and Quartz) with neutron irradiation is described. The authors conclude that compounds with displacive temperature transitions are more likely to suffer irradiation-induced phase transformations than compounds with reconstructive transitions.

Cook, W. R., Jr., Norelco Repts. 10, 144-5, 1963.
Lattice constants of increased accuracy are given for a number of piezoelectric and ferroelectric materials.

Heywang, W. and Schöffer, R., Phys. Verhandl. 1963, 147. (German).
The determination of a phase diagram by means of anomalies in piezoelectric resonances is described.

Grebenshchikov, R. G. and Toropov, N. A., Dokl. Akad. Nauk SSSR 158, 710-13, 1964. (Russian)
Standard enthalpies of formation are calculated for the alkaline earth titanates and zirconates. The curves show that Mg_2TiO_4, Ba_2TiO_4, $SrTiO_3$, and $CaTiO_3$ are the energetically favored forms of each alkaline earth titanate or corresponding zirconate.

Güerci, J., Levialdi, A., and Schoijet, M., Phys. Status Solidi 6, 179-83, 1964.
Transient variations of permittivity in ferroelectric ceramics, resulting from application or removal of a dc field, are explained in terms of domain reversal.

Izhak, I. A., Nauchn. Zap. Dnepropetr. Univ. 61, 49-51, 1963. (Russian).
Uniaxial pressure parallel to an alternating field decreases the dielectric losses of ferroelectrics for weak fields. For pressure perpendicular to field the losses increase with weak fields and decrease for strong fields. A qualitative explanation is offered.

Khuchua, N. P. and Lychkataya, L. F., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 708-13, 1964. (Russian)
The temperature dependence of dielectric constant and loss of ceramic $BaTiO_3$, $Pb_3MgNb_2O_9$, and Pb_2MgWO_6 was investigated from 10^3 to 10^8 cycles/sec. At these frequencies and high temperatures no maximum was observed in dielectric constant for $BiFeO_3$, $BiFeO_3$-$LaFeO_3$, and $BiFeO_3$-$LaAlO_3$.

Belyaev, L. M., Belikova, G. S., Dobrzhanskii, G. F., Netesov, G. B., and Shaldin, Yu. V., Fiz. Tverd. Tela 6, 2526-8, 1964. (Russian). Soviet Phys.-Solid State 6, 2007-8.
The dielectric constant and loss of the electro-optic crystals ADP, KDP, HMT, and CuCl were determined.

Moreno, M. and Gränicher, H., Helv. Phys. Acta 37, 625, 1964. (German).
The pressure dependence of dielectric constants of $BaTiO_3$, $SrTiO_3$, and SbSI is summarized.

Rupprecht, G. and Bell, R. O., Phys. Rev. 135A, 748-52, 1964.
Measurement of microwave dielectric constants of $CaTiO_3$, $SrTiO_3$, $BaTiO_3$, $PbTiO_3$, and $KTaO_3$ gives a Curie-Weiss law of the form $\epsilon = \epsilon_L + \left(\frac{C}{T-T_c}\right)$, where ϵ_L is of the order of 50 and represents the limiting dielectric constant at infinite temperature.

Poplavko, Yu. M., Izv. Kievsk. Politekhn. Inst. 40, 42-58, 1962. (Russian).
Dielectric constant and loss at centimeter wavelengths are reported for $BaTiO_3$, $BaTiO_3$ + 0.5% BaO, and $Ba(Ti_{0.82}Zr_{0.12}Sn_{0.06})O_3$.

Murzin, V. N. and Demeshina, A. I., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 695-702, 1964. (Russian). Fiz. Tverd. Tela 6, 182-92, 1964. (Russian). Soviet Phys.-Solid State 6, 144-52.
Transmission and reflection spectra at 2 to 1000 microns were measured for $BaTiO_3$ and $SrTiO_3$ at several frequencies, and the results were evaluated.

Stankowska, J. and Stankowski, J., Zeszyty Nauk. Uniw. Poznaniu, Mat., Fiz. Chem. No. 5, 81-98, 1962. (Polish).
Crystals of Rochelle salt and triglycine sulfate (TGS) were grown pure and containing $CuSO_4$ additions, and their ferroelectric properties studied. Aged samples containing $CuSO_4$ have constricted hysteresis loops.

Shuvalov, L. A. and Shirokov, A. M., Dokl. Akad. Nauk SSSR 154, 1075-7, 1964. (Russian).
The dependence of mechanical Q on deformation amplitude was studied in Rochelle salt and TGS within and outside the ferroelectric range.

Syrkin, L. N. and El'gard, A. M., Fiz. Tverd. Tela 6, 3235-9, 1964. (Russian).

El'gard, A. M., Fiz. Tverd. Tela 6, 2502-9, 1964. (Russian). Soviet Phys.-Solid State 6, 1984-90.
The influence was investigated of unidimensional pressure on the dielectric and piezoelectric properties of poled ferroelectric ceramics based on $BaTiO_3$, $PbNb_2O_6$, and $Pb(Ti,Zr)O_3$.

Rysanek, V., Cesk. Casopis Fys. 10, 93-7, 1960.
The changes in stress in poled $BaTiO_3$, $(Ba_{0.9}Sr_{0.1})TiO_3$, and Rochelle salt were studied as a function of temperature.

Andronova, I. A., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 722-5, 1964. (Russian).
The current noise resulting from periodic applied voltages of changing frequency was measured in ceramic $BaTiO_3$ and single crystal $BaTiO_3$ and TGS. Changes in domain structure were suggested to be the cause of the effects.

Strizhkov, B. V. and Lapitskii, A. V., Izv. Vysshikh Uchebn. Zavedenii, Khim. i Khim. Tekhnol. 7, 373-7, 1964. (Russian).
Dielectric and piezoelectric constants are reported for ceramics of $(Ba_{0.88}Pb_{0.12})TiO_3$, $(Pb_{0.8}Sr_{0.2})Nb_2)_6$, $(Pb_{0.7}Sr_{0.3})Nb_2O_6$, and $(Pb_{0.6}Ba_{0.4})Nb_2O_6$. $(Ba_{0.88}Pb_{0.12})TiO_3$ has d_{31} = 36-60 and 67-131 x 10^{-12}m/v.

Callaby, D. R. and Fatuzzo, E., J. Appl. Phys. 35, 2443-51, 1964.
The oscillation of a ferroelectric body which is attached to a spring with the frequency of the applied field (reported by Zheludev in 1959) is shown to be due to a shearing of the crystal resulting from the polarization-induced strain.

Mingins, C. R., Barcus, L. C., and Perry, R. W., "Proc. 17th Annual Symp. Frequency Control, Atlantic City, 1963," 51-87.
The reactions of a vibrating piezoelectric crystal plate to externally applied forces are analyzed.

Martin, G. E., J. Acoust. Soc. Am. 35, 510-12, 1963; 36, 1496-1506, 1964.
The theory of vibrations in longitudinally poled ferroelectric ceramic tubes is developed.

Benes, F. and Soska, F., Czech. J. Phys. 14, 189-95, 1964.
The action of a magnetic field on a vibrating piezoelectric body was investigated.

VIII. $BaTiO_3$

A. Theory and Vibrations

Kinase, W., Ishibashi, Y., and Matuura, K., J. Phys. Soc. Japan 19, 264-8, 1964.
Lattice vibrations are calculated for $BaTiO_3$, with interactions among the constituent ions taken into account. The lowest optical mode rapidly becomes unstable with increasing dipole interaction.

Murzin, V. N., Bogdanov, S. V., and Demeshina, A. I., Fiz. Tverd. Tela 6, 3372-7, 1964. (Russian).
A calculation was made by the Cochran method of the dispersion expression for the complex dielectric constant. A comparision of calculated results with experimental data allows an evaluation of some microscopic parameters of $BaTiO_3$.

Janovec, V. and Dvorak, V., Czech. J. Phys. 13, 905-9, 1963.
An attempt to apply simple ion models to the lattice dynamics of $BaTiO_3$ did not give consistent results.

Richard, M., These Doct. Sci. phys. Lyon, 1963. Gap, Impr. Louis-Jean, 1963, 81 pp.
A thermodynamic analysis is made of ferroelectric-paraelectric transitions, and a theoretical interpretation is made of the tetragonal-cubic transition in $BaTiO_3$.

Fontaine, G., Phys. Status Solidi 5, 203-6, 1964.
A calculation is made of the elastic energy of a dislocation in a $BaTiO_3$ crystal as a function of orientation.

Lezgintseva, T. N., Fiz. Tverd. Tela 6, 2401-4, 1964. (Russian). Soviet Phys.-Solid State 6, 1905-7.
An expression is proposed for the dielectric constant of a $BaTiO_3$ crystal with a layered domain structure, and the results are compared with experimental data.

Sannikov, D. G., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 703-7, 1964. (Russian).
Theoretical formulas are derived for $BaTiO_3$, taking into account elastic and electrostrictive effects, which are applied to domain motion, and the dispersion of dielectric constant at 10^9 to 10^{10} cycles/sec.

Fatuzzo, E., Proc. Phys. Soc. (London) 84, 709-17, 1964.
The frequency of infrared absorption bands in barium titanate can be expected to be shifted by a factor of 100 with field of 10-20 kv/cm and temperatures near the Curie point.

Ikegami, S., J. Phys. Soc. Japan 19, 46-51, 1964.
The Raman spectrum of tetragonal $BaTiO_3$ crystals is reported and interpreted.

B. Crystallography and Methods of Preparation

Joho, P., Z. Krist. 120, 329-41, 1964.
The lattice constants of $BaTiO_3$ were measured between room temperature and 200°. The expansion coefficients of $BaTiO_3$ at room temperature are $\alpha_a = 15.9$ and $\alpha_c = -6.7 \times 10^{-6}/°C$ in good agreement with Rhodes (1951).

Motegi, H. and Mitsui, T., J. Phys. Chem. Solids 25, 253-5, 1964.
X-ray back reflection for $BaTiO_3$ shows increase of diffuseness and decrease in intensity as temperature falls to the Curie point, in agreement with theory.

Elliott, W. R. and Bjorkstam, J. L., J. Phys. Chem. Solids 25, 1273-5, 1964.
The EPR spectrum of Fe^{3+} in $BaTiO_3$ is used to demonstrate the first order transition from orthorhombic to tetragonal with temperature or field and the induced tetragonal phase with field above the Curie point.

Minomura, S., Kawakubo, T., Nakagawa, T., and Sawada, S., Japan. J. Appl. Phys. 3, 562-3, 1964.
The shift of Curie point and tetragonal-orthorhombic transition with pressure are -6.3×10^{-3} and -2.8×10^{-3} degree/bar respectively.

Schenk, M., Phys. Status Solidi 4, K25-K28, 1964.
Tetragonal $BaTiO_3$ and cubic $SrTiO_3$ powder were irradiated with neutrons at 35°C. $BaTiO_3$ transforms to cubic at doses of 4.2×10^{18} neutrons/cm^2. Lattice expansion is 2.26% for a and 1.17% for c.

Burfoot, J. C., "Conf. Solid State Phys. Bristol, 1964," Publ. by London Inst. Phys. & Phys. Soc., 93.
The first order transition at 120°C was studied by pyroelectric measurements.

Yamaguchi, S., J. Appl. Phys. 35, 2559-60, 1964.
The structure of barium titanate crystal below and above the Curie point was studied using an electron beam which simultaneously heated the crystal and gave diffraction patterns.

Rothwell, W. S., J. Am. Ceram. Soc. 47, 409-11, 1964.
Plastic deformation in $BaTiO_3$ crystals was studied by observing etch pits.

Philips Electrical Industries Ltd., Brit. Patent 943,184, December 4, 1963; Neth. Appl. June 26, 1961.
Epitaxial growth of crystals such as $BaTiO_3$ is described.

DeVries, R. C., J. Am. Ceram. Soc. 47, 134-6, 1964.
The growth of large single crystals of $BaTiO_3$ is accomplished by heating in a steep temperature gradient, or by seeding polycrystalline aggregates with single crystals and recrystallizing. Both methods result in crystals of high porosity.

Feuersanger, A. E., Hagenlocker, A. K., and Solomon, A. L., J. Electrochem. Soc. 111, 1387-91, 1964.

Japan Telegram and Telephone Corp., Brit. Patent 977,389, December 9, 1964; Japan. Appl. Jan. 14 and June 30, 1960.

Feldman, C., U. S. Patent 3,114,868, Dec. 17, 1963; Appl. June 7, 1956. Methods of making thin barium titanate films are described.

Herczog, A., J. Am. Ceram. Soc. 47, 107-15, 1964.

Ulrich, D. R., Univ. Microfilms, Order No. 63-8075, 139 pp; Dissertation Abstr. 24, 1524, 1963.
The formation and properties are given of $BaTiO_3$ crystallized from a glass.

Nye, J. D., J. Can. Ceram. Soc. 32, 29-33; 1963.
The preparation, properties, and uses of barium titanate are reviewed.

C. Domains and Switching; the Surface Layer

Tanaka, M. and Honjo, G., J. Phys. Soc. Japan 19, 954-70, 1964.
$BaTiO_3$ crystals thinned by etching to as thin as 1000 Å give no evidence of the anomalous surface layer proposed by Kaenzig. The surface changes substantially when heated above 500°C in air, invalidating their evidence for a high Curie point for their layer.

Liesk, W., Appl. Phys. Letters 5, 69-70, 1964.
In thin layers of pseudocubic $BaTiO_3$ formed by melting on Pt, the polarization may be directed in the [111] or [110] direction in the tetragonal range as well as the usual [001] direction.

Caslavsky, J. and Polcarova, M., Czech. J. Phys. 14, 454-8, 1964.

Lambert, M., Quittet, A. M., Taupin, C., and Guinier, A., J. Phys. (Paris) 25, 345-55, 1964.
The arrangement of domains in $BaTiO_3$ crystals was studied optically and by the Berg-Barrett or Lang techniques.

Niizeki, N. and Hasegawa, M., J. Phys. Soc. Japan 19, 550-4, 1964.
Anomalous X-ray dispersion of $CrK\alpha$ radiation is used to detect 180° domains in a *c*-plate of $BaTiO_3$.

Shabana, M. and Jones, R. V., Bull. Am. Phys. Soc. 9, 742, 1964.
Microprobe studies of $BaTiO_3$ crystals have revealed that localized c-domains exist in an a-domain crystal with elliptical shapes, with the major axis of the ellipse parallel to the polarization axis of the crystal.

Stadler, H. L. and Zachmanidis, P. J., J. Appl. Phys. 35, 2625-8, 2895-9, 1964.
A statistical study of the location of domains nucleating on the surface of a $BaTiO_3$ crystal indicated that domains can nucleate at points in the crystal remote from imperfections. The temperature dependence of 180° domain wall velocity in $BaTiO_3$ was also determined. The shape of domains changes with temperature.

Taylor, G. W., Australian J. Phys. 15, 549-67, 1962.
The speed of reversal, direction of movement, and shape of the domains as a result of high fields is described.

Fousek, J. and Brezina, B., J. Phys. Soc. Japan 19, 830-8, 1964; Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 717-21, 1964.
The relaxation and frequency dependence of the motion of 90° domain walls in $BaTiO_3$ were investigated, and interpreted mathematically.

Hayashi, M., Imaizumi, S., and Abe, R., Japan. J. Appl. Phys. 3, 637-43, 1964.
The decay in switching current in $BaTiO_3$ crystals with time is traced to the formation of many thin a-domains (about 10^{-4} cm thick).

Fuchs, E. and Liesk, W., J. Phys. Chem. Solids 25, 845-52, 1964. (German).
Domain structure and domain reversal are described in thin single crystal layers of $BaTiO_3$. Within a layer thickness of 1000 to 3000 Å, the same domain configurations are observed as in bulk crystals.

Kinase, W., Suzuki, K., and Kazami, A., Progr. Theor. Phys. Japan 30, 266-8, 1963.
A quantum mechanical interpretation is given of polarization reversal and the electronic state of the crystal surface of $BaTiO_3$.

Schoijet, M., Phys. Status Solidi 4, 639-43, 1964.
The conductivity of small grained ceramics and fine powders is the same as the conductivity of the bulk crystal. This argues against the existence of an exhaustion layer on the surface of $BaTiO_3$ as proposed by Känzig (1955).

Brezina, B. and Fotchenkov, A. A., Czech. J. Phys. 14, 21-5, 1964.

Brezina, B. and Janovec, V., Czech. J. Phys. 14, 44-7, 1964.
The difference in 180° switching of $BaTiO_3$ crystals with and without a surface layer was studied. A model is proposed for the surface layer in which the dielectric constant gradually decreases towards the surface.

Harland, G. E., Univ. Microfilms, Order No. 64-9990, 120 pp.; Dissertation Abstr. 25, 1989, 1964.
A high resolution X-ray study was made of dislocations and domain structure in barium titanate whiskers.

D. Electrical Data

Merz, W. J., Nachr.-Tech. Fachber. 29, 37-40, 1964.
The polarization, aging, coercive field, and losses in single crystal and ceramic $BaTiO_3$ are reviewed.

Marcus, B. and Melconian, V., Electrotechnica, Romin. 11, 433-40, 1963.
Ceramic piezoelectric elements of $BaTiO_3$ are described.

Klimowski, J., Bull. Soc. Amis Sci. Letters Poznan, Ser. B17, 59-87, 1964.
The change of transition point with high hydrostatic pressure was measured. Different rates are obtained above and below 3500 kg/cm^2.

Blaszkiewicz, B., Posnan. Towarz. Przyjaciol Nauk, Wydzial Mat. Przyrod. Prace Komisji Mat. Przyrod. 11, 173-8, 1964.
The dielectric behavior of polycrystalline $BaTiO_3$ of a range of densities was investigated versus pressure. No variation of Curie point with pressure was found, in contrast to many previous papers.

Goodman, G., J. Appl. Phys. 35, 2725-6, 1964.
Fracturing in $BaTiO_3$ ceramics due to damped high-voltage oscillations is described.

Fedotov, I. I., Fiz. Tverd. Tela 6, 602-10, 1964. (Russian). Soviet Phys.-Solid State 6, 472-8; Izv. Vysshikh Uchebn. Zavedenii, Fiz. 1964, 32-8. (Russian).
The dependence of Young's modulus on temperature, electric field strength, and frequency was determined in ceramic $BaTiO_3$ discs by exciting ultrasonic thickness vibrations. Young's modulus is a minimum at the transitions.

Izhak, I. A., Nauchn. Zap. Dnepropetr. Gos. Univ. 61, 52-3, 1963.
A "piezoelectric" effect is claimed in a freshly fired electroded $BaTiO_3$ ceramic which had not been poled. The effect existed both above and below the Curie point.

Lezgintseva, T. N., Fiz. Tverd. Tela 6, 3509-14, 1964. (Russian).
A method is proposed for evaluating the static piezoelectric moduli of $BaTiO_3$ from measurements of $\Delta\epsilon/\epsilon$ in an unpoled crystal. Measured values were confirmed by other methods. Reorientation of domains by 90° was taken into account.

Krajewski, T., Zeszyty Nauk Uniw. Poznaniu, Mat., Fiz., Chem. No. 5, 3-32, 1962.
The influence of flexural stresses on the dielectric and piezoelectric properties of ceramic $BaTiO_3$ was investigated.

Pietrzak, J. and Budzilowicz, Z., Poznan. Towarz. Przyjaciol Nauk, Wydzial Mat.-Przyrod. 11, 163-72, 1964.
A comparison of $BaTiO_3$ powders compressed with and without an applied field shows significant increase in dielectric constant and spontaneous polarization and decrease of coercive force as a result of the field.

Le Floch, G., Ann. Phys. 8, 524, 1963.
The temperature rise of barium titanate as a result of applied field was measured. The results were analyzed in terms of the dielectric loss.

Bursian, E. V. and Smirnova, N. P., Fiz. Tverd. Tela 6, 1818-20, 1964. (Russian). Soviet Phys.-Solid State 6, 1429-31.
The variation of polarization and dielectric constant of $BaTiO_3$ crystals with decreasing thickness is reported. The results are qualitatively the same as for thick crystals, but greater fields are needed to obtain the same results.

Stadelmaier, H. H. and Derbyshire, S. W., Mater. Sci. Res. 1, 57-65, 1963.
The factors reducing the observed ceramic polarization below the single crystal value are discussed.

Ballantyne, J. M., Phys. Rev. 136A, 429-36, 1964.
High frequency response of the polarization of $BaTiO_3$ crystals versus temperature was studied by infrared transmission and reflectivity measurements.

Godefroy, G., Compt. Rend. 258, 5410-13, 1964. These Doct. Sci. Phys. Paris 1963, J. Peyronnet et Cie, Paris, 1963, 123 pp.
The charge redistribution in ceramic $BaTiO_3$ under applied field was studied, with and without irradiation (α particles from ^{210}Po). The results were interpreted in terms of the migration of oxygen vacancies.

Hilczer, B., Phys. Status Solidi 5, K113-15, 1964.
Changes in $BaTiO_3$ due to neutron irradiation were shown to be due primarily to fast neutrons rather than thermal neutrons.

Beadle, C. W. and Dally, J. W., Experim. Mach. 4, (3), 70-76, 1964.
Strain-wave propagation and the associated charge release was studied in barium titanate ceramics.

Kosman, M. S. and Sozina, A. N., Dokl. Akad. Nauk SSSR 156, 778-80, 1964. (Russian).
"Relaxation oscillations" in barium titanate analogous to current oscillations in Si under pulsed fields are reported.

E. Conduction and Non-stoichiometry in $BaTiO_3$ with and without Additions

Sinyakov, E. V. and Kudzin, A. Yu., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 731-4, 1964. (Russian).
$BaTiO_3$ crystals which have been heated to 900° in air or oxygen show abnormally high conductivity, probably due to reduction and oxygen vacancy migration under maintained field.

Ikegami, S. and Ueda, I., J. Phys. Soc. Japan 19, 159-66, 1964.
Measurements are reported of resistivity, optical transmission, Hall effect, thermoelectric force, and electron spin resonance of $BaTiO_3$ crystals which were reduced in hydrogen.

Glower, D. D. and Heckman, R. C., J. Chem. Phys. 41, 877-9, 1964.
Conduction is mostly ionic in ceramics and in crystals containing iron at 100°, whereas it is mostly electronic in ceramics at 500° and in "pure" crystals at 100° to 600°C.

Cox, G. A. and Tredgold, R. H., Phys. Letters 11, 22-3, 1964.
The hole drift mobility of crystals subjected to pulsed 3725 Å illumination was in the range 2 to 4×10^{-4} cm^2/v sec.

Novak, J. and Arend, H., J. Am. Ceram. Soc. 47, 530, 1964.
An analytical procedure is given for determining the oxygen content of non-stoichiometric barium titanate. The procedure gives good results with oxygen deficiencies as low as 10^{-4} to 10^{-5}.

Goodman, G., Japan. J. Appl. Phys. 3, 123, 1964.
The positive temperature coefficient of resistivity observed by Kawabe and Inuishi (1963) in single crystals is explained as a surface effect rather than a bulk effect.

Brauer, H. and Heywang, W., Phys. Verhandl. 4, 105, 1964.
A modification of the surface state between grains permits one to obtain resistivity changes with temperature in the order of 10^7 and a lowering of the Curie point.

Danilyuk, Yu. L. and Kharitonov, E. V., Fiz. Tverd. Tela 6, 322-4, 1964. (Russian). Soviet Phys.-Solid State 6, 260-1.
The EPR spectra for polycrystalline $BaTiO_3$ and for crystals reduced in H_2 are the same. The spectra are interpreted.

Ueda, I., Takiuchi, M., Ikegami, S., and Sato, H., J. Phys. Soc. Japan 19, 1267-74, 1964.
The temperature dependence of breakdown field, distribution of time lag, and dielectric constant in high electric field are reported for polycrystalline $BaTiO_3$.

Heywang, W., J. Am. Ceram. Soc. 47, 484-90, 1964.
The resistivity anomaly in semiconductive $BaTiO_3$ near the Curie point is explained quantitatively by the barrier layer model.

Jonker, G. H., Solid State Electron. 7, 895-903, 1964.
The different shapes of the resistivity anomalies in various doped barium titanates is explained as a combination of two factors: the barrier layer trapping model of Heywang (which causes a gradual rise of resistivity with temperature) and the sudden lack of polar domain electrons in surface states at the Curie point (which causes a sudden jump in the resistivity level). The exact shape of the resistivity anomaly depends upon the relative importance of the two factors in a particular samples.

Hill, R. A. and Stirling, A. W., U. S. Patent 3,160,944, Dec. 15, 1964; Brit. Appl. Apr. 24, 1959.

Standard Telephones and Cables Ltd. (by R. A. Hill and A. W. Stirling); Brit. Patent 975,286, Nov. 11, 1964; Appl. April 13, 1962.

Siemens and Halske, A.-G., Brit Patent 949, 568, Feb. 12, 1964; Ger. appl. June 5, 1959. Addn. to Brit. Patent 911,741.
These three patents deal with compositional or process modifications of the barrier layer capacitor formed by surface reoxidation of a reduced barium titanate.

Brown, F. and Taylor, C. E., J. Appl. Phys. 35, 2554-6, 1964.
Single crystals of $BaTiO_3$ with 0.1% Nb, grown by the floating zone process, show a sharp decrease in resistivity at the 0° transition and a sharp increase in resistivity at the Curie point (with rising temperatures).

F. Additives

Sasaki, H., J. Phys. Soc. Japan 19, 2238-9, 1964.
An odd domain pattern is described in single crystals of $(Ba,Sr)TiO_3$ and the influence of growing temperature on the pattern is noted. Crystals from a melt of $(Ba_{.96}Sr_{.04})TiO_3$ grown to 1000°C have a Curie point of ~ 120°C, while crystals grown to 850° have a Curie point of ~ 110°C.

Sanvordenker, V. C., Univ. Microfilms (Ann Arbor, Mich.) Order No. 64-8205, 190 pp.; Dissertation Abstr. 25, 2550, 1964.
The transition of $BaTiO_3$ ceramics from tetragonal to cubic was studied optically.

Hegenbarth, E., Monatsber. Dtsch. Akad. Wissensch. Berlin 5, 50-1, 1963.
Curie points in the $(Ba,Sr)TiO_3$ system were measured and temperature lowering by adiabatic depolarization was studied.

Zhukov, O. K., Izv. Vysshikh Uchebn. Zavedenii, Fiz. 1964, 66-8; 1962, 176-7. (Russian).
The hydrostatic d constant of cube-shaped ceramics of $(Ba,Pb)TiO_3$ increased linearly with applied hydrostatic pressure and decreased with $PbTiO_3$ content. $(Ba,Sr)TiO_3$ was also considered.

Schreckenback, W. and Benz, H., Hermsdorfer Tech. Mitt. 1, 12-15, 1960.
A ceramic of $(Ba_{0.825}Pb_{0.175})TiO_3$ is described for use in ultrasonic cleaning.

Kaczmarek, F., Zeszyty Nauk. Uniw. Posnaniu, Mat., Fiz., Chem. No. 5, 33-80, 1962.
The variations of dielectric constant in a pulsed electric field were studied for $BaTiO_3$ crystals and ceramics, Rochelle salt crystals, and ceramics of 74 $BaTiO_3$ - 26 $SrTiO_3$ and 94 $BaTiO_3$ - 6 $SnTiO_3$.

Berberova, L. M., Materialy 4-oi [Chetvertoi] Nauchn. Konf. Aspirantov (Rostov-on-Don. Rostovsk. Univ.) Sb. 1962, 83-6. (Russian).

Sholokhovich, M. L., Khodakov, A. L., Lezgintseva, T. N., and Berberova, L. M., Mekhanizm i Kinetika Kristallizatsii, Nauchn. Sov. Akad. Nauk Belorussk. SSR po Fiz. Tverd. Tela 1964, 50-7. (Russian).
Crystals with up to 1% of group IV elements in the melt were prepared and their dielectric piezoelectric, and expansion properties studied through the Curie point. The amount of additive in the crystals was considerably less than in the melt.

Nekrasov, M. M. and Poplavko, Yu. M., Ixv. Kievsk. Politekhn. Inst. 40, 26-41, 1962. (Russian).
The change of dielectric constant with various applied fields was studied in $Ba(Ti_{0.85}Si_{0.11}Sn_{0.04})O_3$.

Nekrasov, M. M. and Poplavko, Yu. M., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 714-16, 1964. (Russian).

Poplavko, Yu. M., Fiz. Tverd. Tela 6, 58-64, 1964. Soviet Phys.-Solid State 6, 44-9.
The dielectric constant of $BaTiO_3$ and $Ba(Ti,Zr,Sn)O_3$ solid solutions was measured as a function of frequency. Dispersion was found in the range 10^8 to 10^{10} cycles/sec.

Polandov, I. N. and Mylov, V. A., Fiz. Tverd. Tela 6, 499-502, 1964. (Russian). Soviet Phys.-Solid State 6, 393-5.
The dielectric properties of $Ba(Ti,Zr)O_3$ ceramics were studied near the Curie point at high pressures. The Curie point decreased 3.8×10^{-3} degree/atm.

Andronova, I. A., Izv. Vysshikh Uchebn. Zavedenii, Radiofiz. 6, 1060-2, 1963. (Russian).
The noise and ferroelectric current were studied during polarization reversal in $BaTiO_3$ + 8% ZrO_2 and in "VK-1."

Koshkin, L. I., Uch. Zap. Kuibyshevsk. Gos. Ped. Inst. 1964, 37-59. (Russian).
The relaxation polarization in "VK-1", "VK-2", and $(Ba,Sr)TiO_3$ was investigated between 100° and 260°C.

Bochynski, Z., Rzeszowski, R., and Szurkowski, B., Poznan. Towarz. Przyjaciol Nauk, Wydzial Mat. Przyrod. Prace Komisji Mat. Przyrod. 11, 179-97, 1964. (Polish).

Szymanska, J., ibid. 11, 197-20, 1962. (Polish).
The lattice constants versus temperature, the Curie point and domain relaxation time were determined for ceramics in the system $BaTiO_3$-$MgSnO_3$.

Schoijet, M., Brit. J. Appl. Phys. 15, 1124-6, 1964.
The current-voltage characteristics of hexagonal $Ba(Ti_{0.75}Pt_{0.25})$ crystals were investigated.

Widajant, J. and Sroka, J., Szklo Ceram. 15, 243-5, 1964. (Polish).
Ceramic and electrical properties of $BaTiO_3$-$Bi_2Sn_2O_9$ bodies are described.

Zlotnick, H. (to Mucon Corp.), Brit. Patent 971,107, Sept. 30, 1964.
A capacitor body is described containing $BaTiO_3$, bismuth stannate, and Nb_2O_5.

Takeda, T. and Watanabe, A., J. Phys. Soc. Japan 19, 1742, 1964.
The ESR spectrum of Gd^{+3} was studied in $BaTiO_3$ crystals and ceramics. The spectrum changes as the Ba:Ti ratio changes from 0.994 to 1.015 and resistivity increases from 10^2 to 10^{10} ohm cm. At high Ba content the spectrum is postulated to arise from Gd^{+3} in the Ti^{+4} site.

Rabkin, L. M., Materialy 3-ei [Tret'ei] Nauchn. Konf. Aspirantov (Rostov-on-Don: Rostovsk. Univ.) Sb. 1961, 124-30.
The luminescence and absorption spectra of $BaTiO_3$ and $CaTiO_3$ with added Sm^{+3} were measured between -72° and -196°C.

Fesenko, E. G., Prokopalo, O. I., Komarov, V. D., and Shpolyanskii, Ya. A., Izv. Leningr. Elektrotekhn. Inst. 61, 252-9, 1963.
The effect of additions of V_2O_5, Sb_2O_5, Nb_2O_5, and Ta_2O_5 on the dielectric constant and Curie point of $BaTiO_3$ is reported. The hexagonal phase of $BaTiO_3$ was not obtained.

Bogdanov, S. V., Rassushin, V. A., and Sinkha, D. K., Fiz. Tverd. Tela 5, 2703-4, 1963. (Russian).
The dielectric constant and loss versus antimony content are given for $BaTiO_3$ crystals with added antimony oxide, and the results are interpreted as relaxation phenomena.

Sakudo, T. and Unoki, H., J. Phys. Soc. Japan 19, 2109-18, 1964.
The ESR spectra of Fe^{3+} in $BaTiO_3$ were studied for the cubic and rhombohedral phases.

Arnold, R. T. and Stanford, A. L., Jr., J. Chem. Phys. 41, 1520-1, 1964.
A downward shift of the Curie point in excess of 140° per atom % Fe was found in $BaTiO_3$ single crystals, in disagreement with all the previous literature. The iron was preferentially absorbed in the crystal.

Lezgintseva, T. N. and Khodakov, A. L., Izv. Leningr. Elektrotekhn. Inst. 61, 260-7, 1963. (Russian).
Small additions of Fe_2O_3 to $BaTiO_3$-$BaSnO_3$ solid solutions decrease the dielectric nonlinearity of both ceramics and single crystals.

Ikushima, H. and Hayakawa, S., J. Phys. Soc. Japan 19, 1986, 1964.
ESR studies were made of $BaTiO_3$ containing Mn^{+2} in the cubic, tetragonal, and rhombohedral phases. Results were interpreted in terms of Mn^{+2} bonding and oxygen vacancies.

Herbert, J. M., Trans. Brit. Ceram. Soc. 62, 645-58, 1963.
High resistivity ceramics were obtained by sintering $BaTiO_3$ with substantial amounts of manganese oxide in hydrogen.

Caufova, P., Arend, H., and Novak, J., Kristallografiya 9, 113-15, 1964. Soviet Phys.-Cryst. 9, 92-4.
The character of Co additions to barium titanate crystals and ceramics was examined.

Fesenko, E. G., Kramarov, O. P., Komarov, V. D., and Shpolyanskii, Ya. A., Segnetoelectriki, Rostovsk.-na-Donu Gos. Univ., Nauchn.-Issled. Fiz.-Mat. Inst., Sb. Statei 1961, 96-100.
The effect of isomorphous replacement of Ti by Cr, Mn, Co, or Ni on the dielectric and ferroelectric properties of $BaTiO_3$ was determined. Most of the additions promote formation of the hexagonal phase at higher firing temperatures.

Ikeda, Y., Hoshino, M., and Iwanari, S., Proc. Japan Congr. Testing Mater., 6th 1963, 122-3.
The effect of additions of MnO_2, Fe_2O_3, or CoO on the dielectric properties and color of ceramics in the system $BaTiO_3$-$BaZrO_3$-$BaSnO_3$-$CaTiO_3$ was determined.

Steatit-Magnesia A.-G. (by W. Mueller). Fr. Patent 1,351,043, Jan 31, 1964; Ger. appl. Apr. 28, 1962.
Ceramic compositions are reported with Curie points below -20°C, in the system $BaTiO_3$-$BaSnO_3$-$CaZrO_3$, with optionally 2% of heavy metals added.

Kudzin, A. Yu., Kristallografiya 9, 295-7, 1964. Soviet Phys.-Cryst. 9, 233-4.
The effect of additions of oxides of Ni,Nb,Ta, and Co on the lattice constants of $BaTiO_3$ was determined.

Kudzin, A. Yu., Guskina, L. G., and Petrushkevich, I. S., Fiz. Tverd. Tela 6, 92-5, 1964. (Russian). Soviet Phys.-Solid State 6, 73-5.
The domain structure and hysteresis loop of $BaTiO_3$ are stabilized by Ta and Ni oxide impurities.

Ismailzade, I. G., Verbitskaya, T. N., and Nesterenko, V. I., Kristallografiya 9, 412-13, 1964. Soviet Phys.-Cryst. 9, 332-3.
The effect of constant electric fields on the X-ray diffraction pattern of "VK-3" ceramic was determined.

Philips Patentverwaltung G.m.b.H. (by B. Ritscher and H. J. Engel), Ger. Patent 1,173,009, June 25, 1964; Appl. Mar. 3, 1960.
Dielectric constants above 10,000 are obtained on barium titanate modified with ZrO_2, SnO_2, and Al_2O_3.

Butko, S. I., Izv. Kievsk. Politekhn. Inst. 40, 99-116, 117-25, 1962. (Russian).
The effect of the method of preparation and a wide variety of additive oxides (Mg,Sb,Ce,Pb,Cd,Al,Mo,Fe,Cr,Bi,W,Nb,Zr) on the dielectric properties of $BaTiO_3$ is discussed.

Telegraph Condenser Co. Ltd., Brit. Patent 964,726, July 22, 1964; Appl. Dec. 27, 1960.
Fine grained ceramics with excess TiO_2, NiO, and a wide variety of additional substitutions are patented for high dielectric constant.

Waku, S., Rev. Elec. Commun. Lab. (Tokyo) 12, 123-50, 1964.
The electrical characteristics of $BaTiO_3$ crystals containing a variety of impurities are reviewed.

Waku, S., Rev. Elec. Commun. Lab. (Tokyo) 12, 33-62, 1964.
Barium titanate solid solutions in the system $BaTiO_3$-MgO:TiO_2-Rare earth oxides were studied. Crystallization, defects, and use as memory elements were also considered.

IX. Other Perovskites

A. Alkali Niobate-Tantalates

Fullmer, L. D. and Wilcox, W. R., Bull. Am. Phys. Soc. (II) 9, 726, 1964.
Growth is described of colorless crystals of $K(Ta,Nb)O_3$ by the Czochralski technique.

Timofeeva, V. A. and Bychkov, V. Z., Rost Kristallov, Akad. Nauk SSSR, Inst. Kristallogr. 4, 140-3, 1964. (Russian).
$KNbO_3$ crystals were grown on seeds suspended in a melt of K_2CO_3, KOH, and Nb_2O_5.

Dungan, R. H. and Golding, R. D., J. Am. Ceram. Soc. 47, 73-6, 1964.
The field-enforced, ferroelectric phase previously reported for crystals was obtained in ceramics. Phase studies and electrical data are given.

Izmailzade, I. G., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 675-80, 1964. (Russian).
Phase transitions in the system $NaNbO_3$-$NaTaO_3$ were determined versus temperature and composition by X-ray diffraction. Many of the phases in $NaNbO_3$ extend well into the solid solution system.

Joseph, R. I. and Silverman, B. D., J. Phys. Chem. Solids 25, 1125-8, 1964.
The infrared-active modes in $KTaO_3$ are used to interpret the vibrational structure.

Pulvari, C. F., Progress in Solid State Chemistry 1, Pergamon Press, New York, 1964 (H. Reiss and F. C. Tompkins, Ed.).
The work of Pulvari's group on $NaNbO_3$ is reviewed, with special emphasis on its switching characteristics. The structural interpretations are made on an intuitive basis.

B. $A^{+2}B^{+4}O_3$ Compounds

Strontium titanate is ferroelectric only below 35°K. However, the availability of large single crystals has resulted in a great deal of work being done, which is only marginally appropriate for this digest, so the nature of the subject matter will be indicated only roughly.

Itschner, D. and Gränicher, H., Helv. Phys. Acta 37, 624-5, 1964.
Brief summary of Properties.

Cowley, R. A., Phys. Rev. 134A, 981-97, 1964.
Lattice dynamics and phase transitions.

Fraitova, D. and Zentkova, A., Czech. J. Phys. 13, 670-9, 1963.
Lattice vibrations.

Kahn, A. H. and Leyendecker, A. J., Phys. Rev. 135A, 1321-5, 1964.
Electronic energy bands - theoretical.

Taylor, R. W. and Schmalzried, H., J. Phys. Chem. 68, 2444-9, 1964.
Free energy of formation of $SrTiO_3$ and $CaTiO_3$.

Lytle, F. W., J. Appl. Phys. 35, 2212-15, 1964.
Crystal phases.

Weik, H., Phys. Letters 9, 92-3, 1964.
Structure change upon neutron irradiation.

Lambert, V. L. and Weik, H., Phys. Letters 9, 15-17, 1964.
"Electrets", X-irradiation.

Schooley, J. F., Hosler, W. R., and Cohen, M. L., Phys. Rev. Letters 12, 474-5, 1964.
In semiconducting $SrTiO_3$, superconducting transitions at 0.25 and 0.28°K.

Beals, M. D. and Merker, L. (to Titangesellschaft m.b.H.), Ger. Patent 1,177,778, Sept. 10, 1964; U. S. Appl. Oct. 1, 1958.
Improving color and transparency of crystals.

Barrett, H. H., J. Appl. Phys. 35, 1420-5, 1964.
Dielectric breakdown.

Frederikse, H. P. R., Thurber, W. R., and Hosler, W. R., Phys. Rev. 134A, 442-5, 1964.
Electric transport.

Hegenbarth, E., Phys. Status Solidi 6, 333-7, 1964.
Field dependence of dielectric constant.

Kikuchi, A. and Sawaguchi, E., J. Phys. Soc. Japan 19, 1497-8, 1964.
Electrocaloric effect.

Krogstad, R. S. and Moss, R. W., "Conf. Solid State Phys. Bristol, 1964," publ. London Inst. Phys. and Phys. Soc., p. 92.
Acoustic attenuation.

Kirkpatrick, E. S., Müller, K. A., and Rubins, R. S., Phys. Rev. 135A, 86-90, 1964.
EPR spectrum of Fe^{3+}.

Rimai, L., Deutxch, T., and Silverman, B. D., Phys. Rev. 133A, 1123-34, 1964.
EPR spectra of Fe^{3+}, Gd^{3+}, Eu^{2+}, and Cr^{3+}.

Perry, C. H., Khanna, B. N., and Rupprecht, G., Phys. Rev. 135A, 408-12, 1964.
Infrared spectra of $SrTiO_3$, $CaTiO_3$, and $PbTiO_3$.

Bogdanov, S. V. and Kiseleva, K. V., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 636-42, 1964. (Russian).
Dielectric and structure studies of strontiumbismuth titanate.

Panfilov, B. I. and Feodos'ev, N. N., Zh. Neorgan. Khim. 9, 2685-92, 1964. (Russian).
The heats of formation of $CaTiO_3$, $SrTiO_3$, and $BaTiO_3$ are -397.4 ± 1.2, -398.9 ± 2.2, and -394.8 ± 7.6 kcal/mole respectively.

Strizhkov, B. V. and Lapitskii, A. V., Vestn. Mosk. Univ., Ser. II, Khim. 19, 43-6, 1964. (Russian).
The ceramic and dielectric properties of $SrTiO_3$, $CaTiO_3$, and $PbTiO_3$ ceramics were investigated versus firing temperature.

Matsuo, Y. and Sasaki, H., Japan. J. Appl. Phys. 3, 799-801, 1964.
Ceramics of $PbTiO_3 - La_{2/3}TiO_3$ gave semiconducting bodies when fired at 1200°C or in nitrogen, and high resistivity material when fired at 700° to 900°C.

Goulpeau, L. and LeMontagner, S., Ann. Phys. (Paris) 8, 524, 1963.
The well-known double transition in $PbZrO_3$ at 230°C is discussed.

Fedulov, S. A. and Venevtsev, Yu. N., Kristallografiya 9, 358-62, 1964. Soviet Phys.-Cryst. 9, 286-9.
Complete solid solution exists in the system $PbTiO_3$-$CaSnO_3$, while there is a miscibility gap in the system $PbTiO_3$-$CaZrO_3$. Dielectric measurements were carried out on the ceramics.

Belyaev, I. N. and Aver'yanova, L. N., Fiz.-Khim. Analiz Solevykh Sistem (Rostov-on-Don:Rostovsk. Univ.) Sb. 1962, 65-8.
The systems $PbTiO_3$-$PbWO_4$ and $PbTiO_3$-$PbMoO_4$ were studied with X-ray diffraction. The only compound found was $3PbTiO_3 \cdot PbWO_4$.

Isupov, V. A., Strelets, P. L., Serova, I. A., Yatsenko, N. D., and Shirobokikh, T. M., Fiz. Tverd. Tela 6, 790-5, 1964. (Russian). Soviet Phys.-Solid State 6, 615-19.
The dielectric properties and phase relations are reported for the system $Na_{0.5}Bi_{0.5}TiO_3$-$PbTiO_3$. The Curie point passes through a minimum arount 10 mol % $PbTiO_3$.

C. $Pb(Ti,Zr,Hf,Sn)O_3$ Solid Solutions

Anderson, D. H., J. Chem. Phys. 40, 1168-9, 1964.
The shifts of the field for ^{207}Pb resonance in various ferroelectrics and antiferroelectrics were analyzed. The results indicate that changes in the Pb^{2+} covalent character do not cause the ferroelectric or antiferroelectric transition.

Fushimi, S. and Ikeda, T., Japan. J. Appl. Phys. 3, 171-2, 1964.
Small single crystals of mixed $Pb(Ti,Zr)O_3$ were grown from PbO-PbF_2 and KF-PbF_2 fluxes. In both systems it was next to impossible to obtain a range of intermediate compositions.

Sholokhovich, M. L. and Varicheva, V. I., Fiz.-Khim. Analiz Solevykh Sistem (Rostov-on-Don: Rostovsk. Univ.) Sb. 1962, 217-25.
The solubility of $PbZrO_3$ in 35 fluxes was determined. PbF_2 and $PbCl_2$ were the best for crystal growth. A continuous series of $PbTiO_3$-$PbZrO_3$ solid solutions can be obtained using KF.

Mori, S., Mitsuda, H., Date, K., Hiori, Y., and Miyazawa, T., Natl. Tech. Rept. 10, 32-40, 1964.
The reaction of PbO, TiO_2, and ZrO_2 to a $Pb(Ti,Zr)O_3$ solid solution occurs in two steps. First, $PbTiO_3$ is formed with a little Zr in solid solution. Then, either PbO and ZrO_2 react into the $PbTiO_3$, or if more ZrO_2 is present, $PbZrO_3$ is formed, which then reacts with $PbTiO_3$ to form the solid solution.

Berlincourt, D., Krueger, H. H. A., and Jaffe, B., J. Phys. Chem. Solids 25, 659-74, 1964.
Transitions between ferroelectric and antiferroelectric phases in the system $Pb(Zr,Sn,Ti)O_3$ are described which result from varying temperature, pressure, electric field, and composition.

Hall, C. A., Dungan, R. H., and Stark, A. H., J. Am. Ceram. Soc. 47, 259-64, 1964.
Phase relations are described in the antiferroelectric region of the system $PbHfO_3$-$PbTiO_3$-$PbSnO_3$-$PbNb_2O_6$. Ferroelectric-antiferroelectric transitions can also be induced in this system by temperature, electric field, and pressure.

Ikeda, T., Tanaka, Y., Ayakawa, T., and Noake, H., Japan. J. Appl. Phys. 3, 581-7, 1964.
As niobium oxide is added to $Pb(Ti,Zr)O_3$ ceramics, ZrO_2 precipitates out, as shown by electron microproble analysis.

Ikeda, T., Japan. J. Appl. Phys. 3, 493-4, 1964.
Addition of $LaFeO_3$ to $Pb(Ti,Zr)O_3$ ceramics near the phase boundary improves the piezoelectric performance.

Doran, D. G. and Goettelman, R., Appl. Phys. Letters 2, 22, 1963.
The sound velocity increases abruptly, by about 4.5% at the Fe_1-Fe_2 transition near 75°C in $PbZr_{0.95}Ti_{0.05}O_3$.

Wentz, J. L. and Kennedy, L. Z., J. Appl. Phys. 35, 1767-70, 1964.
The primary pyroelectric effect of $Pb(Zr_{0.95}Ti_{0.05})O_3$ was calculated from measurements of the total pyroelectric effect and elastic and piezoelectric coefficients.

Berlincourt, D., J. Acoust. Soc. Am. 36, 515-20, 1964.
The complete set of electroelastic constants of a tetragonal lead titanate zirconate ceramic is shown as a function of thoroughness of poling. Most measurements were repeated on a rhombohedral lead titanate zirconate. In the tetragonal material, anisotropies increase sharply only at the highest poling; for the rhombohedral material, anisotropies increase throughout the range of poling.

Ikeda, T. and Okano, T., Japan. J. Appl. Phys. 3, 63-71, 1964.
Improved piezoelectric ceramics are obtained when $Pb(Ti,Zr)O_3$ is modified by addition of $A^{+}B^{5+}O_3$ (A = K, Na; B = Sb,Nb,Bi) or $A^{3+}B^{3+}O_3$ (A = Bi, La; B = Fe, Al, Cr). Dielectric constant above 1500 and radial coupling coefficient above 0.6 were obtained with $Na^{+1}Sb^{+5}$ substitution.

Haertling, G. H., Am. Ceram. Soc. Bull. 43, 875-9, 1964.
The variation of electrical and ceramic properties of $(Pb_{.97}Bi_{.02})(Ti,Zr)O_3$ compositions was studied as a function of the hot pressing variables temperature, pressure, and hold time.

A number of patents were issued covering compositional variation to improve the electrical properties of lead titanate zirconate ceramics (usually with added alkaline earths or tin oxide). They are listed below, together with the addition element (as oxide unless indicated).

Kulcsar, F. and Jaffe, B., U. S. Patent 3,144,411, Aug. 11, 1964; Appl. Nov. 13, 1961.
Barium addition.

N. V. Philips, Fr. Patent 1,307,095, Oct. 19, 1962; Neth. Appl. Dec. 1, 1960.
Rare earths.

N. V. Philips, Fr. Patent 1,307,172, Oct. 19, 1962; Neth. Appl. Dec. 2, 1960.
Rare earths plus boron and tungsten.

Globe Union, Inc., Fr. Patent 1,308,231, Nov. 2, 1962; U. S. Appl. Dec. 19, 1960.
Bismuth or antimony.

Clevite Corp., Neth. Appl. 6,400,245, July 16, 1964; U. S. Appl. Jan. 15, 1963.
Chromium plus heating in nitrogen or argon.

Clevite Corp., Neth. Appl. 6,400,246, July 17, 1964; U. S. Appl. Jan. 16, 1963.
Replacement by a lower valence element: K, Sc, and In.

Quartz and Silice, S. A., Fr. Patent 1,358,651, Apr. 17, 1964; Appl. Mar. 8, 1963.
Magnesium and cobalt.

N. V. Philips, Fr. Patent 1,307,171, Oct. 19, 1962; Neth. Appl. Dec. 2, 1960.
Zinc or cadmium.

Omnium de Techniques Avancees (O.T.E.C.N.A.) (by M. T. Munier and P. Belloc), Fr. Patent 1,371,238, Sept. 9, 1964; Appl. June 13, 1963.
Magnesium plus Pb_3O_4 or PbO_2 instead of PbO.

D. $BiFeO_3$ Plain and Modified

For several years one group in Russia has been claiming ferroelectric properties for $BiFeO_3$. This writer has considered the claim to be far from proven. This year several bits of evidence have been published tending to confirm this.

Koizumi, H., Niizeki, N., and Ikeda, T., Japan. J. Appl. Phys. 3, 495-6, 1964.
The phase relationships in the Bi_2O_3-Fe_2O_3 system were determined. The compound $BiFeO_3$ decomposes at 780°C, close to the 800° Curie point claimed by Fedulov and co-workers.

Smolenskii, G. A. and Bokov, V. A., J. Appl. Phys. 35, 915-18, 1964.

Smolenskii, G. A., Bokov, V. A., and Mitsek, A. I., Izv. Akad. Nauk SSSR, Ser. Fiz. 38, 614-19, 1964. (Russian).
These two papers cover all the recent materials which may be ferrimagnetic and ferroelectric or antiferroelectric. The two papers come to different conclusions concerning the probability of ferroelectricity in $BiFeO_3$. $Pb_3Fe_2WO_9$ and Pb_2FeNbO_6 are also discussed.

Plakhtin, V. P., Mal'tsev, E. I., and Kaminker, D. M., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 436-9, 1964. (Russian).

Tomashpol'skii, Yu. Ya., Venevtsev, Yu. N., and Zhdanov, G. S., Dokl. Akad. Nauk SSSR 153, 1313-14, 1964. (Russian).
The structure of $BiFeO_3$ was investigated by neutron and electron diffraction. The first paper related the structure to that of $LaAlO_3$ and discussed the magnetic structure. The second one related the structure to a pyroelectric arrangement.

Venevtsev, Yu. N., Zhdanov, G. S., Roginskaya, Yu. E., Fedulov, S. A. Ivanova, V. V., Chkalova, V. V., Viskov, A. S., Kapyshev, A. G., Bondarenko, V. S., and Ladyzhinskii, P. B., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 683-90, 1964. (Russian).

Fedulov, S. A., Ladyzhinskii, P. B., and Venevtsev, Yu. N., Kristallografiya 9, 516-20, 1964. Soviet Phys.-Cryst. 9, 428-31.

Fedulov, S. A., Ladyzhinskii, P. B., Pyatigorskaya, L. I., and Venevtsev, Yu. N., Fiz. Tverd. Tela 6, 475-8, 1964. (Russian). Soviet Phys.-Solid State 6, 375-8.
Phase studies, electrical, and magnetic measurements were conducted on the systems $BiFeO_3$-$LaFeO_3$, $BiFeO_3$-$LaCrO_3$, $BiFeO_3$-$LaAlO_3$, $BiFeO_3$-$PbTiO_3$, and $BiFeO_3$-$PbZrO_3$. A number of ferroelectric phases were found. The system $BiFeO_3$-$LaAlO_3$ does not form a complete solid solution. "Curie points" extrapolated to pure $BiFeO_3$ yield values of 800° to 850°C.

Yudin, V. M., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 451-3, 1964. (Russian).

Smolenskii, G. A. and Yudin, V. M., Fiz. Tverd. Tela 6, 3668-75, 1964. (Russian).
The weak ferromagnetism found in the system $BiFeO_3$-Pb_2FeNbO_6 disappears on transition from a complex unit cell to a simple one. The magnetic moment increases after cooling to liquid nitrogen temperature in a field of 8 koe.

Mitrofanov, K. P., Viskov, A. S., Driker, G. Ya., Plotnikova, M. V., Fang, J.-H., Venevtsev, Yu. N., and Shpinel, V. S., Zh. Eksperim. i. Teor. Fiz. 46, 383-6, 1964. (Russian).
The change in the resonance absorption spectra of γ-rays from 23.8 kev ^{119}Sn during phase transitions was studied in the system $BiFeO_3$-$Sr_3SnMn_2O_9$.

E. Complex and Miscellaneous Perovskites

Fesenko, E. G., Filip'ev, V. S., and Kupriyanov, M. F., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 669-74, 1964. (Russian).

Venevtsev, Yu. N., Roginskaya, Yu. E., Viskov, A. S., Ivanova, V. A., Tomashpol'skii, Yu. Ya., Shvorneva, L. I., Kapyshev, A. G., Teverovskii, A. Yu., and Zhdanov, G. S., Dokl. Akad. Nauk SSSR 158, 86-8, 1964. (Russian).

Isupov, V. A. and Krainik, N. N., Fiz. Tverd. Tela 6, 3713-15, 1964. (Russian).
A large number of complex perovskites are reported; many, especially those containing lead, are ferroelectric or antiferroelectric; both new and previously reported compositions are included.

Sleight, A. W., Univ. Microfilms (Ann Arbor, Mich.), Order No. 64-3565, 95 pp.; Dissertation Abstr. 24, 4393, 1964.
The incidence of the ordered perovskite structure was studied.

Bokov, V. A., Kizhaev, S. A., Myl'nikova, I. E., and Tutov, A. G., Fiz. Tverd. Tela 6, 3038-44, 1964. (Russian). Soviet Phys.-Solid State 6, 2419-24.
The crystal symmetry, electrical, and magnetic properties of Pb_2CoWO_6 crystals are reported. In the antiferroelectric phases double loops are reported with a decreasing critical field as temperature is lowered, suggesting a transition to ferroelectric below -196°C.

Filip'ev, V. S. and Fesenko, E. G., Kristallografiya 9, 293-5, 1964. (Russian). Soviet Phys.-Cryst. 9, 230-1.
X-ray and dielectric measurements identify a transition in Pb_2CoWO_6 at 20° from cubic to either ferroelectric or antiferroelectric.

Tomashpol'skii, Yu. Ya. and Venevtsev, Yu. N., Fiz. Tverd. Tela 6, 2998-3003, 1964. (Russian). Soviet Phys.-Solid State 6, 2388-92.
The structural and electrical characteristics of the system Pb_2CoWO_6-Pb_2YbNbO_6 were investigated, and a phase diagram was constructed.

Krainik, N. N., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 643-7, 1964. (Russian).
Six basic types of phase diagrams are given for $PbHfO_3$, $NaNbO_3$, and $PbMgWO_6$ solid solutions with a series of other components, and the results analyzed with respect to the occurrence of antiferroelectricity.

Ioffe, V. A., Leonov, A. I., and Razumeenko, M. V., Fiz. Tverd. Tela 6, 2405-10, 2314-21, 1964. (Russian). Soviet Phys.-Solid State 6, 1908-12, 1833-8.
The hysteresis loops and other nonlinear properties in $CeAlO_3$ are a result of the nonlinear dependence of electrical conductivity on the field intensity and do not indicate ferroelectricity. The dielectric constant and loss of solid solutions of $CeAlO_3$ with aluminates of La,Sm,Nd, and Eu are reported.

Kinase, W., Ishibashi, Y., and Kurasawa, Y., J. Phys. Soc. Japan 19, 273-81, 1964.
The relative stability of ferroelectric and antiferroelectric arrangements in an AO_3 crystal such as WO_3 is treated mathematically.

Takamori, T., J. Am. Ceram. Soc. 47, 534-5, 1964.
The thermal expansion of WO_3 was measured between 40° and 600°C.

Fiegel, L. J., Mohanty, G. P., and Healy, J. H., J. Chem. Eng. Data 9, 365-9, 1964.
The equilibrium diagram of the system Nb_2O_5-WO_3 was determined, and includes some data on the low temperature transformation of WO_3.

Tanaka, M., Oyo Buturi 33, 260-3, 1964. (Japanese).
Dielectric measurements were made on solid solutions of WO_3 with Fe_2O_3,TiO_2, MgO, and PbO.

X. Miscellaneous Oxides

Goodman, G., U. S. Patent 3,116,262, Dec. 31, 1963; Appl. May 19, 1961.
Semiconducting $PbNb_2O_6$ modified with Fe, W, or La is described which has a positive temperature coefficient of resistivity near the Curie point.

Krucans, J., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 691-4, 1964. (Russian).

Krucans, J., Latvijas PSR Zinatnu Akad. Vestis Fiz. Tehn. Zinatnu Ser. 1964, 8-17. (Russian).

Krucans, J. and Freidenfelds, E., Latvijas PSR Zinatnu Akad. Vestis, Kim. Ser. 1963, 637-40. (Russian).

Krucans, J. and Maksimova, O. S., ibid 1963, 705-10. (Russian).
Solid solutions of $PbNb_2O_6$ with 21 other compounds are reported, with Curie points, lattice parameters, and sometimes dielectric measurements. Solid solutions with $La_{2/3}TiO_3$ and $BaTiO_3$ were studied in the most detail.

Krainik, N. N., Isupov, V. A., Bryzhina, M. F., and Agranovskaya, A. I., Kristallografiya 9, 352-7, 1964. (Russian). Soviet Phys.-Cryst. 9, 281-5.
Fifteen new tungsten bronze compounds are reported of type $A_6B_{10}O_{30}$ or $A_5B_{10}O_{30}$ with A = K^+,Ba^{2+},Sr^{2+},Pb^{2+},La^{3+},Sm^{3+},Gd^{3+},Nd^{3+},Bi^{3+}, or Ce^{4+} and B = W^{6+},Nb^{5+},Fe^{3+},Ni^{2+}, or Mg^{2+}. All the compounds are ferroelectric with weakly defined transition points. Some structural interpretations are given.

Illyn, A. V., Palmer, G. G., and Popoff, V. L. (to Compagnie Francaise Thomson-Houston), Fr. Patent 1,352,560, Feb. 14, 1964; U. S. Appl. Apr. 2, 1962.
Certain mixtures of barium-lead niobate are patented for use as electrical circuit filters.

Anan'eva, A. A. and Ugryumova, M. A., Akust. Zh. 10, 265-70, 1964. (Russian).
The effect of addition of the oxides of Sc^{3+},Y^{3+},La^{3+},Nd^{3+},Hf^{4+},Ti^{4+}, and Zr^{4+} on the piezoelectric properties of $Pb_{0.6}Ba_{0.4}Nb_2O_6$ was investigated. The greatest improvement in properties and the greatest lowering of the Curie point resulted from the La^{3+} addition.

Masuno, K., J. Phys. Soc. Japan 19, 323-8, 1964.
New ferroelectrics of tungsten bronze type and formula approximating $(Ba_{0.75}R_{0.17})Nb_2O_6$ were made with R = Sm, La, and Y, having Curie points of 189°, 10°, and 278° respectively. A range of rare earth content is possible for Sm and La. Hysteresis loops are mentioned but not shown.

Gasperin, M., Bull Soc. Franc. Mineral. Crist. 87, 50-2, 1964.
The symmetry of $PbTa_2O_6$ is reported to be P 42/m. Heavy atom positions are given. The correlation factor (R) is only 40%.

Sawaguchi, E. and Kikuchi, A., J. Phys. Soc. Japan 19, 579, 1964.
The crystal structure and dielectric properties of the new tungsten bronze structure $K_2Ta_4O_{11}$ was reported. No evidence for ferroelectricity was found above 4°K.

Allen, R. E. and Herczog, A. (to Corning Glass Works), Belg. Patent 626,995, July 10, 1963; U. S. Appl. Jan. 10, 1962.
A high dielectric constant glass is described in which submicroscopic barium and sodium niobate crystals are responsible for the high dielectric constant.

Shapiro, Z. I., Fedulov, S. A., and Venevtsev, Yu. N., Fiz. Tverd. Tela 6, 316-7, 1964. Soviet Phys.-Solid State 6, 254-5 (transl. j. gives wrong authors).
The Curie point of $LiTaO_3$ ("ilmenite-type" structure) was found to be 665 ± 5°C. The material was high resistivity, and showed a weak piezoelectric effect.

Remeika, J. P. and Ballman, A. A., Appl. Phys. Letters 5, 180-1, 1964.
Crystals of the newly discovered compound $LiGaO_2$ are piezoelectric with piezoelectric coupling > 30% and high acoustic Q. The material is not ferroelectric above -196°C.

Cummins, S. E., J. Appl. Phys. 35, 3045-6, 1964.
$Bi_4Ti_3O_{12}$ crystals when subject to a voltage pulse opposite to the polarization show ability to withstand reverse switching below certain voltage levels. Many loops showed a bias similar to ferroelectric crystals which had been irradiated.

Bertaut, E. F., Roult, G., Delapalme, A., Bassi, G., Mercier, M., Murasik, A., Van Qui, V., Aleonard, A., Pauthenet, R., Chevreton, M., and Jansen, R., J. Appl. Phys. 35, 952-3, 1964.
The magnetic structures of several compounds are described, including ferroelectric $MnYO_3$.

Nedlin, G. M., Fiz. Tverd. Tela 6, 2708-16, 1964. (Russian). Soviet Phys.-Solid State 6, 2156-61.
Possible magnetic structures for $YMuO_3$ are analyzed. He disagrees with the magnetic structure proposed by Bertant and co-workers.

Smolenski, G. A. and Bokov, V. A., J. Appl. Phys. 35, 915-17, 1964.

Bokov, V. A., Smolenskii, G. A., Kizhaev, S. A., and Myl'nikova, I. E., Fiz. Tverd. Tela 5, 3607-9, 1963. (Russian). Soviet Phys.-Solid State 5, 2646-7.
Ferroelectric data are given for $YMnO_3$ crystals at several temperatures. No Curie point was found. $E_C = 15 - 20$ kV/cm, $Ps = 4.5 \times 10^{-6}$ Coul/cm^2, $\epsilon_{11} \cong 20$ at room temperature.

Mazelsky, R. and Kramer, W. E., J. Electrochem. Soc. 111, 528-33, 1964.
The conductivity of $Cd_2Nb_2O_7$ was judged to be largely ionic, while the conductivity of $Pb_{1.5}Nb_2O_{6.5}$ was almost completely electronic.

Abrahams, S. C. and Reddy, J. M., Phys. Rev. Letters 13, 688-90, 1964.
A structure determination and new magnetic measurements are reported for gallium iron oxide. The piezoelectricity seems to originate in the O atom arrangement, whereas the ferromagnetism is primarily due to the cations.

Guerchais, J. E. and Rohmer, R., Compt. Rend 259, 394-6, 1964.
Ammonium niobate crystals were found to be piezoelectric. Their formation and decomposition were studied, as well as infrared spectra.

Dengel, O., Eckener, U., Plitz, H., and Riehl, N., Phys. Letters 9, 291-2, 1964.
Current and dielectric constant anomalies in ice were explained as due to ferroelectricity with a Curie point of ~ 100°K. This behavior was observed only if the water used for the crystal growth was not extremely pure.

Philgreen, F. A., J. Am. Ceram. Soc. 47, 49-50, 1964.
Dielectric and X-ray studies were made on the system Ga_2O_3-Nb_2O_5. Five intermediate compounds were found, none of which were ferroelectric.

Roth, R. S. and Waring, J. L., Am. Mineralogist 48, 1348-56, 1963.
The synthesis and stability of bismuthotantalite, stibiotantalite, and a number of similar compounds are reported. Some of the natural minerals have been reported to be pyroelectric.

LeTraon, F. and LeTraon, A., Ann. Phys. 8, 524, 1963.
The properties of TiO_2 are related to those of the ferroelectric titanates. They suggest a tendency towards dipole formation in TiO_2 below 65°K.

XI. Semiconductors and Sphalerite-Wurtzite Structure Compounds

Merz, W. J. and Nitsche, R., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 681-2, 1964.
The ferroelectric properties of SbSI are described.

Arndt, R. and Niggli, A., Naturwissenschaften 51, 158, 1964. (German).
The polar phase of SbSI has the symmetry $Pna2_1$, while the nonpolar phase is Pnam. As the crystal cools through the Curie point, *c* increases, *b* decreases, and *a* remains unchanged.

Mori, T. and Tamura, H., J. Phys. Soc. Japan 19, 1247, 1964.
The SbI_3-Sb_2S_3 phase diagram and the growth of SbSI crystals are described.

Nitsche, R., Roetschi, H., and Wild, P., Appl. Phys. Letters 4, 210-11, 1964.
The Curie points of compounds isomorphous with SbSI were reported: BiSI (-160°), BiSBr (-170°), and SbSBr (-180°). Oxygen was the only substitution in SbSI which raised the Curie point (to 65° from 22° for a crystal grown from a melt of $SbS_{0.8}O_{0.2}I$).

Sasaki, Y., Japan. J. Appl. Phys. 3, 558-9, 1964.
The photoconductivity of SbSI was measured both above and below the Curie point. The energy gap is 2.0 ev in both phases.

Quentin, G. and Thuillier, J. M., Solid State Commun. 2, 115-17, 1964. (French).
The electromechanical coupling constant of a tellurium crystal was determined to be 0.35.

Kilja, R. and Stubb, T., Acta Polytech. Scand., Phys. Nucl. Ser. 28, 32 pp., 1964.
The dielectric constant and resistivity of selenium at 24 kMc were measured versus temperature.

Cochran, W., Phys. Letters 13, 193, 1964.
The dielectric constant of lead telluride was determined to be 310 at room temperature by optical frequency measurements, with no evidence for ferroelectricity.

Smith, D. K., Newkirk, H. W., and Kahn, J. S., J. Electrochem. Soc. 111, 78-87, 1964.
A new precision determination of the crystal structure of BeO results in the u parameter = 0.3786 ± .0005. Etching studies show the hemimorphic symmetry.

Laudise, R. A., Kolb, E. D., and Caporaso, A. J., J. Am. Ceram. Soc. 47, 9-12, 1964.

Kuz'mina, I. P. and Antonova, V. F., Rost Kristallov, Akad. Nauk SSSR, Inst. Kristallogr. 4, 151-6, 1964. (Russian).
The hydrothermal growth of ZnO crystals is described.

Heiland, G., Kunstmann, P., and Pfister, H., Z. Physik 176, 485-97, 1963.
The etching character and sign of the piezoelectric effect was correlated with the polar atomic arrangement in ZnO. The Zn face is positive, and etches less than the O face.

Western Electric Co., Inc., Brit. Patent 959,293, May 27, 1964; U. S. Appl. Apr. 7, 1960.
The growth and use of ZnO piezoelectric crystals is described. An electromechanical coupling coefficient of 0.33 was obtained.

Pastrnak, J. and Roskovcova, L., Phys. Status Solidi 7, 331-8, 1964. (German).
Morphology and growth of AlN crystals is described.

Mason, W. P., U. S. Patent 3,122,662, Feb. 25, 1964; Appl. May 23, 1962.
Several crystals belonging to class $\bar{4}3m$ are patented for precision-frequency piezoelectric uses, where unlike quartz they are free of aging effects.

Daniels, W. B., Proc. Intern. Conf. Phys. Semicond., Exeter, Engl. 1962, 482-9.
The low thermal expansion of diamond and sphalerite structure compounds is explained theoretically.

Sullivan, J. J., J. Phys. Chem. Solids 25, 1039-56, 1964.

Tsuboi, M., J. Chem. Phys. 40, 1326-35, 1964.
Lattice vibrations of wurtzite structure crystals are used to develop expressions for the elastic, dielectric, and piezoelectric constants, and also the wurtzite and sphalerite-type force constants.

Sysoev, L. A., Obukhovskii, Ya. A., and Bidnaya, D. S., Rost Kristallov, Akad Nauk SSSR, Inst. Kristallogr. 4, 157-9, 1964.
Hexagonal plates of CdS up to 4 mm across were grown from a $CdCl_2$-CdI_2 flux by cooling from 680° to 360° at 5° to 20° per hour.

Arlt, G., Phys. Verhandl. 4, 41, 1964.
The resonance method of measuring piezoelectric effect is extended to semiconducting substances.

Bass, F. G., Gredeskul, S. A., and Kaganov, M. I., Fiz. Tverd. Tela 6, 3577-84, 1964. (Russian).

Kroger, H., Appl. Phys. Letters 4, 190-2, 1964.

Laikhtman, B. D., Fiz. Tverd. Tela 6, 3217-21, 1964. (Russian).

Browne, M. E., Helv. Phys. Acta 37, 545-53, 1964.

Prohofsky, E. W., Phys. Rev. 136A, 1731-40, 1964.

Mahan, G. D. and Hopfield, J. J., Phys. Rev. Letters 12, 241-3, 1964.

Osaka, Y., J. Phys. Soc. Japan 19, 2347-8, 1964.

Pokatilov, E. P., Fiz. Tverd. Tela 6, 2809-18, 1964. Soviet Phys.-Solid State 6, 2233-9.
Various aspects are mathematically considered of the piezoelectric interactions of electrons and phonons.

Merten, L., Z. Naturforsch. 19a, 788-93, 1161-9, 1964.
The piezoelectric potential fields around a screw dislocation or a step dislocation were calculated for crystals of the sphalerite and wurtzite structures.

Grinberg, A. A., Dokl. Akad. Nauk SSSR 155, 1293, 1964. (Russian).
It is shown theoretically that the excess energy formed at such voltages that the drift velocity is larger than the velocity of sound, is evolved as Joule heat rather than generating ultrasonic vibrations.

Gurevich, V. L. and Kagan, V. D., Fiz. Tverd. Tela 6, 2212-14, 1964. (Russian). Soviet Phys.-Solid State 6, 1752-4.
A quantitative theory is evolved for the acoustic instability occurring when the drift velocity exceeds the sound velocity.

Blotekjaer, K. and Quate, C. F., Proc. IEEE 52, 360-77, 1964.
The amplification of acoustic waves in piezoelectric semiconductors is analyzed as a function of the normal modes of the noncoupled system; experimental results on CdS confirm the general character of the theory.

Grinberg, A. A. and Kramer, N. I., Dokl. Akad. Nauk SSSR 157, 79-82, 1964.
A theoretical study is made of the "acousto-magnetic" effect in piezoelectric semiconductors: the current or electric field generated when ultrasound is passed through a crystal which is in a magnetic field.

Zook, J. D., Phys. Rev. 136A, 869-78, 1964.
The theory of the scattering of acoustic modes in piezoelectric semiconductors is generalized to take account of the anisotropic scattering probability.

Greebe, C. A. A., Phys. Letters 4, 45-6, 1963.
The frequency dependence of the acoustical-electrical effect in piezoelectric semiconductors was investigated.

Damon, R. W., Kroger, H., and Prohofsky, E. W., Proc. IEEE 52, 912-21, 1964.
A new mode of energy transport in piezoelectric semiconductors is described - giving a collective phonon-density wave travelling with a velocity only slightly slower than the speed of sound. Experimental observations are described which appear to verify these predictions.

Midford, T. A., J. Appl. Phys. 35, 3423-4, 1964.
Ultrasonic amplification is described in CdSe, using an experimental arrangement similar to that of Hutson, McFee, and White (1961).

Newell, W. E., Trans. AIME 230, 315-20, 1964.
A simplified calculation is suggested for evaluating the relative ultrasonic amplification of various piezoelectric semiconductors.

Ashley, J. C., Univ. Microfilms (Ann Arbor, Mich.), Order No. 63-5915, 154 pp.; Dissertation Abstr. 24, 1667-8, 1963.
Ultrasonic amplification and phonon emission are considered in piezoelectric semiconductors.

Mertsching, J., Monatsber. Deutsch. Akad. Wissensch. Berlin 6, 394-5, 1964.
A comparison is made of the effects of ultrasound in piezoelectric semiconductors and ordinary semiconductors.

Chaban, A. A., Fiz. Tverd. Tela 6, 2217-19, 1964. (Russian). Soviet Phys.-Solid State 6, 1758-9.
Ultrasonic amplification and the non-ohmic character of the resistance in CdS are examined.

Ogawa, T., Oyo Buturi 33, 153-66, 1964. (Japanese).
The isoelectric sequence and polarity of semiconductor piezoelectrics is discussed.

XII. Quartz, and Other Silicates, and Quartz Isomorphs

A. Quartz

Petkof, B., Minerals Yearbook (U. S. Bur. Mines) 1, 937-41, 1963. (publ. 1964).
The supply of electronic grade quartz is reviewed.

Zedlitz, O., Urner Mineralien-Freund 2, 65-8, 1964. (German).
Some unusual morphologies of quartz crystals are described.

Muto, F. and Taki, S., Yamanashi Daigaku Kogakubu Kenkuy Hokoku, No. 13, 152-5, 1962. (Japanese).

Heydemann, A., Beitr. Mineral. Petrog. 10, 242-59, 1964.

Kristall-Synthese Dr. Baumann & Co., (by W. Baumann), Ger. Patent 1,172,652, June 25, 1964; Appl. Jan. 23, 1962.

Takeuchi, M. and Suzue, T., Japan. Patent 16,619, Sept. 2, 1963; Appl. Sept. 18, 1959.
Various aspects of the hydrothermal growth of quartz are considered. According to Heydemann, the conversation of amorphous silica to quartz (100° to 250°C) occurs in three steps: amorphous → SiO_2-X (X-ray pattern given) → cristobalite → quartz.

Smid, J., Czech. Patent 110,953, May 15, 1964; Appl. Mar. 11, 1963.
A seed shape is described, which was first proposed in this country almost ten years ago.

Western Electric Co., Brit. Patent 965,345, July 29, 1964; U. S. Appl. Dec. 20, 1961.
Crystals with improved acoustic efficiency result from the incorporation of 100 to 500 ppm Li in the crystal during hydrothermal growth.

Tsinober, L. I. and Kamentsev, I. E., Kristallografiya 9, 448-50, 1964. (Russian). Soviet Phys.-Cryst. 9, 374-7.
As the growth rate on the rhombohedron face decreases, the amount of aluminum impurity in the quartz lattice increases, as shown by increased smoky color and an increase in the lattice constants.

Sosman, R. B., Am. Ceram. Soc. Bull. 43, 213, 1964.
A review is presented of the presently known silica phases, crystalline and amorphous, and consists of twenty-three phases. The wirter does not believe that the silica-X mentioned above corresponds to any of the phases on this list.

Yasukawa, K., Mem. Coll. Sci. Univ. Kyoto, Ser. B. 30, 121-45, 1963.

Kitahara, S. and Kennedy, G. C., J. Geophs. Res. 69, 5395-5400, 1964.
The quartz-coesite transition was studied versus temperature and pressure. Transition curves obtained were $P = 10.5 + 0.025, t$ and $p = 21.0 + 0.10, t$ respectively. The heat of transition is -155 cal/mole at 25°.

Barsanov, G. P. and Gur'eva, E. Ya., Dokl. Akad. Nauk SSSR 153, 909-12, 1963. (Russian). Tr. Mineralog. Muzeya, Akad. Nauk SSSR No. 15, 3-38, 1964. (Russian)
A method of identifying quartz grains involved in α-β transitions and the differences in appearances of such grains are detailed.

Tsinzerling, E. V. and Mironova, Z. A., Kristallografiya 9, 565-7, 1964. (Russian). Soviet Phys.-Cryst. 9, 478-9.

Tsinzerling, E. V., Zap. Vses. Mineralog. Obshchestva 93, 342-8, 1964.

Hanyu, T., J. Phys. Soc. Japan 19, 1489, 1964.
Etch channels in quartz are related to dislocations. Effective means of producing them are discussed.

White, G. K., Cryogenics 4, 2-7, 1964.
The thermal expansion of quartz parallel and perpendicular to the optic axes and of amorphous silica was measured between 2° and 30°K. α_c remains positive, but α_a has a minimum of -3.3×10^{-8} at 12.3°K.

Myers, M. B. and Vedam, K., Bull. Am. Phys. Soc. (II) 9, 447, 1964.
The optical rotatory power of α quartz decreases on application of 10 kb uniaxial pressure by an amount greater than 60% of its initial value at $\lambda = 5893$Å.

Shustin, O. A., Kristallografiya 9, 925-7, 1964. (Russian).
The changes in the optical dielectric constant of quartz near its α-β transition are described.

Mikheeva, L. F. and Shustin, O. A., Kristallografiya 9, 423-5, 1964. (Russian). Soviet Phys.-Cryst. 9, 347-8.
The ratio of the discontinuity in specific rotation of quartz at its α-β transition to the specific rotation at room temperature was 1.5 to 1.7×10^{-2}, independent of wavelength. The magnitude of the discontinuity was quite dependent on wavelength. The measurements are consistent with a first order transition.

Milne, E. L. and Gibbs, P., J. Appl. Phys. 35, 2364-7, 1964.
Silver ion migration was studied in quartz subjected to a dc voltage.

Tsinzerling, E. V., Kristallografiya 9, 69-73, 1964. (Russian). Soviet Phys.-Cryst. 9, 52-6.
The influence of added impurities of Li,Na,Ge or Al on twin formation in quartz was investigated.

Stevels, J. M. and Volger, J., Phys. Chem. Glasses 4, 247-52, 1963.

Snow, E. H. and Gibbs, P., J. Appl. Phys. 35, 2368-74, 1964.
The relation of dielectric loss to impurities and cation migration was analyzed in α-quartz.

Fraser, D. B., J. Appl. Phys. 35, 2913-18, 1964.
The internal friction peaks and their change with alkali ion doping was studied for natural quartz.

Detwiler, D. P. and Holden, S. J., Bull. Am. Phys. Soc. (II) 9, 492, 1964.
Loss peaks were found at 200°, 385°, and 550°K. An anomalous dip in frequency at 210°K was reported, accompanied by a small relaxation peak.

Whitelaw, J. H., J. Sci. Instr. 41, 215-18, 1964.
The internal friction of small diameter quartz strands was studied at low frequencies.

Laves, F. and Pfenninger, H., Naturwissenschaften 51, 81, 1964.
A warning is issued that the conductivity of quartz crystals may not be uniform, and results should not be generalized from a single experiment.

Weissmann, S., Imura, T., Nakajima, K., and Wisnewski, S. E., J. Phys. Soc. Japan 18, Suppl. III, 179-88, 1963.
Fast neutron irradiation produced no difference in lattice defects in natural and synthetic crystals, but did produce substantial differences between Z-cut and X-cut crystals.

Kato, T., Proc. Fujihara Mem. Fac. Eng., Keio Univ. No. 60, 1-27, 1963.

Vakhidov, Sh. A. and Akhmedzhanov, O., Radiats. Effekty v Kondensirovannykh Sredakh, Akad. Nauk Uz. SSR, Inst. Yadern. Fiz. 1964, 5-8.
The chemical and spectral aspects of the coloration of quartz upon γ-ray and X-ray irradiation are investigated.

Kiriyama, R. and Kawai, S., Nippon Isotope Kaigi Hobunshu 4, 286-91, 1961.
The effects of X-ray and γ-ray irradiation on the dielectric behavior of quartz and some silicates was investigated.

Starodubtsev, S. V., Vakhidov, Sh. A., and Kaipov, B., Radiats. Effekty v Kondensirovannykh Sredakh, Akad. Nauk Uz. SSR, Inst. Yadern. Fiz. 1964, 9-11. (Russian).
The effect of electrical treatment on the absorption spectra of quartz was studied for samples with and without Ge.

Pfenninger, H. H., Naturwissenschaften 47, 275, 1960.
Elastic oscillations were observed during the electrolysis of Z-cut quartz plates subjected to dc voltage at elevated temperature. The oscillations were interpreted as a resonance effect, and were eliminated by putting the crystal in an atmosphere high in hydrogen.

Koga, I., J. Appl. Phys. 34, 2357-65, 1963.
The radio-frequency vibrations of rectangular AT-cut quartz plates are analyzed theoretically.

Sauerbrey, G., "Proc. 17th Annual Symp. Frequency Control, Atlantic City, 1963," U. S. Army Electron. Res. Dev. Lab., Fort Monmouth, N. J. 28-50, 1963.
A description is given of an optical technique for observing amplitude distributions in vibrating AT quartz plates which allows detection of amplitudes below 10^{-7} to 10^{-8} cm.

Gates, E., Proc. IEEE 52, 1129-37, 1964.
The acoustic attenuation in quartz at gigacycle frequencies can be significantly reduced by flexing the samples to improve the parallelism of reflecting faces.

Thaxter, J. B. and Tannenwald, P. E., Appl. Phys. Letters 5, 67-8, 1964.
The attenuation of 70 Gc/sec acoustic waves in quartz was determined from 4.2 to 30°K.

Maris, H. J., Phil. Mag. 9, 901-10, 1964.
The attenuation of longitudinal waves in X-cut quartz and of transverse waves in AC-cut quartz was determined from 600 to 1110 Mc/sec. versus temperature.

Sinha, D. K., J. Acoust. Soc. Am. 36, 1926-8, 1964.
The radial deformation of a composite piezoelectric annular disc has been analyzed using equations of elasticity and piezoelectricity for quartz.

Thaler, W. J., Appl. Phys. Letters 5, 29-31, 1964.
The frequency modulation of an He-Ne Laser beam using ultrasonic waves in quartz is described.

Hutton, D. R., Phys. Letters 12, 310-11, 1964.
The paramagnetic resonance of Fe^{3+} in amethyst and citrine quartz is described. Removing the amethyst color by heat treatment does not change the EPR spectrum.

B. Other Silicates and Quartz Isomorphs

Smith, G. S. and Isaacs, P. B., Acta Cryst. 17, 842-6, 1964.
The atomic positions of the quartz form of GeO_2 are reported to good accuracy.

Yamaguchi, S., J. Appl. Phys. 35, 1654-5, 1964. Naturwissenschaften 51, 55, 1964.
Electron diffraction patterns of tourmaline at elevated temperatures are analyzed. A polarization of the electron beam is found similar to light polarization in tourmaline.

Hearst, J. R., Geesaman, L. B., and Power, D. V., J. Appl. Phys. 35, 2145-50, 1964.
The piezoelectric sensitivities of 20 Z-cut tourmaline crystals were compared up to 7 k-bar. Deviations from the mean value of up to 15% were found.

Kravchenko, V. B., Kristallografiya 9, 182-9, 1964. (Russian). Soviet Phys.-Cryst. 9, 143-8.
The atomic positions of the piezoelectric crystal searle-site, $NaBSI_2O_5(OH)_2$ were determined. The space group is $P2_1$.

Solov'eva, L. P. and Belov, N. V., Kristallografiya 9, 551-3, 1964. (Russian). Soviet Phys.-Cryst. 9, 458-60.
The atom positions have been determined for Bertrandite, $Be_4Si_2O_7(OH)_2$, space group $Cmc2_1$.

Sharan, B. and Dutta, B. N., Acta Cryst. 17, 82-5, 1964.

Dutta, B. N., Indian J. Pure Appl. Phys. 2, 362, 1964.
The atomic positions were determined for the form of $AlPO_4$ which is isomorphous with α-quartz. The *c*-axis is twice that of quartz.

XIII. Rochelle Salt and Other Tartrates

Myl, J., Solc, Z., and Kvapil, J., Sb. Ved. Praci, Vysoka Skola Chem.-Technol., Pardubice 1963, 89-96.
The solubilities of Rochelle salt and dipotassium tartrate were determined in the crystal growth region. Viscosities of the saturated solutions were measured.

Abe, R., Japan. J. Appl. Phys. 3, 243-9, 1964.
The domain wall motion in Rochelle salt at very low frequencies was observed by optical transmission in polarized light. The wall motion is jerky.

Michel, R., These Doct. 3eme Cycle, Phys. sup. Lyon, 1963. Ed. A.G.E.L., Lyon, In-4°, 97 pp., 1963.
Dielectric measurements at 37 Gc/sec, the results of γ-irradiation, and EPR measurements are used to understand the ferroelectricity in Rochelle salt. The double-well interpretation is used.

Guillien, R. and Mounier, S., Ann. Phys. (Paris) 8, 523-4, 1963.

Bae, P. and Guillien, R., "Magnet. Electr. Resonance Relax. Proc. XIth Coll. Ampere, Eindhoven, 1962," North-Holland Publ. Co., Amsterdam, 1963, 272-80.
Dielectric phenomena in Rochelle salt under the influence of a variety of fields are described.

Baeumler, P., Blum, W., and Deyda, H., Z. Physik 180, 96-104, 1964.
The complex dielectric constant of Rochelle salt was measured at 9.6 kMc as a function of temperature. The atmospheric humidity had no effect on the measurements. In the X-direction, the real part of the dielectric constant showed distinct minima at the Curie points.

Weissbach, G. and Müser, H. E., Phys. Verhandl. 4, 84, 1964.
The effect of air humidity on the ferroelectric properties of Rochelle salt was studied.

Unruh, H.-G., Z. angew. Phys. 16, 315-24, 1963.
The relation of the dielectric relaxation spectrum to lattice defects, particularly H_2O defects, is investigated.

Rewaj, T., Acta Phys. Polon. 24, 45-50, 1963.
Pure Rochelle salt exhibits no time dependence of permittivity on removing a dc poling voltage. Cu-doped Rochelle salt does exhibit a time dependence due to the tendency of Cu^{2+} to immobolize the domains.

Eisner, I. Ya., Kristallografiya 9, 111-13, 1964. Soviet Phys.-Cryst. 9, 90-2.
The domain structure was studied in Rochelle salt which had been irradiated in order to make the domains visible.

Asada, T., Nippon Isotope Kaigi Hobunshu 4, 617-21. (Japanese).
^{60}Co irradiation causes Rochelle salt to turn yellow, etch pits to increase, and normal hysteresis loops to become double.

Asch, G., Fontanel, M., and Mesnard, G., J. Phys. Radium 23, 1006-8, 1962. (French).
The magnetic resonance spectrum of Rochelle salt, completely hydrated and anhydrous, was compared with the spectra of Na tartrate · $2H_2O$, K_2 tartrate · $0.5H_2O$, anhydrous NH_4 tartrate, anhydrous KH tartrate, and anhydrous tartaric acid, after each had been irradiated with X or γ-rays. The spectrum associated with water of hydration was identified.

Blinc, R., Petkovsek, J., and Zupancic, I., Phys. Rev. 136A, 1684-92, 1964.
The ^{23}Na nuclear quadrupole resonance was measured in both the paraelectric and ferroelectric states of normal and deuterated Rochelle salt, and the results are interpreted structurally.

Miller, N. C. and Casabella, P. A., Bull. Am. Phys. Soc. (II) 9, 503, 1964.
A continuous change was found in the ^{23}Na nuclear quadrupole coupling between 28° and 3°C.

Kiosse, G. I., Golovastikov, N. I., and Belov, N. V., Kristallografiya 9, 402-3, 1964. (Russian). Soviet Phys.-Cryst. 9, 321-2.
The lattice constants, space groups, and comparison of the piezoelectric effect with that of quartz are given for a group of antimonyl tartrates: d-NH_4Sb tartrate, $C222_1$, > quartz; d-RbSb tartrate, $C222_1$, > quartz; d-KSb tartrate, $C222_1$, > quartz; d,ℓ-KSb tartrate - $Pca2_1$, < quartz.

XIV. Phosphates and Arsenates and Isomorphs

Silsbee, H. B., Uehling, E. A., and Schmidt, V. H., Phys. Rev. 133A, 165-70, 1964.
The modified and extended Slater theory of ferroelectricity in KH_2PO_4(KDP) type crystals is re-examined in the light of recent measurements. The agreements and discrepancies are analyzed.

Gavrilova, I. V. and Kuznetsova, L. I., Rost Kristallov, Akad. Nauk SSSR, Inst. Kristallogr. 4, 85-8, 1964. (Russian).

Furuya, N. and Mizota, T., Yamanashi Daigaku Kogakubu Kenkyu Hokoku No. 14, 58-66, 1963.
The various conditions necessary for good growth of KDP crystals, such as pH, impurities, and growth rate, are discussed.

Byteva, I. M., Rost Kristallov, Akad. Nauk SSSR, Inst. Kristallogr. 4, 22-6, 1964. (Russian). Kristallizasiya Zhidkosti, Sb. Statei No. 2, 28-31, 1963. (Russian).
The crystallization of $NH_4H_2PO_4$ (ADP), particularly versus pH, was investigated.

Zenin, S. E., Fiz.-Khim. Analiz, Akad. Nauk SSSR, Sibirsk. Otd., Inst. Neorgan. Khim., Tr. Yubileinoi Konf., Novosibirsk 1960, 125-32 (publ. 1963). (Russian).
Phase relations were investigated in aqueous systems containing K^+, NH_4^+, NO_3^-, and $H_2PO_4^-$ ions.

Pozin, M. E., Kopylev, B. A., and Shilling, N. K., Zh. Prikl. Khim. 37, 2341-8, 1964. (Russian).
Solubilities in the system $NH_4H_2PO_4$-NH_4NO_3-KCl-H_2O were investigated.

Paretzkin, B. and Peiser, H. S., Science 146, 260-1, 1964.
The use of high voltage Laue photographs to study ADP doped with Cr^{3+} is described.

Belt, R. F., J. Appl. Phys. 35, 3063-4, 1964.
Etching and X-ray topograph studies were performed on ADP crystals, indicating high crystal perfection.

Hill, R. M. and Ichiki, S. K., Phys. Rev. 135, 1640-2, 1964.
The interaction of polarized light and the domains in KDP below its Curie point is explained.

Aleksandrov, K. S. and Ryzhova, T. V., Kristallografiya 9, 373-6, 1964. (Russian). Soviet Phys.-Cryst. 9, 298-300.
Inner conical refraction previously predicted theoretically in tetragonal crystals was experimentally verified in ADP.

Murphy, E. J., J. Appl. Phys. 35, 2609-14, 1964.
The conduction in ADP is investigated in a number of different ways. It is proposed that the mechanism in the pure crystal is the simultaneous breaking of two H-bonds. It is shown that hydrogen gas is generated by the electrolysis of the crystals.

Pellicori, S. F., Appl. Optics 3, 361-6, 1964.
Transmittance data between 1900 and 3400A are given for a number of materials, including ADP.

Gainon, D. J. A., Jaffe, H., and Sliker, T. R., J. Appl. Phys. 35, 1166-8, 1964.
Elastic resonances in ADP were studied by an optical method which depends on the elasto-optic effect. The various modes obtained were analyzed.

Haussühl, S., Z. Krist. 120, 401-14, 1964.
New data are given for elastic constants, thermoelastic constants, lattice constants, and thermal expansion of KDP, ADP, $NH_4H_2AsO_4$, KH_2AsO_4, and RbH_2PO_4, and the results are analyzed thoroughly. No evidence is found for any deviation from Voigt's theory of elasticity.

Inoue, T. and Satta, K., Ritumeikan Daigaku Rikogaku Kenkyusho Kiyo No. 8, 13-18, 1962. (Japanese).
Some data on the piezo-optical properties of ADP are presented, along with a description of its use as a light modulator.

Wiener, E. and Pelah, I., Phys. Letters 13, 206-7, 1964.
The infrared absorption spectra of KDP were obtained at temperatures above and below the Curie point. Splitting of peaks between 250 and 450 cm^{-1} supports the existence of a low frequency H tunneling mode.

Stekhanov, A. I., Gabrichidze, Z. A., and Popova, E. A., Vodorodnaya Svyaz, Akad. Nauk SSSR, Inst. Khim. Fiz., Sb. Statei 1964, 126-37. (Russian).

Blinc, R. and Hadzì, D., Spectrochim. Acta 16, 853-62, 1960.
The infrared and proton magnetic resonance spectra of a number of materials with short hydrogen bonds are considered. These include many materials isostructural with KDP and KH phthalate.

Stavitskaya, G. P. and Ryskin, Ya. I., Optika i Spektroskopiya 10, 343-7, 1961. (Russian).
The infrared spectra of SrH_2GeO_4 and SrD_2GeO_4 (isostructural with ADP) were investigated.

XV. Sulfates, Selenites, and Isomorphs

A. Triglycine Sulfate (TGS) and Isomorphs

Gonzalo, J. A. and Lopez-Alonso, J. R., J. Phys. Chem. Solids 25, 303-10, 1964.
The results of a study of the variation of coercive field and spontaneous polarization with temperature are used to derive a simple model for TGS using statistical mechanics.

Wieder, H. H. and Parkerson, C. R., J. Phys. Chem. Solids 25, 241-5, 1964.
Adding Tl^+ to the solution produced tabular plates, inhibiting the growth along the c-axis. Electrically charged edge dislocations rather than impurities appear to be responsible for the internal biasing fields in TGS.

Sirota, N. N., Varikash, V. M., and Ovseichuk, E. A., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 666-8, 1964. (Russian). Dokl. Akad. Nauk Belorussek. SSR 8, 220-2, 1964. (Russian).
The change of intensity of the X-ray diffraction lines was investigated as TGS or triglycine selenate was heated through the Curie point.

Authier, A. and Petroff, J. F., Compt. Rend. 258, 4238-41, 1964.
Dislocations and domains in TGS were investigated by a topographic technique.

Meleshina, V. A., Kristallografiya 9, 381-7, 1964. (Russian). Soviet Phys.-Cryst. 9, 304-8.
A solution of HNO_3 and d,l-alanine in AcOH was found to be a good etchant for showing both dislocations and domain structure in TGS.

Strukov, B. A., Fiz. Tverd. Tela 6, 2862-5, 1964. (Russian). Soviet Phys.-Solid State 6, 2278-9.
The heat capacity of TGS was measured from 0° to 55°C. There is an even increase of heat capacity from 0.35 to 0.40 cal/g. deg. at 0° to 37°, a plateau at 37 to 39°, and then a rapid increase.

Dimarova, E. N. and Poplavko, Yu. M., Fiz. Tverd. Tela 6, 2878-9, 1964. (Russian). Soviet Phys.-Solid State 6, 2293-4.
The thermal conductivity of TGS decreases with increasing temperature. There is probably a small anomaly at the Curie point.

Brandt, A. A. and Shevchenko, V. Ya., Kristallografiya 9, 292-3, 1964. (Russian). Soviet Phys. Cryst. 9, 230-1.
The coercive field was determined for TGS between 10^2 and 10^{-5} cps. The results at 200 cps agreed with those of Pulvari and Kuebler (1958).

Tambovtsev, D. A., Kristallografiya 9, 511-15, 1964. (Russian). Soviet Phys.-Cryst. 9, 425-7.

Wieder, H. H., J. Appl. Phys. 35, 1224-7, 1964.
The nature of polarization reversal in TGS was investigated.

Rudyak, V. M. and Kamaev, V. E., Kristallografiya 9, 755-8, 1964. (Russian). Soviet Phys.-Cryst. 9, 638-40.
The relation of barkhausen noises to domain wall movement was studied in TGS.

Meleshina, V. A. and Rez. I. S., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 735-40, 1964. (Russian).
The interrelationship of hysteresis loop asymmetry, electrical conductivity, and point defects, and their dependence on etching treatment are described for TGS.

Lauginie, P., Ann. Phys. (Paris) 8, 523, 1963.
The dielectric properties of TGS were studied above and below the Curie point.

Kazarnovskii, D. M., Konstantinova, V. P., and Feofanov, B. N., Izv. Leningr. Elektrotekhn. Inst. 61, 242-51, 1963. (Russian).
The nonlinear dielectric properties of TGS were studied in dc and ac at 500 cycles at temperatures up to the Curie point.

Stankowska, J., Poznan. Towarz. Przyjaciol Nauk, Wydzial Mat. Przyrod. Prace Komisji Mat. Przyrod. 11, 207-11, 1964.
The comparison of dielectric constant change in dc fields was made for TGS pure and containing 5-10% $CuSO_4$. Differences were found between fresh and aged samples.

O'Brien, E. J. and Litovitz, T. A., J. Appl. Phys. 35, 180-6, 1964.

O'Brien, E. J., Dissert. Abstr. 24, 1671, 1963.
Ultrasonic waves traveling perpendicular to the b-axis exhibited marked relaxation effects below the Curie point. The measurements were related to the Landau-Khalatnikov theory of long range order. Some changes in results above the Curie point were interpreted as showing a persistence of some needle shaped domains, comparable in cross section to the sound wavelengths.

White, D. J., J. Appl. Phys. 35, 3536-42, 1964.
The pyroelectric response of TGS crystals to X-band microwave signals was obtained for a range of frequencies, modulation coefficients, and power levels. The results were compared with theory.

Malek, Z., Mastner, J., Hrdlicka, J., and Janta, J., Solid State Electronics 7, 655-69, 1964.

Glanc, A., Solid State Electronics 7, 671-6, 1964.

Malek, Z., Strajblova, J., Mastner, J., Moravec, F., and Novotny, J., Phys. Letters 13, 273-4, 1964.

Strajblova, J. and Fiala, J., Phys. Letters 8, 306-7, 1964.
The construction and use of a device using TGS is described. It is called TANDEL, for "temperature autostabilizing nonlinear dielectric element," depends upon the stabilizing out of the dielectric heating during use, and is operated near the Curie point.

Rewaj, T., Phys. Status Solidi 6, 163-8, 1964.
The changes in hysteresis loops with X-ray irradiation are documented for TGS. Up to 13 Mr., double loops are obtained in strong ac fields with uniform irradiation. Nonuniform irradiation leads to distortion of the loop.

Yurin, V. A. and Zheludev, I. S., Izv. Akad. Nauk SSSR, Ser. Fiz. 28, 726-30, 1964. (Russian).
The use of γ-irradiation to stabilize the spontaneous polarization and the thermoelectric effect is investigated.

Gonzalo, J. A. and Arndt, R. A., Bull. Am. Phys. Soc. (II) 9, 491, 1964.
The polar anisotropy in γ-irradiated TGS is described.

Hilczer, B. and Jaskulski, J., Bull. Acad. Polon. Sci., Ser. Sci., Math., Astron. Phys. 11, 715-17, 1963.

Hilczer, B. and Galica, J., Poznan. Towarz. Przyjaciol Nauk, Wydzial Mat. Przyrod. Prace Komisji Mat. Przyrod. 11, 199-206, 1964.
The effect of ^{60}Co irradiation on the Curie point and temperature hysteresis of TGS was investigated. Fewer defects for a given dose were introduced with larger dose rates. Differences were found in the Curie point shift of aged and de-aged samples.

Ovenall, D. W. and Mueller, K. A., Helv. Phys. Acta 34, 786-90, 1961.
The electron spin resonance spectrum of γ-irradiated TGS was measured above and below the Curie point.

Belyaev, L. M. and Bendrikova, G. G., Fiz. Tverd. Tela 6, 645-7, 1964. (Russian). Soviet Phys.-Solid State 6, 506-7.
In measuring the photoemission intensity from TGS before and after polarization reversal, it was found that the intensity from the negatively charged (010) surface was many times that from the positively charged surface.

Sirota, N. N., Tekhanovich, N. P., and Varikash, V. M., Mekhanizm i Kinetika Kristallizatsii, Nauchn. Sov. Akad. Nauk Belorussk. SSR po Fiz. Tverd. Tela 1964, 58-62. (Russian).
The ultrasonic velocity in triglycine selenate was measured from -20° to +50°C. The anomalies in ultrasound velocity and elasticity modulus at the Curie point are much less than in TGS, but the intensity changes of the Bragg reflections are greater.

Balasubramanian, K. and Krishnan, R. S., Proc. Indian Acad. Sci. Sect. A 58, 209-15, 1963.
The Raman spectrum of triglycine selenate was determined, and the structural implications discussed.

B. Other Sulfates, Selenites, and Isomorphs

Brown, I. D., Acta Cryst. 17, 654-60, 1964.

Van den Hende, J. H., Acta Cryst. 17, 660-3, 1964.
The atomic positions of ferroelectric lithium hydrazinium sulfate (space group $Pbn2_1$) are reported.

Niizeki, N. and Koizumi, H., J. Phys. Soc. Japan 19, 132-3, 1964.
Structural evidence is reported which contradicts the established ferroelectric behavior, and the implications are discussed.

Vanderkooy, J., Cuthbert, J. D., and Pethc, H. E., Can. J. Phys. 42, 1871-8, 1964.
The conduction in lithium hydrazinium sulfate was found to be protonic, with the direction of easiest conduction along the ferroelectric axis. The conduction is discussed in terms of the crystal structure and proton reorientations.

Strukov, B. A. and Toshev, S. D., Kristallografiya 9, 426-7, 1964. (Russian). Soviet Phys.-Cryst. 9, 349-51.
The domain structure and phase boundaries in $(NH_4)_2SO_4$ were observed at the transition temperature, and showed that the phase transition is first order.

Reshetnikova, L. P., Novoselova, A. V., and Zakharova, B. S., Vestn. Mosk. Univ., Ser. II, Khim. 19, 30-2, 1964. (Russian).
Solubilities were determined in the systems $(NH_4)_2BeF_4$ - propyl alcohol (0.215% fluoride) and $(NH_4)_2BeF_4$ - butyl alcohol (0.309% fluoride) at 25°C.

Strukov, B. A., Minaeva, K. A., and Rodicheva, E. N., Fiz. Tverd. Tela 6, 76-9, 1964. Soviet Phys.-Solid State 6, 59-62.
Polarization reversal was studied in NH_4HSO_4, and was found to fit the Merz model.

Iwasaki, H., Japan. J. Appl. Phys. 3, 59, 1964. J. Phys. Soc. Japan 19, 1256-7, 1964.
Dislocation etch pits and EPR spectra were studied in $LiH_3(SeO_3)_2$. The EPR spectra were of γ-irradiated crystals.

Makita, Y., J. Phys. Soc. Japan 19, 576, 1964.
The specific heat anomalies of methylammonium alum and $NaH_3(SeO_3)_2$ at their ferroelectric transitions and the differential thermoelectric force of $NaH_3(SeO_3)_2$ were determined.

Fletcher, R. O. W. and Steeple, H., Acta Cryst. 17, 290-4, 1964.
The atom positions in the low temperature ferroelectric form of methylammonium alum are reported.

Kuzenetsova, G. P., Plyushchev, V. E., and Oboznenko, Yu. V., Izv. Vysshikh Uchebn. Zavedenii, Khim. i Khim. Tekhnol. 7, 355-9, 1964. (Russian).
Solubilities in the system Li_2SO_4-Rb_2SO_4-Rb_2SO_4-H_2O were determined at 25° and 50°C.

Larson, A. C., U. S. At. Energy Comm. TID-13975, 21 pp., 1960.
A three-dimensional refinement of the crystal structure of $Li_2SO_4 \cdot H_2O$ was carried out.

Van Beek, L. K. H. and Bront, R., Physica 30, 1682-8, 1907-8, 1964.
The dielectric behavior of $Li_2SO_4 \cdot H_2O$ was determined under a variety of conditions.

XVI. Nitrites and Nitrates

Protsenko, P. I. and Shisholina, R. P., Ukr. Khim. Zh. 30, 912-15, 1964. (Russian).
Several alkali nitrite mixed systems were studied, including $LiNO_2$-$NaNO_2$.

Hoshino, S., J. Phys. Soc. Japan 19, 140-1, 1964.
The transition in $NaNO_2$ near 163°C is resolved into two transitions, a first order transition from ferroelectric to antiferroelectric, followed by a transition from antiferroelectric to paraelectric.

Takagi, Y. and Gesi, K., J. Phys. Soc. Japan 19, 142-3, 1964.

Hamano, K., J. Phys. Soc. Japan 19, 945-51, 1964.
A new transition was found 1° above the previous Curie point by dielectric measurements and piezoelectric measurements under bias field. The higher temperature transition is probably second order.

Canut, M. L. and Mendiola, J., Phys. Status Solidi 5, 313-27, 1964.
The diffuse scattering of X-rays in $NaNO_2$ was analyzed. Elastic constants obtained were $c_{11} = 2.4$, $c_{22} = 5.5$, $c_{33} = 5.6 \times 10^{-11}$ dynes/cm^2 at 20°.

Canut, M. and Hosemann, R., Acta Cryst. 17, 973-81, 1964.
Laue patterns of $NaNO_2$ obtained at 185° are interpreted as showing very small ferroelectric domains statistically oriented parallel or antiparallel to the polar axis.

Sawada, S. and Asao, Y., Japan. J. Appl. Phys. 3, 494-5, 1964.
Techniques for obtaining single domain areas in $NaNO_2$ are given, and the reasons for their success are discussed.

Hatta, I., Sawada, S., Asao, Y. and Yanagi, T., J. Phys. Soc. Japan 18, 1229-30, 1964.
The switching time of $NaNO_2$ was found to be 10^{-2} seconds, three orders of magnitude slower than any other ferroelectric. A true coercivity is absent, as in other ferroelectrics.

Sawada, S. and Tokugawa, Y., J. Phys. Soc. Japan 19, 2105-8, 1964.
After some ac treatment, a 50 cycle hysteresis loop was observed on a c-plate of $NaNO_2$, although the ferroelectric axis is b. The reasons for this are discussed.

Gesi, K. and Takagi, Y., J. Phys. Soc. Japan 19, 632-9, 1964.
As a result of γ-irradiation of $NaNO_2$, the Curie temperature and maximum dielectric constant decreased, coercive field increased, and double loops appeared.

Gesi, K. and Takagi, Y., Japan. J. Appl. Phys. 3, 126-7, 1964.
The infrared absorption of $NaNO_2$ was measured after γ-irradiation.

Tateno, J. and Gesi, K., J. Chem. Phys. 40, 1317-21, 1964.
The ESR spectrum of γ-irradiated $NaNO_2$ crystals was measured.

Dork, R. A., Schubring, N. W., and Nolta, J. P., J. Appl. Phys. 35, 1984-5, 1964.
The total switching time and peak switching current density of KNO_3 were measured as a function of applied field and temperature.

Yanagi, T. and Sawada, S., J. Phys. Soc. Japan 18, 1228-9, 1964.
The ferroelectric phase III in KNO_3 is increased in stability in the system $(NH_4)_xK_{1-x}NO_3$ up to $x = 0.5$. Hysteresis loops and crystal growth are described.

Kawabe, U., Yanagi, T., and Sawada, S., J. Phys. Soc. Japan 19, 767-8, 1964.
Lattice constants, dielectric, and hysteresis properties were determined on ferroelectric crystals in the system $Rb_xK_{1-x}NO_3$.

Davis, B. L., Science 145, 489-91, 1964.
A form of calcite was obtained at high pressure which is probably isostructual with phase III of KNO_3.

Mitani, S., J. Phys. Soc. Japan 19, 481-6, 1964.
Dielectric and X-ray studies were made on the ferroelectric phase transition of glycine silver nitrate. Results were compared with phenomenological theory.

XVII. Miscellaneous Ferroelectric and Piezoelectric Crystals

Krajewski, T., Poznan. Towarz. Przyjciol Nauk Wydzial Mat. Przyrod. Prace Komisji Mat.-Przyrod. 11, 175-96, 1962. (Polish).
The dielectric and piezoelectric properties of ammonium pentaborate are reported. Two molecules of H_2O are lost at 150°, above which the crystal is not piezoelectric.

Krajewski, T. and Blaszkiewicz, B., Poznan. Towarz. Przyjaciol Nauk Wydzial Mat.-Przyrod. Prace Komisji Mat.-Przyrod 11, 213-26, 1964. (Polish).
The dielectric and piezoelectric properties of potassium pentaborate are reported. The piezoelectric constants obtained were $d_{32} = 6.0$, $d_{33} = 5.0$, and

$d_{24} = 3.2 \times 10^{-12}$ Coul/N, the first two of which agree with the values of Cook and Jaffe (1957). The value for d_{24} was only a third of the value of Cook and Jaffe.

Parkerson, C. R., U. S. Dept. Com., Office Tech. Serv. AD 411,490, 29pp., 1963.
The strontium isomorph of colemanite was synthesized, and is ferroelectric.

Ascher, E., Schmid, H., and Tar, D., Solid State Communic. 2, 45-9, 1964.

Tar, D., Helv. Phys. Acta 37, 165-72, 1964.
Several compounds of the boracite structure were investigated for evidence of ferroelectricity. Dielectric anomalies were very small, but movement of domains was observed under an electric field.

Goetz, H., Phys. Status Solidi 5, 477-9, 1964. (German).
The excitation of shear vibrations in $NaClO_3$ crystals by a high frequency magnetic field was described. The excitation of the vibrations was ascribed to the piezoelectric effect.

Kasatkin, A. P., U.S.S.R. Patent 161,690, Apr. 1, 1964; Appl. May 20, 1963.
Conditions are described for stabilizing the growth rate of $NaBrO_3$ crystals.

Kasatkin, A. P., Kristallografiya 9, 302-5, 1964. (Russian). Soviet Phys.-Cryst. 9, 239-42; Vestn. Leningr. Univ. 19, No. (18) Ser. Geol. i Geogr. No. 3, 114-16, 1964. (Russian).
Growth nuclei and their relation to defects and control by shock waves were investigated in the growth of $NaBrO_3$ crystals.

Kaenzig, W., Hart, H. R., Jr., and Roberts, S., Phys. Rev. Letters 13, 543-5, 1964.
Measurements were reported on KCl with KOH impurities which indicated the presence of ferroelectricity at low temperatures.

Matusevich, L. N. and Blinova, N. P., Zh. Prikl. Khim. 37, 710-16, 1964.
Crystal growth investigations were carried out on several materials including $K_4Fe(CN)_6 \cdot 3H_2O$.

Nakagawa, T., Sawada, S., Kawakubo, T., and Nomura, S., J. Phys. Soc. Japan 18, 1227, 1964.
The specific heat of $K_4Fe(CN)_6 \cdot 3H_2O$ and thiourea was measured between -150° and 20°C, with particular attention to their ferroelectric transitions.

Tsang, T., McCormick, G. K., O'Reilly, D. E., and Schacher, G. E., Bull. Am. Phys. Soc. (II) 9, 503, 1964.
The deuteron magnetic resonance of $K_4Fe(CN)_6 \cdot 3D_2O$ was studied both above and below the Curie point at 249°K, and the results interpreted.

O'Konski, C. T. and Shirai, M., Biopolymers 1, 557-62, 1963.

O'Konski, C. T., Moser, P., and Shirai, M., Biopolymers, Symp. No. 1, 479-500, 1964.
The hysteresis loops of solid sodium deoxyribonucleate (DNA) are shown to be due to ionic conduction and electrolysis rather than ferroelectricity as reported by Polonsky and co-workers (1960).

Mesnard, G. and Vasilescu, D., Compt. Rend. 258, 3373-6; 259, 1451-3, 1964.
Piezoelectric resonances were obtained from microcrystalline powders of cytosine, adenosine, purine, uridine, thymidine, and deoxyadenosine. A single crystal of cytosine was also studied.

Aharoni, A. and Sapoznikov, D., J. Appl. Phys. 35, 1906-9, 1964.
Resonant frequencies, sound velocity, and elastic constants were determined for various crystals of salicylidene aniline.

Chang, L.-W., Likhacheva, Yu. S., and Dobrzhanskii, G. F., Rost Kristallov, Akad. Nauk SSSR, Inst. Kristallogr. 4, 81-4, 1964. (Russian).
Single crystals of acenaphthene were grown in sealed pyrex tubes by a modified Stockbarger method. Piezoelectric constants were: $d_{33} = 0.6$, $d_{32} = 0.2$, $d_{31} = 1.3$, $d_{24} = 1.4$, and $d_{15} = -0.33$, all x 10^{-12} Coul/N, ± 8 to 10%.

Kolontsova, E. V. and Telegina, I. V., Kristallografiya 9, 282-4, 1964. (Russian).
The nature of the structural breakdown in pentaerythritol crystals which have been irradiated with X-rays was examined.

Fukada, E. and Yasuda, I., Japan. J. Appl. Phys. 3, 117-21, 502, 1964.
The direct and converse piezoelectric effect was measured in collogen from the achilles tendon of cows and horses. Values obtained were $d_{14} = d_{25} = 2.3$, $d_{15} = d_{24} = 1.4$, $d_{31} = d_{32} = 0.09$, $d_{33} = 0.07$, all x 10^{-12} Coul/N.

CHAPTER VI

HIGH POLYMERIC MATERIALS

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I. Introduction

Chemical Abstracts was used in the compilation of these references. Our review of high polymer dielectrics will depart from the review of last year in the subject matter covered, format, and grouping of references. Patents have been excluded from this review, but those applicable to this chapter can be easily found in Chemical Abstracts. The references have been grouped according to the physical properties investigated and we have categorized the 1964 literature on high polymer dielectrics into the following areas: Theoretical Papers; Relaxation Phenomena; Dipole Moments and Polymer Structure; Semiconducting Polymers; Biopolymers; Effects of Radiation; and Technology.

The total number of papers which we list is 229. This continued high rate of publishing causes problems not only for the authors of this review but also for the researcher who must examine scores of papers in order to find a few significant contributions. Therefore, in this introduction we will point out those papers which, in our opinion, merit special attention.

Mandel[1], Mori[2], and Birshtein[3] have made theoretical calculations of the mean square dipole moment (MSDM) of a vinyl polymer molecule in solution. Mandel and Mori conclude that it is difficult to deduce the tacticity of a polymer molecule from measurement of MSDM. Birshtein's calculation is concerned with the relationship between the MSDM of a statistically coiled isotactic molecule and the geometry of the molecule in the helical crystalline state. Birshtein's work may provide a link between structure and dipole moment for an isotactic molecule.

Only one paper appeared in 1964 on the theoretical aspects of electrical conductivity in polymeric systems. This paper by Barker and Thomas[4] concentrated on ionic conduction in amorphous hydrophilic polymers. They put forth a model for ionic conduction in which the effect of moisture is to increase the concentration of ions by reducing the effective dissociation energy.

Relaxation phenomena in bulk polymers were studied theoretically by Gotlib[6], Dill[7], and LeGrand[8]. These works are phenomenological in content. Dill shows that the Boltzman superposition principle can be extended to strain birefringence experiments and LeGrand interprets rheo-optical properties in terms of the Debye model for dielectric relaxation.

Stockmayer and Bauer[9] discuss dielectric relaxation of polymers in solution in terms of the Zimm theory and point the way to new experiments in this area.

Experimentally, Mikhailov's group continues to produce noteworthy work[10,11], comparing the dielectric relaxation measurements on many similar but systematically altered polymer molecules. Heydeman[12] measured the dependence on pressure and temperature of the relaxation times of polyvinylchloride and adapted the superposition technique of Ferry and co-workers to include pressure shifting factors. Dielectric relaxation in crystalline oxidized polyethylene was observed by Tuijnman[13] and the data were interpreted in terms of the orientation of dipoles in a crystalline field.

Two significant experimental contributions to the field of relaxation phenomena in polymers were made by Connor[14] and Passaglia and Martin[15]. Connor used dielectric relaxation data as a reference in the interpretation of NMR data. Passaglia and Martin measured the dynamic mechanical properties of polypropylene. They presented the data in plots of modulus, loss tangent, and compliance versus temperature and noted the different relaxation patterns which can arise when using different functions to present the data. Any comparison of dielectric and mechanical relaxation data should be carried out in the light of the work of Passaglia and Martin.

Other interesting experimental studies were published by Leturcq and Martinot[16], and Hara and Okamoto[17]. In the first case[16] an extremely low frequency measurement (10^{-4} cycles/sec) was made. Hara and Okamoto continued their study of the polycarbonates presenting data over a wide temperature range.

Birefringence relaxation data in bulk polymers were analyzed by Read[18] by introducing reduced variables and superposition of data. Birefringence measurements on polymethyl methacrylate in solution were carried out by

Tsvetkov and Budtov[19] and the effects of molecular weight, intrinsic viscosity, and viscosity of the solvent were noted.

In connection with dipole moments and polymer structure, Smith[60] has done outstanding work in a calculation of polymer chain stiffness from measurements of static dielectric constant of a polar-nonpolar copolymer. Veselovskii and Matveev[61], and Mikhailov and Burshtein[62] investigated the effects of tacticity on dielectric properties. Ilberg and Muendoerfer[63] compared the birefringence measurements obtained from several different polymers.

The field of semiconducting polymers continues to demand much attention particularly from the Russian scientists who published 60 per cent of the papers written in this field in 1964. With the exception of the work of Barker and Thomas[4] on ionic conductivity, most of the work was on electronic conductivity. Baker[69] gives an excellent review, presents new conductivity data, and succeeds in isolating general behavior in semiconducting polymers. Pohl and Chartoff[70] continue to develop the concept of ekaconjugation, i.e., a polymer molecule containing conjugated chemical bonds plus symmetry. Other workers[71-74] continue to prepare semiconducting polymers in various ways (pyrolysis, irradiation, doping, electron transfer agents, etc.) and to interpret the data in terms of π-orbital overlap and molecular structure.

Wildi and Katon[72] and Berlin[98] report methods of polymerization to directly synthesize polymers with high conductivity. Lupinski and Kopple[75] prepared a semiconducting polymeric material that was soluble and the conductivity of which could be controlled.

Technological applications of polymeric materials as semiconductors are beginning to be realized, but for the most part technological advances involved the production of new insulating materials or the improvement of already existing insulation products. Several technologically oriented reviews of uses of polymeric insulating materials appeared in 1964[160-163,165,188,193]. The possible uses of semiconducting polymers is discussed by Neiman and Johnson[164] in an excellent paper which reviews the current concepts of polymer conductivity in a qualitative manner.

New techniques in materials evaluation were described by Torossian and Jones[166], Zelenev and Lyalina[171], and Steck[172]. The properties of the more common polymers (polyethylene, polystyrene, polyvinyl chloride, etc.) were evaluated under various conditions[169,174,185,187] and improved by various techniques[170,190].

II. Theoretical Papers

1. Mandel, M., Mol. Phys. 7, 433-42, 1963-64.
Expressions are derived for dipole moment and end-to-end distance of polar monosubstituted vinyl polymers. No correlation between these quantities is found.

2. Mori, T., J. Phys. Soc. Japan 19, 1361-75, 1964.
The dipole moment and end-to-end distance of a syndiotactic vinyl polymer in dilute solution were calculated and compared with those of an isotactic vinyl polymer, where the excluded volume effect is large.

3. Birshtein, T. M., Vysokomolekul. Soedin. 5, 1675-83, 1963.
This is a theoretical paper on the conformations of isotactic macromolecules and their properties in solution. A relationship is obtained between the mean dimension, dipole moments, and internal rotation angles.

4. Barker, R. E. and Thomas, C. R., J. Appl. Phys. 35, 3203-15, 1964.
Several problems associated with ionic conduction in amorphous hydrophilic polymers were investigated from a theoretical point of view and then discussed in the light of experiments with alkali-halide doped cellulose 2.5 acetate. Two points were emphasized: (1) the change of activation energy for conduction with moisture content and (2) non-ohmic behavior.

5. Bradley, D. F., Lifson, S., and Honig, B., Electron. Aspects Biochem., Proc. Intern. Symp. Revello, Italy 1963, 77-91.
Calculations of dipole-dipole interactions in a helical biopolymer were made. It is shown that it is necessary to consider more than nearest neighbor interactions.

6. Gotlib, Yu. Ya., Fiz. Tverd. Tela 6, 2938-44, 1964.
The theory of dielectric relaxation processes in amorphous polymers above the glass temperature is discussed. It is assumed that reorientation of polar groups takes place only after the occurrence of an interchain cooperative process with a large temperature coefficient.

7. Dill, E. H., J. Polymer Sci. Pt. C5, 67-74, 1964.
The birefringence shown by high polymers can be explained by considering light as an electromagnetic wave propagating through an anisotropic dielectric. The observed dependence of the birefringence on the deformation is described by expressing the dielectric tensor as a function of the strain history. For small strains, this function can be approximated by an integral such that the birefringence and strain are related by a law having the form of the Boltzmann superposition integral.

8. LeGrand, D. G., J. Polymer Sci. Pt. A2, 923-30, 1964.
A theory of the rheo-optical properties of polycrystalline polymers was developed using a model similar to the dielectric relaxation model of Debye. Crystal sizes were calculated.

III. Relaxation Phenomena

9. Stockmayer, W. H. and Baur, M. E., J. Am. Chem. Soc. 86, 3485-9, 1964.
Dielectric dispersion, relaxation of the Kerr effect and relaxation of the Benoit-Wippler effect are discussed for flexible-chain molecules in terms of the model used by Zimm to treat viscoelastic behavior of dilute polymer solutions. Low-frequency dispersion is related to the long-wave Fourier components of the electric charge distribution along the chain backbone.

10. Mikhailov, G. P. and Borisova, T. I., Vysokomolekul. Soedin. 6, 1778-84, 1964.
"Dipole elastic" losses were determined in polymers in relation to their structure, by measurement of ϵ (dipole moment) and tan δ from -170° to 160°C and from 0.02 to 150 kc for polymers of chloromethyl-, β-chloroethyl-, γ-chloropropyl-, and δ-chlorobutyl-methacrylates. The relaxation time τ and the apparent activation energy of the relaxation process, and the effective dipole moment of the kinetic segment decreased with increasing length of the side chain. Introduction of polar substituents increased τ and T_g, independent of the position of the substituent.

11. Mikhailov, G. P. and Borisova, T. I., Vysokomolekul. Soedin. 6, 1785-90, 1964.
Dipole relaxation of normal poly(chloroalkyl methacrylates) was studied at low temperatures. Two regions of "dipole radical" losses were found: One at 70° attributed to the motion of CO_2 groups in the glass. The other at -100°C, corresponding to mobility of the kinetic units formed by the ends of the side chains. Lengthening of the side chains resulted in a decrease in the relaxation time, and increases in effective dipole moment and tan δ_{max}.

12. Heydemann, P., Kolloid-Z. 195, 122-8, 1964.
The dielectric relaxations of poly(methylmethacrylate) and poly(vinylchloride) were examined as a function of pressure, temperature and frequency. The influence of pressure on dielectric relaxation in polymers can be predicted from the apparent activation energy and the specific volume, if the energy of activation is known as a function of the free volume at one atmosphere.

13. Tuijnman, C. A. F., Polymer 4, 315-28, 1963.
The low frequency losses in oxidized polyethylene (crystallized under high pressure) are attributed to rotation of oxidized crystallized chains. Dielectric loss results from jumping of dipoles between potential minima which exist in the crystalline field.

14. Connor, T. M., Trans. Faraday Soc. 60, 1574-91, 1964.
Dielectric and NMR relaxation data were obtained for glycerol, polyethylene glycol 200, and polyoxymethylene. It is assumed that the same molecular motions are involved in both dielectric and NMR relaxations. If it is assumed that the distribution of the NMR relaxation times is the same as the distribution of dielectric relaxation times, then activation energies obtained from NMR and dielectric measurements agree.

15. Passaglia, E. and Martin, G. M., J. Res. Natl. Bur. Stds. 68A, 519-27, 1964.
Dynamic mechanical measurements were made at 1 cps over a temperature range of

-180° to 150°C on a series of isotactic polypropylene samples prepared by various thermal treatments. The difficulty in analyzing the data using different functions, tan δ, modulus, and compliance is pointed out.

16. Leturcq, and Martinot, H., Compt. Rend. 258, 5367-70, 1964.
The correspondence between resorption currents and slow relaxation spectra of macromolecules was studied using the Cole-Cole relations. Measured parameters for gumlac and methyl-phenyl-polysiloxane are given. The method is suitable for very low frequencies (10^{-4} cps).

17. Hara, T. and Okamoto, S., Japan. J. Appl. Phys. 3, 499-500, 1964.
Dielectric properties were measured on poly(bisphenol-A carbonate) and poly (tetrachlorobisphenol-A carbonate) from -170° to 250°C. Data are given on the temperatures and activation energies of the α, β, and γ absorptions.

18. Read, B. E., Polymer 5, 1-18, 1964.
The molecular mechanism of relaxation processes in polymers was investigated by measurement of the amplitude and relative phases of stress, strain, and birefringence of polymethyl methacrylate in the frequency range 1-20 cps and temperature range 16° to 62°C. A method of reduced variables (similar to Ferry's reduced variables and superposition) was proposed.

19. Tsvetkov, V. N. and Budtov, V. P., Vysokomolekul. Soedin. 6, 1203-12, 1964.
The intrinsic orientation angle of birefringence (relaxation times) for polymethyl methacrylate in solution was measured as a function of molecular weight, M, intrinsic viscosity $[\eta]$, and viscosity of solvent η_0. A plot of relaxation time versus $M[\eta]\eta_0/RT$ is not linear and the product $M[\eta]\eta_0$ can not be regarded as an index of internal viscosity.

20. Curtis, A. J., High Polymers 20, Pt. 2, 105-30, 1964.
Electrical properties of polyolefins are reviewed (51 references).

21. Hoffman, J. D., Am. Chem. Soc., Div. Polymer Chem., Preprints 4, 150-56, 1963.
The dielectric properties of semicrystalline polymers are surveyed and illustrated by poly(chlorotrifluoroethylene). Molecular mechanisms are discussed in connection with the three principal loss peaks, and comparisons are made with corresponding dynamic mechanical data.

22. Passaglia, E., SPE Trans. 4, 169-77, 1964.
Relaxation processes in crystalline polymers may be studied by measurement of dielectric constant and mechanical internal friction. Three processes are observed, involving progressively larger regions of the chains as the temperature is raised (27 references).

23. Mikhailov, G. P., Lobanov, A. M., Shevelev, V. A., and Orlova, T. P., Vysokomolekul. Soedin. 6, 868-70, 1964.
The temperature dependence of ε' and tan δ was determined at 4.7×10^8 cps for poly(tetrafluoroethylene) annealed, hardened, compressed or elongated. Tan δ_{max} occurs at 323°K. Elongation and pressure do not affect the value of tan δ_{max}, but hardening increases it. Above 248°K, the kinetic unit has nearly the same dimension as the monomer.

24. Timofeeva, V. G., Boriscova, T. I., Mikhailov, G. P., and Kozlov, P. V., Vysokomolekul. Soedinl, Tsellyuloza i ee Proizvodnye, Sb. Statei 1963, 174-80.
The dielectric loss in cellulose triacetate was observed in mixtures with butyl stearate and other low molecular weight compounds. The changes with concentration were associated with the decomposition of the supramolecular structures under the action of a low molecular weight substance.

25. Mikhailov, G. P. and Lobanov, A. M., Vysokomolekul. Soedin., Geterotsepnye Vysokomolekul. Soedin. 1964, 175-80.
Dielectric properties were measured for poly(4,4'-isopropylidenediphenol sebacate) at frequencies of 2 x 10^2 to 10^{10} cps and at temperatures -150° to 200°C. The ϵ'' - log f plot shows two maxima: -110° to 20°C and 40° to 150°C. T_g is 26°C.

26. Mikhailov, G. P. and Lobanov, A. M., Vysokomolekul. Soedin., Geterotsepnye Vysokomolekul. Soedin. 1964, 181-5.
Cole-Cole diagrams were used to analyze the dielectric data for poly(4,4'-isopropylidene diphenol sebacate). The spectra of relaxation times for low and high temperature loss regions were observed to narrow with increase in temperature.

27. Zelenev, Yu. V. and Bartenev, G. M., Vysokomolekul. Soedin. 6, 915-22, 1964.
The influence of plasticization on the relaxation properties was investigated for sulfur-vulcanized natural, butyl, nitrile, Thiokol, and butadiene-styrene rubbers, over temperatures -140 to 160°C and frequencies 10^{-3} to 10^6 cps. The relationships of polarity of the rubber, concentration of plasticizer, temperature, and frequency are shown.

28. Zelenev, Yu. V. and Bartenev, G. M., Vysokomolekul. Soedin. 6, 1047-53, 1964.
Measurements were done on mixtures of polar and non-polar rubbers using dynamic mechanical and electrical methods over the range 10^{-3} to 10^6 cps and from -170° to 140°C. The effects of the degree of compatibility and of the ratio of components on the properties were examined.

29. Sistig, E. and Zeil, W., Z. Physik. Chem. 41, 236-44, 1964.
Dielectric constant and loss factor were measured for linear and branched polyethylenes at room temperature in the range 7.5 to 36.3 kMc/sec. Both parameters were found to be independent of the frequency for both kinds of polyethylene.

30. Haase, J., Sistig, E., and Zeil, W., Z. Naturforsch. 19a, 660-1, 1964.
The dielectric constant of Plexiglas was calculated from refractive index measurements using an interference method at 36 and 42 kMc. The average values of the dielectric constants were 2.54_9 and 2.55_8, respectively.

31. Zeil, W. and Sistig, E., Kolloid-Z. 196, 8-17, 1964.
Dielectric constant and loss factor were measured for linear and branched polyethylenes and for Plexiglas in the range 211° to 373°K at 24.3 x 10^{10} cps. The maximum absorption of the polyethylenes agrees with previous results, but Plexiglas has a different maximum.

32. Schlosser, E., Plaste Kautschuk 10, 644-7, 1963.
An analysis is made of dielectric measurements of polymers in the high frequency and high temperature range. The several relaxation features are discussed.

33. Connor, T. M., Read, B. E., and Williams, G., J. Appl. Chem. 14, 74-80, 1964.
The dielectric, dynamic mechanical, and nuclear resonance properties of polyethylene oxide were studied as a function of molecular weight and degree of crystallinity. It is proposed that the relaxation behavior arises from motion of the main chain in crystalline and strained regions.

34. Work, R. N., McCammon, R. D., and Saba, R. G., J. Chem. Phys. 41, 2950-51, 1964.
The dielectric loss for atactic polypropylene was measured in the frequency range 100 cps to 20 kc/sec and temperature range 4° to 300°K. One loss region was observed. The effective dipole moment contributing to the dispersion was calculated to be 0.05 D.

35. Pegoraro, M. and Zelinger, J., Chim. Ind. 46, 258, 1964.
Dielectric constant and loss of isotactic polypropylene were measured at 50 cps over a temperature range of -35°C to the melting point. Loss is observed to increase with increased oxidation and is close to zero when the sample is oxygen free.

36. Bartenev, G. M. and Zelenev, Yu. V., Dokl. Akad. Nauk SSSR 154, 661-4, 1964.
The low temperature relaxation processes of natural rubber, butadienestyrene rubber, atactic polybutadiene rubber, and nitrile rubber were studied in the temperature range -180° to 25°C. The temperature dependence of relaxation time followed the Arrhenius law.

37. Golubkov, G. E., Tr. Vses. Elecktrotekhn. Inst. 1963, 35-120.
The dielectric properties of organic Si polymers were studied by chemically substituting side groups. Methyl, ethyl, phenol, and highly polar groups were substituted and the effect on the dielectric properties and intermolecular forces were discussed.

38. Lauttman, R. G. and Stein, M. V., U. S. Dept. Comm., Office Tech. Serv. Ad 291,504, 20 pp., 1962.
The effect of moisture and crystallinity on the dielectric properties of nylon 66, nylon 610, and Mylar was measured. The sorption of H_2O by these polymers was of two types, strong and weak bonding.

39. Usmanova, N. F., Golubeva, A. V., Bulatova, V. M., and Sivograkova, K. A., Plasticheskie Massy 1964, 7-8.
Dielectric and mechanical properties of polystyrene and copolymer of styrene and α-methylstyrene are compared over a wide range of temperatures and frequencies.

40. Skarga, J., Polimery 8, 223-9, 1963.
Dielectric loss was measured for several polyformaldehydes in the form of films 20-30μ thick, after different thermal treatments. Crystalline and amorphous loss mechanisms are discussed.

41. Weyl, D. A. and Neale, S. M., Dielectrics 1, 22-5, 1963.
A comparison was made of the dielectric behavior of a charged and uncharged polymer in aqueous solution.

42. Terada, M., Lassier, B., Bensasson, R., and Brot, C., J. Chim. Phys. 60, 701-2, 1963.
Polyacrylonitriles were prepared by radiation polymerization of the liquid monomer (1) and frozen monomer (2). Dielectric and NMR measurements indicate the existence of enclosed monomer molecules in sample 2.

43. Urazovski, S. S. and Ezhik, I. I., Tr. Khar'kovsk. Politekhn. Inst. 39, 85-90, 1962.
Dielectric loss measurements of some polymers in solution indicate the presence of solid phase and intermediate structure conversions. It is hypothesized that this effect occurs in the near electrode capacitance area.

44. Hara, T. and Okamoto, S., J. Phys. Soc. Japan 19, 1087-88, 1964.
The dielectric increment, $\epsilon-\epsilon_\infty$, of the β-absorption in polyvinylacetate was measured as a function of degree of polymerization, n. For $n = 240$, $\epsilon_s-\epsilon_\infty = 0.19$ at -70°C. For $n > 600$, $\epsilon_s-\epsilon_\infty = 0.09$. It is concluded that the end groups contribute to β-absorption but not to the α-absorption.

45. Conklin, G. E., J. Appl. Phys. 35, 3228-35, 1964.
The mechanism contributing to dielectric loss in polyethylene at 55.2×10^9 cps was identified as imperfections in the form of vinyl unsaturation which can orient in the presence of a microwave field. The loss decreased by a factor of 1.5 from 4.5×10^{-5} when the vinyl groups were destroyed by γ-irradiation.

46. Ishida, Y., Yamafuji, K., and Shimada, K., Kolloid-Z. 200, 49, 1964.
The symmetry of the dielectric β-absorption of poly(ethylene adipate) was examined in the temperature range -73.6 to -104°C and frequency range 5 cps to 1 Mc.

47. Ishida, Y., Watanabe, M., and Yamafuji, K., Kolloid-Z. 200, 48, 1964.
The dielectric loss of a sample of linear poly(vinylidene fluoride) of molecular weight 250,000 was measured between -10.9° and -73.1°C and from about 5 cps to about 0.5 Mc.

48. Ishida, Y., Matsuo, M., Ueno, Y., and Takayanagi, M., Kolloid-Z. 199, 67-8, 1964.
In earlier work on the dielectric behavior of polyacrylonitrile, the β-absorption was presumed to have merged into the tail of the α-absorption. The β peak can be found by depressing the α peak, using a solution-grown sample of high crystallinity.

49. Ishida, Y., Ueno, Y., Togami, S., and Matsuo, M., Kolloid-Z. 199, 70, 1964.
Isotactic poly-1-butene showed three dielectric loss peaks: at 0°C caused by segmental motion of the chains, at -50°C attributed to local twisting action of chains, and at -100°C, the result of motions of side groups.

50. Ishida, Y., Matsuo, M., Ueno, Y., and Takayanagi, M., Kolloid-Z. 199, 69-70, 1964.
Dielectric measurements on solution-grown crystals of poly(ethylene terephthalate) showed two absorption regions.

51. Ishida, Y. and Yamafuji, K., Kolloid-Z. 200, 50-1, 1964.
The α-absorption at -59.7° to 42.7°C for poly(vinyl fluoride) is much larger than that of other poly(vinyl halides), with an activation energy of about 10 kcal/mole. The chain of poly(vinyl fluoride) is more compact, therefore its rotation as a whole is easier than in the other halides.

52. Ishida, Y., Shimada, K., Matsuura, K., and Takayanagi, M., Kolloid-Z. 200, 51-2, 1964.
Dielectric behavior was compared for copolymers and block polymers of methyl acrylate-styrene. The copolymers show α-peaks in the span 0° to 125°C and β-peaks at about -75°C. The block polymers show three peaks characteristic of each homopolymer.

53. Ishida, Y., Amano, O., and Takayanagi, M., Kolloid-Z. 172, 126-9, 1960.
The temperature-time superposition principle was checked on several polymers. Superposition was carried out for absorptions above and below the glass transition. The effect of crystallinity was examined.

54. Murakami, I., Ishii, T., and Yamamura, H., J. Sci. Hiroshima Univ., Ser. A-II 27, 125-32, 1964.
The effect of stretching on the dielectric properties of polymethylmethacrylate was measured in the temperature range 15° to 130°C and a frequency range 10^{-4} to 10^{6} cps. The β-absorption was not affected by stretching but the α-relaxation shifted to higher frequencies because the orientation of the polymer chain was less restricted in the stretched state.

55. McCall, D. W., Am. Chem. Soc., Div. Polymer Chem., Preprints 4, 157-9, 1963.
Conduction, polarization and relaxation processes in polyamides are discussed in terms of molecular motions in crystalline, amorphous and glassy regions. An influence of water on the glass transition was noted and a water dipole relaxation was observed.

56. Flowers, L. C. and Berg, D., J. Electrochem. Soc. 111, 1239-43, 1964.
Polyvinyl alcohol was treated with acrylonitrile, i.e., cyanoethylated. Measurements of ϵ' and ϵ'' generally increased with increased cyanoethylation. Polar group substitution presumably accounts for the observed variations in dielectric properties.

57. LeGrand, D. G., J. Polymer Sci. Pt. A, 2, 931-942, 1964.
The rheo-optical properties of some common polymers were studied as a function of temperature and frequency.

58. Tsvetkov, V. N. and Budtov, V. P., Vysokomolekul. Soedin. 6, 16-21, 1964.
Birefringence measurements were made on polymethyl methacrylate in ten solvents of different viscosity. For low solvent viscosities orientation of the molecule alone is seen. For high solvent viscosities orientation plus deformation effects are observed.

59. Andrews, R. D. and Kimmel, R. M., J. Appl. Phys. 35, 3194-3202, 1964.
Birefringence measurements were made as a function of temperature (-200° to 190°C) on polyacrylonitrile and a 7% vinyl acetate copolymer. A set of complicated data was obtained showing creep, stress relaxation, effects of temperature cycling, and mechanical history. The data defied any simple explanation in terms of molecular morphology.

IV. Dipole Moments and Polymer Structure

60. Smith, F. H., Ph. D. Thesis, The Pennsylvania State University, 1964.
Static dielectric constant measurements of polar-nonpolar copolymers were used to determine polymer chain stiffness and conformation. Measurements were made on suitably pure copolymers of p-chlorostyrene and p-methylstyrene containing a wide range of concentrations of polar repeat units. Effective dipole moments were calculated and interpreted in terms of nearest neighbor and next nearest neighbor dipole directional correlation. It is shown that the correlation extends to next nearest neighbors.

61. Veselovskii, P. F. and Matveev, V. K., Vysokomolekul. Soedin. 6, 1221-7, 1964.
The temperature dependence of ϵ' and tan δ was determined for polymethyl methacrylate solutions in toluene in the temperature range -150° to 200°C and frequency range 50 to 1.8×10^6 cps. The curves for isotactic, syndiotactic and atactic polymers are compared. The effect of steroregularity is associated mainly with intramolecular properties. The results agree with earlier conclusions for bulk measurements.

62. Mikhailov, G. P. and Burshtein, L. L., Vysokomolekul. Soedin. 6, 1713-16, 1964.
The dipole moments of poly tert-butyl methacrylate and tert-butyl methacrylate were measured in benzene. The results were: for atactic polymer 1.54D; isotactic polymer 1.73D; syndiotactic polymer 1.63D; and monomer 1.95D. The rotation of steroregular dipole groups is restricted.

63. Ilberg, W. and Muendoerfer, B., Kolloid-Z. 198, 23-27, 1964.
The birefringence observed in polyvinyl chloride, polymethylmethacrylate and polystyrene are compared. Results are discussed in terms of the different dipolar orientations.

64. Wendisch, P., Kolloid-Z. 199, 27-31, 1964.
The change in dielectric constant of nitrocellulose solutions in butyl acetate with shearing strain is nearly linear with the velocity gradient. The increase is 10^{-3} to 10^{-2} units, being larger with higher concentration or lower temperature.

65. Dubova, L. S., Berestnev, V. A., and Nagdaseva, I. P., Khim. Volokna 1964, 52-5.
Birefringence was used to study the structure and orientation of polyamide fibers.

66. LeFevre, R. J. W. and Sundrama, K. M. S., J. Chem. Soc. 1964, 556-62.
The molar Kerr constants and apparent dipole moments of indene and polyindenes were measured in benzene solution. The dipole moments are independent of molecular weight. No definite molecular configuration for the polyindenes is concluded from the measurements.

67. Hoshino, S., Stein, R. S., and Sasaguri, K., U. S. Dept. Comm., Office Tech. Serv., AD 420,049, 1962.
Birefringence measurements were made on polypropylene fractions as a function of tacticity. The more tactic polymers had negative birefringence and atactic sample had positive birefringence. The difference in sign of amorphous and crystalline contributions permits their separation.

68. Veselovskii, P. F., Ukr. Fiz. Zh. 9, 99-100, 1964.
Dielectric constant and loss measurements were made on concentrated solutions of polyvinylacetate in H_2O and toluene. H_2O interacts with the dipoles in polyvinyl acetate whereas toluene has no effect on the dipole moment of the polyvinyl acetate monomer unit. The comparison of the solution properties is offered as a means for studying polymer structure.

V. Semiconducting Polymers

69. Baker, W. O., J. Polymer Sci. Pt. C, 4, 1633-50, 1964.
This paper is a review of electronic conductivity in polymeric systems. Structural changes with pyrolysis are diagrammed and general phenomena (ESR, optical absorption, and conductivity) in polymer systems are pointed out.

70. Pohl, H. A. and Chartoff, R. P., J. Polymer Sci. Pt. A, 2, 2787-806, 1964.
Semiconduction and ESR measurements on polyacetylenes, polybenzimidazoles, and polyacene quinone radical polymers were made. Resistivities were 270 to 10^{16} ohm-cm. The relationships of properties, structure, and concentration of unpaired spins are discussed.

71. Carlton, D. M., McCarthy, D. K., and Genz, R. H., J. Phys. Chem. 68, 2661-5, 1964.
The electrical conductivity as a function of temperature was measured for polyazophenylenes and the effect of molecular structure was examined. The degree of π-orbital overlap along a conjugated chain is thought to be the most important structural feature affecting conductivity.

72. Wildi, B. S. and Katon, J. E., J. Polymer Sci. Pt. A, 2, 4709-8, 1964.
Semiconducting polymers derived from low molecular weight nitriles are described. The insoluble, infusible materials have low resistivities (1.5×10^{-3} to 63 ohm-cm). Probable structures are discussed. Energy gaps of 0.06 to 0.98 ev are given.

73. Mainthia, S. B., Kronick, P. L., and Labes, M. M., J. Chem. Phys. 41, 2206-7, 1964.
The conductivity was measured on complexes of poly(vinylpyridine) with iodine. Resistivities at room temperature of 10^4 to 10^7 ohm-cm were found. The complexes are stable toward moisture and heat to 147°C (m.p.).

74. Inami, A., Morimoto, K., and Mayashi, Y., Bull. Chem. Soc. Japan 37, 842-4, 1964.
The photoconductivities of thin films of polyacenaphthylene and partially nitrated (10-30%) polymer were compared. Nitration increases the photoconductivity by means of a charge-transfer mechanism.

75. Lupinski, J. H. and Kopple, K. D., Science 146, 1038-9, 1964.
Electroconductive polymers were prepared by combining tetracyanoquinodimethane (TCNQ) alkylated poly(2 vinylpyridene). The conductivity of the product depended on the amount of neutral TCNQ present and reached conductivities of 10^{-3} $\text{ohm}^{-1}\text{cm}^{-1}$.

76. Hatano, M., Kagaku To Kogyo (Tokyo) 17, 792-802, 1964.
The sysntheses and properties of polymeric semiconductors are reviewed (86 references).

77. Mizoguchi, A., Moriga, H., Shimizu, T., and Amano, Y., Natl. Tech. Rept. (Matsushita Elec. Ind. Co., Osaka) 9, 407-15, 1963.
Charge-transfer type electroconductive linear polymers were prepared and measured. Poly(2-vinylpyridine) and poly(4-vinylpyridine) were used as electron donors and $SbCl_3$, Br, and tetracyanoquinodimethane were used as electron acceptors. Mixing electron donors and acceptors in different molar ratios produced compounds with specific resistivity about 10^8 ohm-cm which was exponential with temperature.

78. Kho, J. H. T. and Cappas, C., U. S. Dept. Comm., Office Tech. Serv. AD 416,462, 41 pp., 1963.
Highly conuugated polyacene quinone semiconducting polymers were prepared. The semiconducting properties were studied as a function of hydrocarbon portion in polymer, metallic salt formation, pressure and temperature, etc.

79. Mainthia, S. B., Kronick, P. L., Ur, H., Chapman, E. F., and Labes, M. M., Am. Chem. Soc., Div. Polymer Chem., Preprints 4, 208-12, 1963.
Poly-p-phenylene-iodine stable complex $[(C_6H_4)_4I_2]_{9-10}$ has a resistivity of 2.5×10^4 ohm-cm, lower by 11 decades than that of poly-p-phenylene, and that of iodine by 4 decades. The activation energy for conduction is 0.87 ev. It is suggested that charge separation due to donor-acceptor interaction leads to some orbital overlap between molecules containing delocalized electrons.

80. Kambara, S., Hatano, M., and Kubushiro, K., Bull. Tokyo Inst. Technol. 39, 29-38, 1964.
Semiconducting compounds were obtained from poly (α-chloroacrylonitrile) by pyrolysis and by dehydrochlorination. The differences between dehydrochlorination and pyrolysis were studied.

81. Tsuchida, E., Shinohara, I., and Kambara, S., Kogyo Kagaku Zasshi 66, 1404-5, 1963.
The products of a dehydrochlorination process carried out with polyvinyl chloride gave resistivities of 10^3-10^4 ohm-cm.

82. Harrison, S. E., U. S. Atomic Energy Commission TID-16040 (20 pp.), 1962.
Gamma-ray-induced photoconductivities were measured for polyethylene, polystyrene, a mica-filled epoxy, polypropylene, nylon, Teflon, diallyl phthalate and H-film, at intensities of 10^{-3} to 10^4 rads (H_2O)/sec at 38° - 71°C. The behavior of the conductivity in consecutive time periods was discussed.

83. Bashara, N. M. and Doty, C. T., J. Appl. Phys. 35, 3498-507, 1964.
Current-voltage-thickness characteristics of thin films (100-500 Å) of polybutadiene showed that space-charge-limited current occurs at fields of 3×10^4 V/cm where trap densities are $10^{22}/m^3$. Tunnel current is also observed in some cases.

84. Hamann, C., Inst. Angew. Physik. Reinsstoffe (Dresden), Rept. No. IFR 13, 1-9, 1962.
The mechanism of conduction in organic semiconductors was examined by measurements on polyacrylonitrile and copper phthalocyanine. The dependence of specific resistance on molecular weight (pyrolysis), radiation dose (cobalt 60) and on α-β transformation in phthalocyanine was determined.

85. Van Beek, L. K. H. and Van Pul, B. I. C. F., Carbon 2, 121-6, 1964.
The nonohmic behavior of some carbon black-loaded rubbers is explained by tunneling effects between imputities. A series of samples containing 50 weight per cent of six different blacks seems to follow ohm's law.

86. Lamm, A., Lamm, G., Coelho, R., and Belloc, P., Colloq. Nationaux Centre Natl. Rech. Sci. (Paris) 24, 127-31, 1963.
The electrical resistivities were measured on sheets of unvulcanized natural rubber made by air-drying latex and mixtures of latex with carbon black dispersions. The effects of gamma irradiation of the components before casting were examined.

87. Brown, G. P. and Aftergut, S., J. Polymer Sci. Pt. A, 2, 1839-45, 1964.
Poly[bis-(imidazolato) metal] was prepared with copper (II), zinc (II) or cobalt (II). The cobalt-imidazole polymer had a resistivity of 10^{17} ohm-cm at 114°C, which was inversely proportional to temperature, following the exponential law, with an activation energy of 1.55 e.v. at 114° to 149°C. The cobalt-and zinc-imidazole polymers had resistivities of 10^{15} at 150° and 10^{15} at 140°C, respectively. The resistivity of imidazole is 10^{11} ohm-cm at 27°C.

88. Liang, C. Y. and Scalco, E. G., J. Chem. Phys. 40, 919, 1964.
Electric and photo conductivities of Na-DNA salt were measured in the dry and wet state. It is proposed that electrical conductivity arises from electrons excited from impurity centers.

89. Christy, R. W., J. Appl. Phys. 35, 2179-84, 1964.
The current through silicone polymer films formed by electron beam bombardment in the thickness range 50-150Å was measured as a function of voltage and temperature at 77°-300°K. The behavior is ohmic at low voltages and log I varies

as $V^{1/2}$ at higher voltages up to IV. Simple tunneling theory fails to account for all the data.

90. Holland, L. and Laurenson, L., Vacuum 14, 325-32, 1964.
Silicone 704 was polymerized with γ-rays under vacuum and in the presence of different gases (O, N, H, H_2O). The volume resistivity of the products was measured.

91. Taneguchi, A., et al., Bull. Chem. Soc. Japan 37, 1386-8, 1964.
The electrical properties of poly(N-vinylcarbazole) tetracyanoquinodimethane charge-transfer complex were studied. The resistivity at room temperature is 10^{14}-10^{16} ohm-cm.

92. Oikawa, E. and Kambara, S., Bull. Chem. Soc. Japan 37, 1849-54, 1964.
The physical properties and structure of polyacetonitrile were investigated. Electrical conductivities were 10^{-6} to 10^{-10} $ohm^{-1}cm^{-1}$. Results indicate that C:N and C:C bonds are present.

93. Okamoto, Y. and Alia, D., Chem. Ind. (London) 1964, 1311-12.
The energy gaps and resistivities of polypyridylacetylenes were compared with those of polyphenylacetylene. The values for all were in the range 0.96 to 1.2 e.v. and 1.7×10^{15} to 4.9×10^{16} ohm-cm, respectively, showing little effect from the presence of the nitrogen atom. The large values are explained by non-coplanarity in the chain.

94. Kuwata, K., Sato, Y., and Hirota, K., Bull. Chem. Soc. Japan 37, 1391, 1964.
Semiconducting compounds were prepared by mixing a polymer of diphenylamine, an electron donor, with electron acceptors, iodine and chloranil.

95. Morimoto, K., Hayashi, Y., and Inami, A., Bull. Chem. Soc. Japan 36, 1651-4, 1963.
A photoconductive polymer, poly[1,3-diphenyl-5-(4-vinylphenyl)-2-pyrazoline] was prepared. The photoconducting properties of a 20μ film were reported. The charge carriers were electrons.

96. Berlin, A. A., Ganina, V. I., Kargin, V. A., Kronman, A. G., and Yanovskii, D. M., Vysokomolekul. Soedin. 6, 1684-7, 1964.
The IR spectra and electrical and physical properties of the salts formed by reaction of poly(vinyl chloride) with nitrile or methylvinylpyridine rubbers were studied. The formation of high molecular weight products reduces the specific volume resistance.

97. Berlin, A. A., et al., Vysokomolekul. Soedin. 6, 832-7, 1964.
Phthalocyanine polymers were prepared by polycoordination of 1,2,4,5-tetracyanobenzene and phthalonitrile and the effect of the oxygen-containing groups and the branching of the structure on the electrical properties was studied. The conductivities of various polymers and copolymers ranged from 10^{-3} to 10^{-5} $ohm^{-1}cm^{-1}$.

98. Berlin, A. A., Zherebtsova, L. V., and Razvodovskii, Ye. F., Vysokomolekul. Soedin. 6, 58-63, 1964.
A method of polymerization is proposed for the synthesis of polymers with conjugated bonds. The polymers showed high conductivity.

99. Slindkin, A. A., Dulov, A. A., and Rubinshtein, A. M., Izv. Akad. Nauk SSSR, Ser. Khim. 1964, 1769-75.
The magnetic properties, electroconductivity, and the EPR spectra of quinizarin and bis(8-hydroxy-5-quinolyl)methane polycoordination polymers complexed with Ni, Co, Mn, Cu, and Zn were studied. Conductivity and activation energy are determined chiefly by the nature of the polychelate chain and the concentration of charge transfer complexes, which is increased by heat treatment.

100. Dulov, A. A., Slinkin, A. A., and Rubinshtein, A. M., Izv. Akad. Nauk SSSR, Ser. Khim. 1964, 26-34.
Samples of poly(methyl vinyl ketone) were thermally treated at three temperatures: < 500°C, 585°C, 670°C. The resultant samples are semiconductors. The low temperature samples are of the n-type while medium and high temperature treatment yields semiconductors of the p-type.

101. Dulov, A. A., et al., Izv. Akad. Nauk SSSR, Ser. Khim. 1964, 909-12.
Electrical conductivity and EPR spectra are given for polyarylenequinones, formed by polycondensation of p-benzoquinone with tetrazotized diamines, in linear and crosslinked forms from 150° to 350°C. The influence of structural features on the conductivity is pointed out.

102. Drabkin, I. A. and Rozenshtein, L. D., Izv. Akad. Nauk SSSR, Ser. Khim. 1964, 1113-15.
Polyacrylonitrile films, heated in vacuum at 200-300°C became semiconductive and photoconductive. The time-temperature curves of photoconductivity corresponded to the development of conjugated double bonds.

103. Gugeshashvili, M. I., Davydov, B. E., Korshak, Yu. V., and Rozenshtein, L. D., Izv. Akad. Nauk SSSR, Ser. Khim. 1964, 1703-5.
Interruption of conjugation in linear polymer chains (polyazines) by hetero atoms with unshared electrons (oxygen or sulfur) was studied by measurement of UV absorption spectra. Activation energies of conduction from 3.4 to 4.7 e.v. were observed.

104. Korshak, V. V., Sosin, S. L., and Sladkov, A. M., J. Polymer Sci. Pt. C, 4, 1315-26, 1964.
Polymers containing conjugated C-N and C-C bonds were prepared. The polymers and high resistivities (10^{12}- 10^{14} ohm-cm) which were exponentially dependent on temperature up to 700°C. At 800°C a sharp drop in resistivity to 10 ohm-cm was noted.

105. Airapetyants, A. V., Vlasova, R. M., and Geiderikh, M. A., Izv. Akad. Nauk SSSR, Ser. Khim. 1964, 1328-30.
The ionic and electronic conductivities of thermally treated polyacrylonitrile were measured. Ionic conductivity is dominant at temperatures up to 150-300°C and decreases above this temperature. Electronic conductivity increases at the higher temperatures (up to 450°C) because of the increase in the number of conjugated bond system structures.

106. Airapetyants, A. V. and Davydov, B. E., Organ. Poluprov., Akad. Nauk SSSR, Inst. Neftekhim. Sinteza, Inst. Poluprov. 1963, 291-315.
The electrical properties of polymer semiconductors are reviewed. Conductivities in the range 10^{-1} to 10^{-13} $ohm^{-1}cm^{-1}$ are noted. Thermo-and photo-e.m.f.'s may be found in these polymers.

107. Airapetyants, A. V., et al., Vysokomolekul. Soedin. 6, 86-8, 1964.
Thermal treatment of oriented polyacrylonitrile fibers at 520°, 610° and 700°C yielded semiconducting materials. Elongation decreases the resistivity.

108. Topchiev, A. V., Davydov, B. E., and Airapetyants, A. V., Organ. Poluprov., Akad. Nauk SSSR, Inst. Neftekhim. Sinteza, Inst. Poluprov. 1963, 258-90.
Methods of preparation and electrical conductivities of semiconducting polymers are reviewed (87 references).

109. Gel'fman, A. Ya., et al., Dokl Akad. Nauk SSSR 154, 894-6, 1964.
Powdered polyvinyl alochol was pyrolyzed in a stream of air or inert gas. The crystallinity and electrical conductivity of the product were studied.

110. Vannikov, A. V., Dokl. Akad. Nauk SSSR 152, 905-7, 1963.
The electrical conductivity of polyethylene containing indium and modified by irradiation and thermal treatment is 4×10^{-4} $ohm^{-1}cm^{-1}$. For samples containing indium the activation energy is 0.01 e.v. and for free polyethylene it is 0.33 e.v. The diode characteristics of the samples are reported.

111. Frankevich, E. L., Busheva, L. I., Balabanov, E. I., and Cherkashina, L. G., Vysokomolekul. Soedin. 6, 1028-34, 1964.
The electrical conductivity of polymeric copper phthalocyanine was found to be 1 to 2×10^{-3} $ohm^{-1}cm^{-1}$ at 22°C, and its activation energy was 0.1 e.v. The presence of oxygen decreased the conductivity by reducing the mobility of charge carriers.

112. Kustanovich, I. M., Patalakh, I. I., and Polak, L. S., Vysokomolekul. Soedin. 6, 197-200, 1964.
The semiconductor properties of pyrolyzed polyacrylonitrile fibers were measured. Surfaces having adsorbed oxygen showed hole-type conductance, and the body of the polymer showed electron conductance.

113. Nikitina, V. I., Maklakov, A. I., Balakireva, R. S., and Pudovik, A. N., Vysokomolekul. Soedin. Geterotsepnye Vysokomolekul. Soedin. 1964, 87-90.
The electric and magnetic properties of poly(phenylenimines) were studied. The electrical conductivity is in the range 10^{-9} to 10^{-13} $ohm^{-1}cm^{-1}$, and is decreased by heat treatment. The conductivity is ascribed to unpaired electrons.

114. Zhuravleva, I. P., Zgadzai, E. A., and Maklakov, A. I., Vysokomolekul. Soedin. 6, 488-92, 1964.
Electrical properties were compared for poly(phenylenimine) prepared with and without catalyst, recrystallized and non-crystallized, dried and undried, and dried and rewet. The conductivity varied with heat treatment and was related to the H_2O content. Static magnetic susceptibilities showed no ferromagnetic impurities were present.

115. Boguslavskii, L. I. and Stil'bans, L. S., Vysokomolekul. Soedin. 6, 1802-5, 1964.
Resistances and activation energies of polymeric complexes of tetracyanoethylene, which were prepared at 300° and 500°C, were measured as a function of frequency from 0.5 cps to 200 Mc. The 300°C sample had resistance which decreased with frequency and the 500°C sample had low resistance for all frequencies.

116. Pil'menshtein, I. D., Shenfil, L. Z., and Vyshegorodskaya, R. A., Kauchuk i Rezina 23, 38-41, 1964.
Electric conductivity of films of natural rubber and polychloroprene filled with C_2H_2 black were measured. The conductivity increases with increasing concentration of filler reaching a value of 1 $ohm^{-1}cm^{-1}$ at 40% filler. The conductivity of the films depends on the possibility of forming chain structures of filler inside of the capillaries of the gel.

117. Paushkin, Ya. M., et al., J. Polymer Sci. Pt. C., 4, 1481-94, 1964.
Electrophysical properties of new polymers based on ferrocene were measured. Conductivity versus temperature data in the range 20-200°C show semiconductor characteristics. The specific electroconductivity at 50°C is 1×10^{-14} - 5×10^{-6} $ohm^{-1}cm^{-1}$.

118. Konobievs'kii, I. D. and Kagan, G. T., Plasticheskie Massy 1964, 46-8.
The specific volume resistance was measured from 25° to 200°C for polyester resins from ethylene- or diethylene-glycol and maleic anhydride, modified with phthalic anhydride, cyclopentadiene or anthracene, and cured by copolymerization with styrene. Thermal pretreatment of the cured resins at 175°C increases the resistance and the glass temperature.

119. Van-Gaut, Yu. N., Ol'shanskaya, L. A., and Sokolova, R. S., Plasticheskie Massy 1964, 42-5.
Semiconducting materials were obtained by adding carbon black to polyvinylchloride. The volume resistivity decreased steadily with increased amounts of carbon black.

120. Kargin, V. A. and Krentsel, B. A., Organ. Poluprov., Akad. Nauk SSSR, Inst. Neftekhim. Sinteza, Inst. Poluprov. 1963, 232-57.
Present concepts of polymer compounds are reviewed and the possibility of imparting a conductivity to polymers is considered.

121. Konobievs'kii, I. D., Khim. Prom., Inform. Nauk-Tekhn. Zb. 1964, 45-6.
The temperature dependence of the electric resistivity of glass-fiber plastics was determined. Unsaturated polyester resins, crosslinked with styrene and modified with cyclopentadiene or anthracene were used. The resistivity was 10^{14} to 10^{16} ohm-cm at 298° to 333°K and 423° to 473°K, but decreased to 10^{11} to 10^{13} in the interval 333° to 423°K.

122. Benderskii, V. A., Kogan, B. Ya., Gachkovskii, V. F., and Shlyapnikova, I. A., Vysokomolekul. Soedin., Karbotsepnye Vysokomolekul. Soedin., Sb. Statei 1963, 253-9.
The nature of paramagnetic centers and mechanism of electroconduction were studied in polyphenylacetylene by measurement of ESR, optical and luminescence

spectra. Conduction obeys the exponential law and is 10^{-18} to 10^{-20} $\text{ohm}^{-1}\text{cm}^{-1}$ at room temperature. The activation energy is 2.15 e.v. Both quantities are independent of molecular weight (240-1870) and presence of oxygen.

123. Sazhin, B. I. and Skurikhina, V. S., Vysokomolekul. Soedin., Karbotsepnye Vysokomolekul. Soedin., Sb. Statei 1963, 60-73.
Specific volume resistance of various polyethylenes containing catalysts was measured at 20-180°C. Relationships of stress time, temperature, amount of catalyst, and degree of crystallinity were examined. Temperature is found to have a critical effect.

124. Myl'nikov, V. S., Dokl. Akad. Nauk SSSR 157, 1184-7, 1964.
Photo and electric conductivities of acetylene polymers containing C:C groups were studied.

125. Vlasov, A. V., et al., Dokl. Akad. Nauk SSSR 158, 141-2, 1964.
The polymerization (by irradiation) of acetylenic monomers to produce semiconducting samples with good mechanical properties was reported.

126. Mal'tsev, V. I. and Itskovich, V. A., Vysokomolekul. Soedin. 5, 1367-70, 1963.
The electrical resistance of oxidation products of some aromatic amines is $10^3 - 10^4$ ohm-cm which is in the semiconductor range.

126a. Petrosyan, V. P., Izv. Akad. Nauk Arm. SSR, Khim. Nauki 17, 122-30, 1964.
The volume resistivity was observed during the polymerization of chloroprene in benzene, and found to change little. Resistivity increases with crystallinity. The energy of activation for amorphous and crystalline polymers is 44.6 and 21.9 kcal/mole, respectively.

126b. Mann, H. T., J. Appl. Phys. 35, 2173-9, 1964.
Current through silicone polymer films induced by electron-beam bombardment was measured as a function of voltage and temperature at 4°-300°K. Electron transport in the films (500-2500Å) was nonlinear and depended on thickness and voltage. The effects of H_2O and O_2 diffusion in the film were observed.

126c. Krotova, N. A., Issled. Obl. Poverkhn. Sil, Akad. Nauk SSSR, Inst. Fiz. Khim., Sb. Dokl. na Vtoroi Konf., Moscow 1962, 293-311, 1964.
Changes in the surface state of a semiconductor when adhesive bonds with a polymer are formed can be investigated by measurement of the surface conductivity and rate of recombination. Parameters which characterize the interface are given for several polymers on germanium.

VI. Biopolymers

127. Tinoco, I., Jr. and Bush, C. A., Biopolymers, Symp. No. 1, 235-50, 1964.
The influences of static electric and magnetic fields on the optical properties of polymers are reviewed (58 references).

128. Watanabe, H., Yoshioka, K., and Wada, A., Biopolymers 2, 91-101, 1964.
Dielectric constant and birefringence measurements on poly(γ-benzyl-L-glutamate) and $(CH_2Cl)_2$ solutions are reported. With the addition of a large amount of $CHCl_2CO_2H$ (ca. 75% concentration) the helix-coil transformation is observed.

129. O'Konski, C. T., Moser, P., and Shirai, M., Biopolymers, Symp. No. 1, 479-500, 1964.
Conductivity and dielectric properties of solid Na, Li, and Mg deoxyribonucleate were measured. A conductivity dispersion region was observed in the megacycle/sec region. Basic structural properties of DNA are discussed in relation to conductivity.

130. Krause, S. and O'Konski, C. T., Biopolymers 1, 503-15, 1963.
Kerr constants and rotational diffusion coefficients were determined for several proteins in water and in glycerol-water solutions. The results agree in several instances with those obtained by the dielectric relaxation time method.

131. Hikichi, K., et al., J. Phys. Soc. Japan 19, 577, 1964.
Dielectric measurements were made on solid poly(γ-benzyl-L-glutamate), M_w = 123,000, at frequency range of 0.3 to 10^6 cycles/sec and temperature range of 18-58°C. The apparent activation energy for side-chain relaxation is 46.6 kcal/mole.

132. Makino, S., Kamashina, K., Kubota, S., and Sugai, S., Japan. J. Appl. Phys. 3, 55-6, 1964.
Dielectric properties of synthetic polypeptides in the solid state were measured. Activation energy of a dispersion region attributed to side chain rotation was calculated.

133. Goebel, I. W. and Vogel, H., Z. Naturforsch. 196, 292-302, 1964.
Dielectric measurements on horse methemoglobin in water solution were made in the frequency range 0.1 Mc/sec to 10 Mc/sec. Dipole moment calculation gave 430 D. A good correlation between viscosity and relaxation time was found.

134. Marchal, J. and Marchal, E., Vysokomolekul. Soedin. 6, 561-7, 1964.
The use of dielectric properties of solutions of rod-like macromolecules for determination of their length and polydispersity, as well as rigidity is discussed. Poly(γ-benzyl-L-glutamate) and poly(DL-phenylalanine) were measured in chloroform. The polydispersity strongly influences the shape of the dielectric absorption curve.

135. Mukohata, Y. J. Mol. Biol. 7, 442-5, 1963.
An alternating electric field was used in studying electric-streaming birefringence of poly(γ-benzyl-L-glutamate) in m-cresol. The method is useful for distinguishing between permanent and induced electric effects and for estimating the values of each.

136. Johnson, G. A., Bol. Sco. Chilena Quim. 12, 11-13, 1962.
The dielectric behavior of polyelectrolytes (ribonucleic acid, suspensions of Al_2O_3 and carborundum in H_2O) showed three absorption regions, ca. 5 Mc/sec, 200 kc/sec and 1000 cycles/sec. The absorption regions are explained as Debye, Maxwell-Wagner, and O'Konski absorptions.

137. Wojtech, L., Biophysik 1, 60-72, 1963.
The conductivity of polyvinyl chloride plastic Trovidur increased by a factor of 1.3×10^4 when subjected to irradiation.

138. Pullman, B., Compt. Rend. 259, 3101-3, 1964.
Calculations on purine and pyrimidine bases lead to the prediction that the semi-conductivity of biological polymers occurring in nucleic acids would increase with a proportionate increase of guanine-cytosine pairs over adenine-thymine pairs. Experimental results indicated greater electronic interaction between G-C than between A-T pairs.

139. Golub, E. I., Dvorkin, G. A., and Nazarenko, V. G., Biokhimiya 28, 1041, 1963.
In an evaluation of the rigidity of DNA molecules in solution, the relaxation times of electric birefringence were found to be the same for DNA from two sources, having mol. wts. 8×10^6 and 9×10^7. The "kinematic segment" was 4.1×10^3Å long in 0.001 M NaCl and 7.7×10^3Å in water.

140. Mesnard, G. and Vasilescu, D., Biochim. Biophys. Acta 91, 531-3, 1964.
Dielectric properties of solutions of DNA in salt water, formamide and urea were measured during slow heating and cooling. A partial renaturation of the DNA occurs during slow cooling in salt solution. In solutions of DNA in formamide or 8 M urea, the DNA is always in a denatured state.

141. Kobayashi, S., Biochim. Biophys. Acta 88, 541-52, 1964.
F-actin, oriented by flow, was exposed to pulsed electric fields and the disorientation was followed by measuring the birefringence. The results suggest that F-actin has a large permanent dipole moment perpendicular to the fiber axis.

142. Kobayashi, S., Asai, H., and Oosawa, F., Biochim. Biophys. Acta 88, 528-40, 1964.
Electric birefringence was measured during the polymerization of actin. Initial polymers showed positive birefringence, being oriented with the long axis parallel to the electric field. Later polymers of F-actin showed a large negative birefringence, with the long axis perpendicular to the field.

143. Houssier, C. and Fredericz, E., Biochim. Biophys. Acta 88, 450-2, 1964.
Birefringence and dichroism of nucleic acids (DNA) and nucleoproteins (DRP) were measured. Results indicated that the structure of DNA essentially remains the same in DRP.

144. Golub, E. I. and Dvorkin, G. A., Biofizika 9, 545-8, 1964.
Electric dichroism and birefringence were measured at various wavelengths for solutions of tobacco mosaic virus and 100s ribosomes.

145. Golub, E. I. and Nazarenko, V. G., Biofizika 9, 657-65, 1964.
Electric birefringence was measured in dilute solutions of RNA in distilled water or 0.001 M NaCl. RNA having helical content about 70% showed negative birefringence as a result of the anisotropy of helical segments. When all RNA was in the coiled form, the birefringence was positive, corresponding to the orientation of the coil. Relaxation times are given.

146. Eley, D. D. and Leslie, R. B., Electron. Aspects Biochem., Proc. Intern. Symp., Ravello, Italy 1963, 105-17, 1964.
The effects of deuteration on the conductivity of RNA, glycine and a tripeptide were studied. For bovine albumin at 21°C the specific conductivity increases in the order H_2O, D_2O, CH_3OH, at low adsorbate content. At 1.0 mole adsorbate/100 g protein appreciable polarization occurs.

147. Epstein, C. J., Nature 203, 1350-2, 1964.
The influences of polar residues in the evolution of proteins is discussed. It is hypothesized that the polar residues of myoglobin are situated on the surface of the molecule while non-polar residues inhabit the interior.

148. Watanabe, H., Nippon Kagaku Zasshi 85, 403-10, 1964.
Electric birefringence measurements were made on poly(γ-benzyl-L-glutamate) solutions. Relaxation time, average length of the polypeptide (1600 Å), and dipole moment (4.3×10^3 D) were calculated.

149. Yoshioka, K. and Watanabe, H., Nippon Kagaku Zasshi 84, 626-8, 1963.
A method of analyzing build-up and decay curves of electric birefringence for polydisperse systems is presented. The method was applied successfully to poly(γ-benzyl-L-glutamate).

VII. Effects of Radiation

150. Yahagi, K., Waseda Daigaku Rikogaku Kenkyusho Hokoku 23, 9-15, 1963.
The conductivity induced by gamma rays in low density polyethylene and Teflon films was measured as a function of temperature (-80° to 20°C), dose rate and applied voltage. Below -40°C the induced current was independent of temperature, but above -40°C it fit the Arrhenius plot with activation energy 0.3 - 0.4 e.v.

151. Karpov, V. L., et al., Tr. Tashkentsk. Konf. po Mirnomu Ispol'z. At. Energii, Akad. Nauk Uz. SSR 1, 383-9, 1961.
The use of gamma or electron irradiation to increase the thermal stability of polyethylene insulation was studied. The best strength is achieved with up to 100 megarads in vacuum of 1 m.e.v. for 2-4 min. Samples irradiated with electrons are more resistant to thermal aging than those with an equivalent gamma dose.

152. Hedvig, P., J. Polymer Sci. Pt. A, 2, 4097-103, 1964.
Radiation-induced conductivities as high as 10^{-12} ohm^{-1}cm^{-1} were measured in polyamide copolymers irradiated by X-rays or gamma-rays at dose rates of 0.1 to 20 roentgens/sec. No temperature dependence for the induced conductivities could be detected between 10° and 60°C, while dark conductivities followed the exponential rule with activation energies of 1 to 2 e.v.

153. Grishina, A. D. and Vannikov, A. V., Dokl. Akad. Nauk SSSR 156, 647-9, 1964.
Paramagnetism of irradiated polyethylene heated in vacuum below 800°C is ascribed to structural defects such as broken bonds. Above 800°C the high concentrations of both the paramagnetic centers and the current carriers is noted.

154. Nakai, T. and Sakakibara, T., Denki Gakkai Zasshi 88, 263-71, 1963.
The effect of γ-ray irradiation on the electrical properties of Mylar was investigated. The loss tangent and volume resistivity increased after irradiation in air. Only small changes were noticed after irradiation in vacuum.

155. Nesterov, V. M., Nesmelora, E. S., Ol'shanskaya, N. I., and Mikhailova, T. G., Izv. Vysshikh Uchebn. Zavedenii, Fiz. 1964, 147-52.
The action of gamma-radiation on the electrical conductivity and dielectric loss of some cable insulation materials was studied as a function of irradiation time. The properties may increase, decrease or remain unaffected, depending on the nature of the insulating material.

156. Kryszewski, M., Kurczewska, H., and Szymanski, A., J. Polymer Sci. Pt. C, 4, 1417-27, 1964.
The effect of ultraviolet radiation on the luminescence and electric resistance of polyamides and copolymers of vinylidene chloride and vinyl chloride were investigated. Resistance decreases in both cases; luminescence decreases in the polyamides and increases in the copolymers after irradiation.

157. Watanabe, M., Tanaka, S., and Tada, S., Nippon Isotope Kaigi Hobunshu 4, 380-3, 1961.
The effects of electron irradiation on polyethylene cable insulation were examined, and little change was observed in dielectric constant or loss. Heat aging increases the loss in proportion to the irradiation dose.

158. Posselt, K., Elektrie 18, 145-9, 1964.
Irradiation (electron) improves the mechanical properties without impairing the electrical properties of polymers used as insulating materials.

159. Asch, G., Felix, M. C., and Ongaro, R., Compt. Rend. 258, 3982-5, 1964.
Polystyrene was given gamma-irradiation then polarized by placing between condenser plates to give permanent electrification. Variables studied were irradiation time, polarization time, potential applied in polarization, time interval between irradiation and polarization, and discharge by short circuiting.

VIII. Technology

160. McPherson, A. T., Rubber Chem. Technol. 36, 1230-1302, 1963.
This paper is a review of the electrical properties of polymers, with 234 references.

161. Grange, P. W., Dulin, C. I., Hodges, R., et al., Rubber Plastics Age 45, 394-411, 1964.
The uses of various plastics in electric and electronic applications are briefly reviewed.

162. Swiss, J., Mod. Plastics 42, 141-4, 1964.
Designing with fluorocarbon plastics for various electrical applications is reviewed.

163. Chandler, R. H., Paint Manuf. 34, 52-4, 1964.
Insulating lacquers are reviewed (43 references).

164. Neiman, R. R. and Johnson, R. E., Intern. Sci. Technol. 1964 (29), 68.
The possible uses of plastics as active elements in transistors, lasers, photodetectors, and electronic circuits are discussed. The ideas of electron transport are presented qualitatively with the use of many clear illustrations.

165. Mathes, K. N., SPE Journal 20, 634-7, 1964.
The electrical and mechanical behavior of polymers at cryogenic temperatures are discussed. The electrical properties of several polymeric films are reviewed and dielectric losses and voltage breakdown are shown.

166. Torossian, K. A. and Jones, S. L., J. Appl. Polymer Sci. 8, 489-501, 1964.
The evaluation of polymers for dielectric applications was carried out by observing the change in weight and evolution of gases with change in temperature.

167. Bretts, G. R., Kozol, J., and Ringwood, A. F., Plastics Technol. 10, 32, 1964.
A technique is described for combining a silicone rubber protective coating with a rigid epoxy foam system for encapsulating glass-housed electronic parts for long-time service. The rubber coating effectively cushions the parts from the stresses generated during curing or thermal cycling.

168. Uglione, H. L. and Bell, A. R., Jr., Mod. Plastics 41, 133-7, 1964.
The use of dry epoxy molding powders for encapsulation of electronic modules is described and compared with liquid resins. Dry epoxy molding has many advantages.

169. Phillips, I., Brit. Plastics 37, 261-5 and 325-9, 1964.
The use of plasticized poly(vinylchloride) as an insulator in high temperature service is reviewed. Various formulations were tested and the volume resistivity, power factor and specific inductive capacity are shown. Breakdown voltage and insulation resistance are also given.

170. Boot, R. J. and Jordon, T. J., Plastics Design Process 1963 (Sept.), 11-16.
The physical and chemical properties of chemically crosslinked polyethylene are reported. The crosslinking formula is given. Stiffness, power factor, dielectric constant, and volume resistivity were measured.

171. Zelenev, Yu. V. and Lyalina, N. M., Vysokomolekul. Soedin. 5, 1717-24, 1963.
Dielectric and dynamic mechanical properties of rubberlike polymers were measured and analyzed by the reduced variable methods of J. D. Ferry and co-workers. Ferry's method is much more applicable to rubber containing no active fillers, such as carbon black.

172. Steck, N. S., SPE Trans. 4, 34-8, 1964.
Dielectric measurements on a small sample (0.2 g) made at 60 cycles/sec over temperature range of -40° to 200°C provide α-peak information on many acrylic polymers, and β-peak information on some. α-peak height indicates stereoregularity in methyl methacrylate polymers.

173. Turner, I. T., Mater. Protect. 3 (9), 48, 1964.
Data are tabulated to show corrosivity of many plastic and rubberlike materials toward a number of metals used in electrical equipment, when the insulating materials are vaporized by short circuit.

174. Lacombe, J. and Wrobel, W., Wire Wire Prods. 38, 508, 670, 675, 724, 1963.
A comparative discussion of the physical, chemical, and electrical properties of conventional and chemically crosslinked polyethylene is given.

175. Lever, R. C., Paint Technol. 27, 35-8, 1963.
Electrical characteristics of paints for electrostatic deposition were discussed. Measurement of dielectric constant and dc resistance were described.

176. Warfield, R. W. and Rosen, A. H., U. S. Dept. Comm., Office Tech. Serv., AD 426,954, 7 pp., 1963, and J. Appl. Chem. (London) 14, 554-9, 1964.
Electric volume resistivity measurements were used to study the hardening process and properties of polyvinyl chloride-dibutyl phthalate plastisol.

177. Schael, G. W., J. Polymer Sci. 8, 2717, 1964.
Index of refraction of annealed and unannealed polypropylene films was measured. Using the Lorentz-Lorenz equation and a plot of crystallinity versus specific volume, calculations of density, crystallinity, and birefringence become possible.

178. Dorko, Z. J., Klingender, R. C., Lumb, P. B., and Macht, J. T., Quimia (Barcelona) 120, 13-21, 1963.
The good electrical properties of cis-1,4-polybutadiene suggest useful applications.

179. Whipple, C. L., Symp. Mater. Space Vehicle Use, 6th, Seattle 2, 20 pp., 1963.
The use of vulcanizable silicones in aerospace systems as insulator, encapsulant,etc. is reviewed.

180. Tholstrup, C. E., Proc. Battelle Symp. Thermal Stability of Polymers, Columbus, Ohio, 1963.
New inhibitors of copper-catalyzed oxidation of polypropylene are discussed. The new inhibitors are oxalic acid dihydrazide and oxalic acid bis(2-phenylhydrazide).

181. Algie, J. E., Textile Res. J. 34, 1026-31, 1964.
The measurement of regain of wool by electrical capacity moisture meters is reported. The dielectric effect of water on the polypeptide was greater than the sum of the polarizations of keratin and water, indicating an orientational polarization having a distribution of τ's.

182. Dasgupta, S. and Mital, P. K., J. Appl. Poly. Sci. 8, 2299-304, 1964.
Dielectric properties of an epoxy resin were measured as a function of percent plasticizer.

183. Van Beek, L. K. H., J. Appl. Polymer Sci. 8, 2843-51, 1964.
The dielectric behavior of curing phenolic-formal resins was studied between 0.06 and 300 kc/sec. The loss peak moved to higher frequencies with increasing catalyst and increasing cure, but moved to lower frequencies on drying. It was concluded that water formed during the curing facilitated proton jumps.

184. Green, J. and Mayes, N., NASA Accession No. N64-19801, Report No. AD 429,230, 1963.
Thermally stable linear carborane siloxane polymers for use as embedding compounds and elastomers were prepared. Thermogravimetric and differential thermal analyses were used to evaluate the high temperature properties.

185. Suess, R. H. and Neff, G. R., NASA Accession No. N64-19613, Report No. CR 53815, 1963.
Wire insulations of polyolefin, Teflon, H-film, poly(vinyl fluoride) and polyimide were evaluated for use in the space environment. The Teflon and polyimide systems performed best.

186. Hanna, A. E., U. S. Dept. Comm., Office Tech. Serv. AD 265,782, 29 pp., 1961.
Deterioration of 600 volt cable sheaths by flotation type corrosion inhibitors was studied. A butadiene-acrylonitrile copolymer was superior to all others.

187. Schafer, E., U. S. Dept. of Comm., Office of Tech. Serv. AD 413,907, 37 pp., 1962.
Arc resistance, corona effects, dielectric constant, dielectric strength, dissipation factor, insulation resistance, surface resistivity, and volume resistivity of poly(tetrafluoroethylene) are given.

188. Milek, J. T., U. S. Dept. of Comm., Office of Tech. Serv. AD 413,906, 59 pp., 1963.
Data were compiled on dielectric constant, dielectric strength, dissipation factor, resistivity, and power factor of filled and unfilled silicone rubber (68 references).

189. Baguley, E., Plastics Inst. (London) Trans. and J. 32, J 118-21, 1964.
Intercontinental submarine telephone cables using polyethylene insulation are described.

190. Suba, M. M. and Tomfohrde, F., Rubber Age (N.Y.) 90, 941, 1962.
Polyethylene was chemically crosslinked into a thermosetting material, thus avoiding the limitations of melting or tendency to crack. The product is used as electrical insulator. Vulcanization methods are described.

191. Luttinger, M., Sliemers, F. A., Kircher, J. F., and Leininger, R. L., BMI 1678, 31 pp., 1964.
The development of high dielectric constant, low loss polymers is described. Polymers of methyl methacrylate, β- cyanoethyl acrylate, ethyl vinyl sulfone, and $F_3CCH_2OCH:CH_2$ and copolymers of the above were prepared. Dielectric constants of 15 were obtained.

192. Dyvik, G. K., Bartoe, W. F., and Steck, N. S., SPE Trans. 4, 98-101, 1964.
Dielectric measurements at 60 cps from -40° to 200°C on various acrylic copolymers show good correlation among α-peak, Vicat, and dilatometric glass transition temperatures.

193. Delmonte, J., SPE J. 20, 1223-6, 1964.
Properties of, and advantages and disadvantages in the use of epoxy encapsulating resins for electronic components are reviewed.

194. Anonymous, SPE J. 20, 993-6, 1964.
Results are given from a survey on industry use of tests and standards for plastics used in storage batteries.

195. Dallimore, G., Stucki, F., and Kasper, D., SPE J. 20, 544-6, 1964.
Measurements of internal stress in electronic encapsulating resins using a small transducer are described. The transducer can be embedded in the electronic package while it is subjected to thermal shock or thermal cycling.

196. Wartman, L. H., SPE J. 20, 254-9, 1964.
The effect of plasticizer and ionic impurities on the electric resistance of polyvinyl-chloride was examined. Bis(2-ethylhexyl) phthalate plasticizer gave the best insulator, 2×10^{16} ohm-cm.

197. Marchesini, G. and Gazzana-Priaroggia, P., Proc. Rubber Technol. Conf., 4th, London 1962, (16), 10 pp.
Electrical insulating properties and thermal stability of ethylene-propylene copolymers were studied. The endurances for applied voltages (50 cycles/sec) are 330 days at 40 kv and 163 days at 100 kv.

198. DaSilva, E. M. and Miller, R. E., Electrochem. Technol. 2, 147-50, 1964.
A hot glow discharge technique was used to deposit films of polybutadiene 500-2000 Å thick. High insulation reliability is reported.

199. Peters, H., Herrmann, D. B., Lockwood, W. H., and Luongo, P. J., Proc. Rubber Technol. Conf., 4th, London 1962, (46).
A comparison of the dielectric properties of natural and synthetic-natural hard rubbers was made. The dielectric constant ϵ' was slightly less for synthetics and ϵ'' was considerably lower because the synthetic absorbed less H_2O.

200. Bamford, C. H., Crighton, J. S., and Ward, J. C., Soc. Chem. Ind. (London), Monograph No. 17, 284-301, 1963.
The electric discharge method was used for grafting polymers. The surface properties and the production of free radicals on the surface by the electric discharge was studied by electron spin resonance measurements.

201. Roberts, G. A. H., 3rd reinforced Plastics Conf., London 1962, 10.00-10.19.
Good electrical, water-resistant and mechanical properties are obtained with combinations of non-polar resins and glass or quartz reinforcement.

202. Payne, A. R., Trans. Inst. Rubber Ind. 40, T135-T149, 1964.
The effects of carbon black structures in rubber vulcanizates were examined by means of dynamic mechanical tests. The conductivity minimum varied with amplitude of oscillation in approximately the same way as the shear modulus.

203. Potthoff, K., Elektrotech. Z. A85, 449-54, 1964.
Significant assessment of aging tests on insulating materials requires that sufficient data by available on their structural changes. Data are shown on the degradation of cellulose (paper) and the tan δ for wire enamels.

204. Anonymous, Kunststoffe-Plastics 10, 141-2, 1963.
The effect of humidity on the dielectric properties of some common polymers is discussed. Polystyrene and polyethylene are less affected than polycarbonates.

205. Razinskaya, I. N., Kozlov, P. V., and Shtarkman, B. P., Vysokomolekul. Soedin. 6, 516-21, 1964.
Temperature and frequency dependence of the loss tangent were studied for poly(vinylchloride) plasticized with ethyl stearate, castor oil, and dioctyl phthalate. With increasing concentration of plasticizer, the maximum on the tan δ versus T curves decreases, becomes broader and is shifted to higher temperatures and the activation energy decreases.

206. Assonova, T. V. and Trapeznikov, A. A., Kolloidn. Zh. 26, 640-4, 1964.
The rheological properties of a 2% decalin solution of natural rubber were studied after the addition (0.05 to 2%) of a polar group, butyl alcohol. The elasticity decreases as the polar groups are absorbed by the polymer chain.

207. Andrianov, K. A., Shugal, Ya. L., and Asnovich, E. Z., Plasticheskie Massy 1964, 44-8.
Glass-cloth-reinforced phenol-formaldehyde resins were modified with the addition of 0.5-1.0% of polyaluminophenylsiloxanes. This modification improved the mechanical and electrical properties of the laminates.

208. Mikhailov, G. P., Lobanov, A. M., Shevelev, V. A., and Orlova, T. P., Plasticheskie Massy 1964 (2), 9-12.
Dielectric constant and loss of high and low density polyethylene were measured at 3×10^9 and 4.7×10^8 cycle/sec and over a temperature range -60° to 160°C. The loss was attributed to amorphous region polar groups. The effects of oxidation and extrusion were examined.

209. Penczek, P. Polimery 7, 419-20, 1962.
Mechanical thermal, electrical, and chemical properties of a new Polish unsaturated polyester resin, Polimal 130, are reported.

210. Klosowska, Z., Ostrysz, R., and Penczek, P., Plaste Kautschuk 9, 267-9, 1962.
The dielectric properties of unsaturated polyester resins were studied. The effect of end groups in hardened and elastic resins were compared. Hardened resins show best dielectric properties.

211. Koyanagi, S., Denki Kagaku 28, 274-7, 1960.
Electrical characteristics are compared for printed wiring boards of melamine-glass, phenol-paper, polyester-glass, epoxy-glass, epoxy-Tetoron, and Teflon-glass. The effects of temperature and moisture on the insulation resistance are considered.

212. Yano, S., Kato, S., and Suzuki, M., Denki Kagaku 32, 220-6, 1964.
Dielectric measurements were made as a function of time during the curing of epoxy resin Epikote 828. Various curing agents were used. Generally, ϵ''_{max} shifted to lower frequencies with curing time. The loss region was ascribed to orientation of OH groups.

213. Masuda, Y. and Hani, H., Kogyo Kagaku Zasshi 66, 1361-4, 1963.
Polymerization of epichlorohydrin is described. The dielectric constant is 5; dielectric loss 0.015 - 0.041; dielectric strength is 39 kv/mm; and volume resistance is 10^{11} ohm-cm.

214. Hochauz, E., Przeglad Papier 17, 6-10, 1961.
Manufacture of semiconductive cable paper containing carbon black is described. The desired electrical conductivity can be obtained when 10% semi-activated black is added. Synthetic rubber latexes were added (3-10%) to increase retention of C and strength of the paper.

215. Bershtein, V. A., Kashaev, I. N., Ryt, E. Sh., and Tsodikova, S. T., Sudostroenie 1962, 41-4.
The dielectric properties of epoxy, alkyd, and silicoorganic enamels were measured. These enamels are used for coating of electronic equipment used under conditions of prolonged heat aging, heat shock and tropical moisture. Seven coatings were studied and evaluated with respect to their resistance to varied environmental conditions.

216. Kocharyan, N. M., Akopyan, A. N., Barsamyan, S. T., Tolapchyan, L. S., and Pikalova, V. N., Dokl. Akad. Nauk Arm. SSR 37, 263-7, 1963.
On a chlorinated poly(tetrachlorohexatriene), the loss angle, dielectric permeability (ϵ), specific volume resistivity and effective dipole moment (μ_{ef}) were measured at -64° to 120°C. The polymer showed a high electrical stability. Results at 20 ± 5°C are $\mu_{ef} = 2.36$ D, $\epsilon = 2.3$.

217. Rozenfel'd, I. L., Oshe, E. K., and Akimov, A. G., Lakokrasochnye Materialyiikh Primenenie 1964, 45-50.
Oscillographic determination of polarization and ohmic resistances of polymeric electrode coatings and their porosity in electrolytes is described. Films 10 - 12μ thick of nitrocellulose, poly(butyl methacrylate), alkyd, polyurethane and copolymer of vinyl chloride-vinylidene chloride were measured. The mechanisms of charge transfer are discussed.

218. Shorokhova, V. I. and Kuz'min, L. L., Izv. Vysshikh Uchebn. Zavedenii, Khim. i Khim. Technol. 6, 1002-10, 1963.
The specific resistivity, strength, density, and moisture absorption were determined for electrically conductive polystyrene prepared by hot compression of copper-coated spherical particles. Resistivity varied from .0003 to .15 ohm-cm, and decreased with increasing percent copper and with decreasing particle size.

219. Banaitis, J. and Domanskis, L., Mokslas ir Tech. 1964, 31.
Plastic concrete made with furfuralacetone monomer as a binder for various aggregates has an electrical resistivity of 10^7 to 10^8 ohm-cm.

220. Milov, B. G., Bobrov, A. I., Kulakova, R. V., and Voidenova, K. I., Bumazhn. Prom. 1964, 10-15.
Contrary to the report by Vyatkina and Vyatkin, the use of hardwoods for the manufacture of cable insulation paper should be avoided. The dielectric losses in such paper are larger than in sprucewood papers and increase on aging. The high hemicellulose content, especially pentosans and polyuronides, is responsible.

221. Korchemkin, F. I. and Bobrov, A. I., Bumazhn. Prom. 39, 15-16, 1964.
Properties of acetylated electrical insulation paper were compared with those of ordinary insulation paper. Acetylation to about 35% reduces tan δ by a factor up to 10 at 95% relative humidity, and the resistivity is increased several hundred times.

222. Kirby, P. L. and Walton, B., Proc. Inst. Elec. Engrs. Pt. B, 109, Suppl. No. 21, 47-52, 1962.
A review of properties of C-resin resistors was made. The development of SnO film resistors is discussed.

223. Vaisman, L. M., Proizv. Kondensatorn. Bumagi Sb. 1963, 64-80.
Data are presented showing the effects of impurities, pulp character, and preparation techniques on the dielectric properties of paper. For power capacitors, a low density paper impregnated with chlorinated oil is used.

224. Milov, B. G., Proizv. Kondensatorn. Bumagi Sb. 1963, 25-41.
The improvement of the quality of insulating pulp for use in the production of capacitor paper is reported.

225. Gutman, B. B., et al., Bumazhn. Prom. 39, 12-13, 1964.
The authors duplicate a capacitor paper developed in Finland containing Al_2O_3. In the dry state this paper had the same properties as conventional capacitor paper, but after impregnation with chlorinated biphenyl, the dielectric strength was much higher than similarly impregnated conventional paper.

226. Kronstein, M., Pigments-Peint u res-Vernis 40, 255-266, 1964.
A discussion is given of how oxidation of prepolymerized insulating varnish film can be used to increase the water resistance.

CHAPTER VII

INORGANIC DIELECTRICS

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I. Introduction

In reviewing the literature for the year 1964 it is evident that the number of papers which were concerned with single crystals has increased significantly. These papers were concerned primarily with fundamental dielectric theory. The papers did not concentrate on any particular crystal, but were concerned with a number of different crystals. It is also significant, that only a small percentage of these papers were published in this country.

The literature indicated that a considerable amount of useful effort was directed toward the compilation of dielectric data. The papers concerned with "established" materials were assembled into a special group. Books were listed under a separate classification, but in general most of the books published in 1964 could have been listed under the compilation heading.

In addition to the compilation of dielectric data for "established" materials, many papers assumed a "compilation" aspect concerning new and experimental materials. These papers, however, were listed according to the classification of the material.

Some of the papers on glasses and ceramic materials illustrate this field of activity. The conductivity of a large number of zirconate systems was the subject of a number of papers, and the dielectric properties of the various titanate systems also represented considerable activity in this field. Several papers on glasses also were concerned with the variation of dielectric properties with composition. Thus, the reporting of dielectric data for "established", new, and experimental materials continued to be an important function.

There were many unique and valuable papers published in 1964. It is unfortunate that it is impractical to emphasize each and every one.

However, trends were evident. For example, activity in semi-conducting glasses has increased. Nine papers were concerned with this property and progress was reported on a number of different compositions. The effect of radiation upon the dielectric properties of almost all types of inorganic materials was also the subject of several papers. Light, gamma rays, and fast neutrons represented the wide range of radiations that were reported in this sphere of activity.

The study of the dielectric properties of films again showed vigorous activity. Vacuum deposited SiO and films in the Al-SiO_2-Si system were the subject of several papers. However, the work in this field paralleled the work in the other fields, in that a number of different films were reported.

As might be assumed, most of the patents pertained to devices or materials which can be used in applications. Patents on conducting circuit elements, insulated wire, capacitors, and various dielectric materials summarize these new developments.

II. Single Crystals

Panchenko, V. V., Soviet Phys.-Solid State, 6, 457-61, 1964.
The temperature dependence of the dielectric constant in alkali halide single crystals was studied. It was found that the dielectric constant is a nonlinear function of temperature.

Maycock, J. N., Bull. Am. Phys. Soc. 9, 227, 1964.
DC ionic polarization effects were observed in the alkali halides in the temperature range of 300°C to the melting point. Transient polarization currents were recorded as a function of temperature and applied potential.

Krasnopevtser, V. V., Soviet Phys.-Solid State, 5, 1645-50, 1964.
A study of the dielectric properties and optical absorption of KBr single crystals subjected to bombardment with fast electrons was made. The F and V_2 centers and defects caused the dielectric relaxation.

Economou, N. A. and Sastry, P. V., Physica Status Solidi, 6, 135-40, 1964.
The high temperature dielectric constant of NaCl and KBr was studied. Interpretation of the data in terms of the Debye theory of dipolar relaxation suggests that vacancy pairs are responsible for the phenomenon.

Bucci, C. and Fieschi, R., Phys. Rev. Letters 12, 16-19, 1964.
Ionic thermoconductivity method for the investigation of polarization in KCl and KCl doped $SrCl_2$ crystals was discussed. Analysis of the peaks of the data curves yields the number of dipoles in the sample, the relaxation time, and the activation energy for dipole orientation.

Dasgupta, S. and Hart, J., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 53, 1965.
A study of the thermoelectric power is very sensitive to the thermal history of the sample.

Bogdanovich, A. S., Sikorskii, Yu. A., and Yurachkovskii, P. A., Soviet Phys.-Solid State 5, 2586-89, 1964.
It is shown that the location and half-width of the relaxation peak of dielectric losses in $KCl \cdot CaCl_2$ crystals are sensitive to the thermal and mechanical treatments. As a result of deformation and heating, the set of relaxation times is increased and is accomplished by a broadening of the loss peak.

Azuma, M., J. Phys. Soc. Japan 19, 198-205, 1964.
The wave-number-dependent dielectric function is calculated for crystalline KCl on the basis of expressions derived in a previous paper. The value 2.383 is obtained for the static dielectric constant in the long wave length limit.

Agranovich, V. M. and Knobeer, Yu. V., Soviet Phys.-Solid State 5, 1858-65, 1964.
A calculation of the dielectric permittivity tensor of a crystal is carried out in the region of the exciton absorption band by using the method of Green's functions.

Woodall, J. M., Electro Chem. Technol 2, 167-69, 1964.
High resistivity single crystal GaAs whose impurity concentration is less than 10^{16} atoms per cubic centimeters were prepared.

Fröhlich, H., Machlup, S., and Mitra, T. K., Phys. Cond. Matter. 1, 359-66, 1964.
Measurements show that substances, which exhibit Debye type of dielectric loss due to electrons, also show very low electronic mobility. Relevant substances are ionic crystals such as oxides.

Finkenrath, H., Zeitschr. Fur Angewandte Phys. 16, 503-10, 1964.
The real part of the complex frequency-dependent dielectric constant for cadmium oxide is characterized by a maximum in the absorption edge. This maximum, with increasing occupation of the conduction band, moves toward shorter waves.

Economou, N. A., Bull. Am. Phys. Soc. 9, 491A, 1964.
Dielectric loss measurements were made on potassium chloride, containing strontium chloride in concentrations between 4×10^{-6} and 20×10^{-6} mole fraction. Results indicate that the observed loss is not due to Shottky defects and provide additional evidence that it is due to vacancy pairs.

Gesi, K. and Takagi, Y., J. Phys. Soc. Japan 19, 632-39, 1964.
The effects of gamma-ray irradiation on the dielectric properties of single crystals of sodium nitrite were measured. An increase of the electrical conductivity and a change in its activation energy were observed.

Gibbs, D. F. and Hill, G. J., Phil. Mag. 9, 367-75, 1964.
The variation of dielectric constant with pressure for two diamonds were measured. It was found that the variation conforms closely to that of silicon and germanium.

Grandel'man, G. M. and Ermachenko, V. M., Soviet Phys.-JETP. 18, 358-64, 1964.
The dielectric constant of crystals from the quantum view point and the integral equation for the inverse dielectric constant operator started by Falk and Adler are discussed.

Berge, P., Compt. Rend. 258, 5839-42, 1964.
Using electron paramagnetic resonance at a variable temperature, the determination of the mechanism of the electric conductivity in manganese-doped lithium fluoride was determined.

Querrou, M. and Montagner, S. E., Compt. Rend. 258, 106-08, 1964.
Transient phenomena in the discharge of capacitors with polar dielectrics were investigated, using a constant voltage and a known variable resistance. Materials studied were powders and single crystals.

Swarup, P. and Arora, R. P., Nature 201, 1018, 1964.
Dielectric measurements were made on mixtures of sulphur powder and air. It was found that the K/d ratio is a constant for a powder.

Johnson, J. W., Govt. Report N64-31305, Contract Nobs-88487, AD 604984.
A study of the resistivity and Seebeck coefficients of liquid inorganic sulfide systems is summarized.

III. Ceramics

Simmons, W. C. and Russel, R., Am. Ceram. Soc. Bull. 43, 353, 1964.
Thirty alumina compositions and their effect of phase development on dielectric constant and electrical loss was measured. Dielectric constant was found to be sensitive to phase development while being relatively insensitive to firing conditions.

Insley, R. H. and Barczak, V. J., J. Am. Ceram. Soc. 47, 1-4, 1964.
Thermal conditioning of polycrystalline alumina ceramic showed significant increases in physical and dielectric strengths over as-fired specimens.

Floyd, J. R., J. Am. Ceram. Soc. 47, 539-43, 1964.
An effort was made to determine the cause of high dielectric loss at 1 Mc in dense alkali-free bodies. The mechanism by which Feldspars caused the high dielectric loss was tentatively attributed to thermal expansion mismatch.

Wright, T. R., Kiser, D. E., and Keller, D. L., Govt. Report Nc4-30768, Contract W-7405-Eng-92.
Densification and homogenization of compacted ball-milled powders were accomplished by sintering from 10 to 15 hours at 1,700°C or from 15 to 20 hours at 1,600°C in flowing dry hydrogen. The thermal conductivity of UO_2-50 mole % ZrO_2 composition was found considerably lower than that of UO_2, but higher than that of ZrO_2.

Vest, R. W. and Tripp, W. C., Am. Ceram. Soc. Bull. 43, 351.
Electrical conductivity of ZrO_2 was measured as a function of oxygen partial pressure. The conductivity change accompanied the phase transformation.

Tien, T. Y., J. Am. Ceram. Soc. 47, 430-34.
The electrical conductivity of compositions in the ZrO_2-$CaZrO_3$ system was examined. The conductivity decreases from the single-phase cubic solid solution to both of the adjacent two phase regions.

Strickler, D. W. and Carlson, W. G., J. Am. Ceram. Soc. 47, 122-27.
The ionic conductivity of cubic solid solutions in the system CaO-Y_2O_3-ZrO_2 was examined. Higher ionic conductivities appears to be related to a lower activation energy rather than to the number of oxygen vacancies dictated by composition.

Koenig, J. and Jaffe, B., J. Am. Ceram. Soc. 47, 87-89.
The electrical properties of $BaZrO_3$ containing 2% to 6% La were investigated. The admixture of La^{3+} raised the volume resistivity by several orders of magnitude. The mechanism of conduction was indicated to be p-type.

Carter, R. E., Am. Ceram. Soc. Bull. 43, 351.
The dc and ac properties of zirconia were influenced by the thermal history and interpreted in terms of the structure model.

Barrett, H. H., J. Appl. Phys. 35, 1420-25, 1964.
Measurements of the intrinsic dielectric breakdown strength of single-crystal strontium titanate over a temperature range from -195°C to +100°C and under both pulse and dc conditions are described.

Tien, T. Y. and Moratis, C. J., Am. Ceram. Soc. Bull. 43, 283.
Dielectric studies of strontium titanate solid solutions were made. Permittivity and loss tangent increased with increasing lanthanum concentrations. The frequency and temperature dependence of the dielectric properties were measured.

Lambert, V. and Weik, H., Bull. Am. Phys. Soc. 9, 12A, 1964.
An attempt was made to explain the behavior of the charge-time and lattice distortion-time curves of single crystal electrets of the perovskite structure by means of internal-field characteristics.

Hayes, R. and Walker, G. B., Proc. IEEE 111, 600-04, 1964.
Titania ceramic discs can be made to withstand higher electric intensities by coating the ceramic with a lead borate glaze. Improvement was noted in static and microwave fields.

Herczog, A., J. Am. Ceram. Soc. 47, 107-15, 1964.
Microcrystalline $BaTiO_3$, by crystallization from glass, results in a nearly complete recovery of $BaTiO_3$. Data are presented on dielectric constant and loss tangent at different frequencies.

Tambortser, D. A., Skorikor, V. M., and Zheluder, I. S., Soviet Phys.-Cryst. 8, 713-16, 1964.
The growth of $Bi_4Ti_3O_{12}$ crystals, by crystallization from the melt, and their dielectric properties are described. Results show that the logarithm of resistivity has a discontinuity at 643°C.

Bogdanor, S. V., Soviet Phys.-Solid State 5, 2489-93, 1964.
The dielectric properties of $SrTiO_3$-$Bi_2O_3 \cdot 3TiO_2$ are discussed on the basis of the model proposed by Skanari. The model permits a qualitative explanation of the properties and shows that the material represents a new class of materials between true ferroelectrics and materials in which classical ion relaxation occurs.

Lal, H. B. and Singh, Y. D., Phys. Lett. Neth. 8, 165, 1964.
Room temperature measurements of the dielectric constant of rutile, parallel and perpendicular to the C-axis as a function of electric field, are discussed. At high fields, the dielectric constant tends to become constant.

Guzman, I. Ya. and Serova, G. A., Ogneupory, No. 6, 281-84, 1964.
The results of an investigation of porous articles made from magnesium oxide as compared to dense refractories are reported. Magnesium oxide was used to prepare a permeable, relatively strong, and highly refractory material (30-60% porosity) containing 98% MgO.

Sawaguchi, E. and Kikuchi, A., J. Phys. Soc. Japan 19, 579, 1964.
The crystal structure and the dielectric properties of $K_2O \cdot 2Ta_2O_5$ were determined. The structure is shown to be the tungsten bronze type and the dielectric constant at 1 kc was measured to be 50.

Parlovic, A. S., J. Chem. Phys. 40, 951-56, 1964.
Some dielectric properties of tantalum pentoxide were measured from 77° to 373°K over a frequency range from 100 cycles per second to 100 kc. Alpha Ta_2O_5 exhibited large migrational losses similar to those found in glasses.

Philgreen, F. A., J. Am. Ceram. Soc. 47, 49-50, 1964.
The dielectric properties of Ga_2O_3 x Nb_yO_2 ceramic materials were measured. No ferroelectric hysteresis loops were observed.

Govt. Report N64-21926, FTD-TT-62-1800/1 and 2 and 4.
A study was made on the effect of composition, heat, and electrolytic treatment on the dielectric properties of steatite ceramics.

Sano, S., Ishii, E., Sugiura, M., and Hirai, M., Rep. Govt. Industr. Res. Inst. Nagoya 13, No. 4, 154-160.
The effects of Kaolin on the high frequency dielectric properties of Forsterite were made. Addition of Kaolin extended the temperature range, whereas, the dielectric constant and dielectric loss changes were small.

Iscrov, D. Z., Khaniner, S. P., and Lebedeva, N. I., Energetik No. 3, 32-34, March, 1964.
Foam perlite ceramic was developed for insulating at 650°C. Material consists of fireclay, perlite sand, and a foaming agent.

Mosley, K. and Gumley, P., U. K. Atomic Energy Authority TRG Rep. 592.
This paper assesses the effect of time on the electrical strength of various ceramics between 800 and 1140°C. The influence of electrode material is also discussed.

Jeitner, F., Nedopil, E., and Vohler, O., Ber. Deutsch. Keram. Ges. 41, 166-77, 1964.
The properties and applications of carbons and ceramic materials were compared. The uses of the two materials are strictly divided because of the difference in their electrical conductivity.

Vest, R. W. and Crawford, J. A., Govt. Report AD-606883, Div. 14, 25, Contract AF33657 10815.
This report was directed toward achieving a more fundamental understanding of charge and mass transport mechanisms in refractory metal oxides.

Barr, F. A., Montgomery, T. S., and Long, R. A., Am. Ceram. Soc. Bull. 43, 355.
The electrical and thermal properties of selected oxide ceramics by liquid-phase techniques were presented. Dielectric constant and loss tangent values were measured at various frequencies and temperatures.

IV. Glasses

Piletti, R. C. and Smoke, E. J., Am. Ceram. Soc. Bull. 43, 353.
The compositions, microstructure, and dielectric properties of lanthanum aluminosilicate glasses were presented.

Argyle, J. F., Am. Ceram. Soc. Bull. 43, 353.
Dielectric properties of some progressively crystallized glasses from the system $PbO-BaO-MgO-SiO_2$ are described. Partial phase-relationship studies were made with the dielectric properties.

Bobkova, N. M. and Nemkovich, I. K., Steklo i Keramika 21, No. 6, 5-8, 1964.
The electrical properties of aluminosilicate glasses containing little or no alkali were determined.

Mackenzie, J. D., Am. Ceram. Soc. Bull. 43, 339.
The electrical conductivity of calcium aluminoborate and calcium aluminosilicate glasses containing small amounts of sodium ions can be less than that of "pure" fused silica. Results are presented on the ionic diffusion of oxygen and calcium in these glasses.

Hagel, W. C., Am. Ceram. Soc. Bull. 43, 339.
Cabal glasses possess low dc conductivities and it has been suggested that oxygen ions are the principal current-carrying species. Calculations are performed to indicate that this seems highly improbable.

Hagel, W. C. and Mackenzie, J. D., Physics and Chemistry of Glasses 5, 113-19, 1964.
Electrical conduction and oxygen diffusion in calcium aluminoborate, and

aluminosilicate glasses was explored in further detail by measuring oxygen self-diffusion in two cabal glasses.

Snow, E. H. and Gibbs, P., J. Applied Phys. 35, 2368-74.
The dielectric loss was substantially reduced, when impurities were removed by electrolysis from quartz. The introduction of silver, copper, or sodium gave rise to new loss peaks.

Chakravorty, D. and Cross, L. E., J. Am. Ceram. Soc. 47, 370-74.
Measuring the dielectric properties of glass at very high pressures (60 K bars) showed that the activation energy increased with pressure increase, but then showed saturation. A remanent activation energy was noted.

Barney, W. H., 1964 Annual Report Conf. on Elec. Insul., NAS-NRC Publication 1238, 99, 1965.
The thermal dielectric strength of several glasses was measured and calculated. Good agreement between measured and calculated values was achieved. The analysis revealed that the dielectric strength is proportional to the square root of the product of the electrical resistivity and the thermal conductivity.

Sutton, P. M., J. Ceram. Soc. 47, 219-30.
This paper reviews the present understanding of space charge and electrode polarization in glass and the inter-relations of these concepts with the usually measured electrical properties of glass. Emphasis is placed on the theory describing the distribution of static space charge in material having only one charge carrier.

Penberthy, L., Am. Ceram. Soc. Bull. 43, 339.
Enhanced diffusion of the sodium ion under influence of alternating current in electric melting of glass helps in elimination of cords and microstones.

Primak, W., Edward, W., Keiffer, D., and Szymanski, H., Phys. Rev. 133A, 531-35, 1964.
Ionization expansion of compacted silica and the theory of radiation-induced dilatations in vitreous silica were discussed. The effect is assumed to be associated with the local distortion or energy deposition of the ionization event.

Muray, J. J., Dielectrics 1, 221-24, 1964.
Using a high intensity light beam from a ruby laser, the number of photoelectrons from quartz and borosilicate glass were measured as a function of laser output power. By using the theory of thermal breakdown on a dielectric surface, the observed electron current can be explained.

MacChestney, J. B. and Johnson, G. E., J. Appl. Phys. 35, 2784-85.
Room-temperature dielectric properties of fast-neutron-irradiated fused silica and alumina were found to be a function of fast neutron dose. The dielectric constant decreases and the loss tangent increases with dose.

Belyavskaya, L. M. and Terent'era, N. V., Izv. Vysshikh Uchebn Zaredenii Fiz. No. 2, 169-70, 1964.
Effects of gamma radiation on the electric conductivity of alkali silicate

glass in magnetic fields were studied using 2 x 5 mm by 0.5 to 1 mm thick plates. The electric conductivity of specimens exposed to 10^6 to 10^7 R, at room temperature, varied from the original by 5 to 20% depending on the Na_2O content. The effect was not a function of magnetic field direction and the conductivity returned to normal when the field was reduced to zero.

Dela Ruye, J., Marit, R., and Leger, L., Silicates Industriels 29, 279-84, 1964.
Quality control of glass by measurement of resistivity at 600°C was discussed. As the resistivity of the glass varies with its Na_2O content, a rapid method for detecting composition variation is developed.

Schwabe, K. and Suschke, H. D., Angew. Chem. 76, 39-49, 1964.
Glass as an electrode material was studied. Deviations from the ideal H-function in the acid and alkaline range explains the effects of composition and solubility of glasses on their electromotive behavior.

Chu, Pa-nan, and Hu., Her-fang, Kuei Suan Yen Hsueh Pao, Vol. 3, No. 2, 121-27, 1964.
The influence of reducing agents, added oxides, and atmosphere on the electrical conductivity of titanosilicate glass was studied. A practical method of obtaining a semiconducting glass with high electrical conductivity is described. Base composition is a mixture of 25% BaO, 45% TiO_2, and 30% SiO_2.

Ulrich, D. R., J. Am. Ceram. Soc. 47, 595-96, 1964.
The electrical and infrared properties of glasses in the Bi_2O_3 - TeO_2 system were studied.

Reid, F. J., Matso, L. K., and Miller, J. F., J. Phys. and Chem. of Solids 25, 969-76, 1964.
The electrical conduction in rare earth monoselenides and monotellurides was discussed.

Mazurin, O. V. and Brailovskaya, R. V., Fiz. Tverd. Tela 2, 1477-81, 1964.
Electrical conductivity of glasses in the Na_2O-RO-SiO_2 system was studied. The replacement of SiO_2 by divalent metal oxides increased the electrical conductivity.

MacKenzie, C. D., J. Am. Ceram. Soc. 47, 211-14, 1964.
A general principle for the preparation of semiconducting oxide glasses is presented. The mechanism of electrical conduction was demonstrated to be electronic rather than ionic by the absence of electrolysis, the absence of electromotive force, and the magnitude of the activation energies.

Janakiramarao, B. H. V., Am. Ceram. Soc. Bull. 43, 351, 1964.
Controlled nucleation and phase separation in semiconductor glasses in the GeO_2-P_4O_{10}-V_2O_5 system was found to have great influence on the electronic conductivity. The influence of cations and nucleation were studied.

Grochowski, E. G. and Mason, D. R., J. Phys. and Chem. of Solids 25, 551-58, 1964.
The phase diagram for the binary system Indium Tellurium and electrical properties were studied.

Eaton, D. L., J. Am. Ceram. Soc. 47, 554-58, 1964.
The transformation from one resistance state to another in the As-Te-I system is discussed. A model is also postulated. The anamalous behavior of these glasses results from the thermal breakdown during which reversible glass to crystal phase occurs.

Doinikov, L. I. and Borisova, Z. U., Zhurnal Prikladnoi Khimii 37, No. 7, 1458-62, 1964.
The electrical conductivity of the vitreous systems As Se_x B_y and As Ge Se_x B_y was discussed.

V. Films

Hirose, H. and Wada, Y., J. Appl. Phys. Japan 3, 179-90, 1964.
The dielectric properties from 100 cycles per second to 10 Mc and the dc conductivity of vacuum deposited SiO films were investigated. Two dielectric dispersions were found. The conductivity decreases with increasing oxidation.

Fang, F. and Cheroff, G., I.B.M. J. of Res. and Dev. 8, 416-21, 1964.
The effects of low temperature annealing on the surface conductivity of Si in the Si-SiO_2-Al system were discussed.

Blank, J. M., Ing, S. W., and Russell, V. A., Govt. Report N64-31229, AF33(657)-11079.
Investigation of electron emission from metal-insulator-metal thin film structures was extended to include both Al-SiO_2-Al and Al-Al_2O_3-Al. A study of the conduction in films at low temperatures was carried out.

Caswell, H. L., 1964 Annual Report Conf. on Elec. Insul., NAS-NRC Publication 1238, 57, 1965.
Techniques were described for fabrication of thin film insulation. A number of inorganic materials including silicon monoxide and various refractory metal oxides were discussed.

Charbonnier, F. M., Swanson, L. W., and Cooper, E. C., Govt. Report N64-30802 NASW-458.
Preliminary results of the migration of cesium at various temperatures and on different substrates were presented. Application of a dc electric field produces a decrease in the activation energy for surface diffusion of cesium on tungsten. Pre-breakdown currents were discussed.

Lorenz, R. H. and Michael, A. B., Electrochem. Technol. 2, 160-63, 1964.
The influence of impurities in tantalum on the electrical characteristics of anodic tantalum oxide films was presented. Particles were found to be the source of faults resulting in degradation of electrical properties.

Fridrikhor, S. A., Ivanor, V. M., Serebrov, L. A., and Shertso, A. A., Soviet Phys.-Solid State 6, 187-95, 1964.
Investigation of the secondary electron emission of positively charged dielectric layers of NaCl, MgF_2, glass, and mica showed that the emission coefficient depends strongly on the compactness of the dielectric layer.

Haberecht, R. R., Patterson, R. J., and Humphries, R. D., 1964 Annual Report Conf. on Elec. Insul., NAS-NRC Publication 1238, 50, 1965.
The technique of depositing insulating films of boron nitride on copper substrates was described. Film characteristics were discussed.

Swanson, L. W., Strayer, R. W., and Bennettee, C. J., Govt. Report N64-31012, NAS3-2596.
The behavior of thin alkali layers on refractory substrates was investigated to gain knowledge of voltage breakdown across alkali-coated electrode gaps.

Mark, P. and Rose, A., Govt. Report N64-31118 DA-31-124-ARO(D)-84.
Work is reported on space-charge-limited current flow, double injection, and field emission from electrodes and from surfaces of insulators.

Lilja, R. and Stubb, J., Acta Polytech. Scand. Physics Incl. Nucl. Series No. 28, P. 32, 1964.
Resistivity and dielectric constant of thin semiconductor samples were measured by means of a microwave bridge. Measurements were made on amorphous, polycrystalline, and single crystal selenium. Resistivity was found to have a positive temperature coefficient.

Hickmott, A., 1964 Annual Report Conf. on Elec. Insul., NAS-NRC Publication 1238, 67, 1965.
Conduction in thin oxide insulators was reported. Conduction mechanisms proposed include tunneling, field assisted thermal emission from metal contacts or from traps and impurity conduction. Some of the difficulties in comparing theory and experiment were discussed.

VI. Books

Anderson, J. C., Dielectrics 1964, Chapman and H. London.
This book gives the background and theory to the many advances in dielectric materials. New materials were described and discussed, both theoretically and from the point of view of practical applications. Specifically aimed at providing a third year undergraduate course in dielectrics for electrical engineers and physicists.

Van Vlack, L., Physical Ceramics for Engineers, Addison-Wesley.
Contains a chapter on the electrical and magnetic properties and applications of crystals, nonstoichiometric compounds, glasses, and semiconductors.

Holland, L., Properties of Glass Surfaces, John Wiley and Son, Inc.
Book is concerned with the technical and scientific uses of glass and includes the surface conductivity, electrical properties in relation to composition, atmospheric humidity, coating, and prior handling.

Van Vlack, L. H., Elements of Materials Science, Second Edition, 1964, Addison-Wesley.
Book is directed toward the undergraduate student. Several sections are devoted to ceramics, dielectrics, and the effect of irradiation by gamma rays.

Penkorskii, W., Effect of Radiation on Metals and other High Melting Materials, American Elsevier.
This book treats the technology of high-melting compounds, and systematizes the heretofore widely dispersed information on effect of radiation on metals, alloys, and such other high-temperature materials as graphite, glasses, oxides, carbides, and borides.

Kircher, J. F. and Bowman, R. E., Effects of Radiation on Materials and Components, Reinhold Publishing Co.
This book draws together scattered information regarding effects of radiation on all engineering materials. One chapter deals with ceramic and glass materials.

Samsonov, S. V., Handbooks of High Temperature Materials, Plenum Press.
The book presents data on the general chemical, electrical, mechanical, nuclear, optical, structural, and thermal properties of approximately 520 refractory binary compounds.

Hague, J. R. and Lynch, J. F., Refractory Ceramics for Aerospace.
A Materials Selection Handbook, The American Ceramic Society. Published to the aerospace applications.

Dodd, A. E., Dictionary of Ceramics, Philosophical Library.

Budnikov, P. P., Technology of Ceramics and Refractories, M.I.T. Press.
Translation of a 1962 Russian Textbook, on current engineering techniques in ceramics in the Soviet Union.

O'Dwyer, J. J., The Theory of Dielectric Breakdown of Solids, New York, Oxford.
This book presents theories of intrinsic breakdown. Application is chiefly to the alkali halides. Theories of thermal breakdown and applications are also presented.

Hass, G. and Thun, R. E., Physics of Thin Films, Academic Press.
This book covers advances in research and development, and includes preparation, properties, and applications of thin films in the fields of optics, solid state physics, surface chemistry, and electronics.

Conference on Dielectric and Insulating Materials London: IEE.
The topics of this conference include intrinsic strength, organic and inorganic materials and measurements.

VII. Devices

Hill, A. R. and Stirling, A. W., U. S. Patent 3,160,944.
This patent pertains to a method of manufacturing a circuit element which comprises mixing barium titanate with lanthanum titanate and a binder shaping the mixture, thus, formed into a predetermined shape to produce a conducting ceramic body.

Place, T. M., Sr. and Place, T. M., Jr., U. S. Patent 3,149,002.
Patent describes a method of making an electrical resistance element using finely ground glass and a solution of at least one noble metal-organic compound.

Randolph, W. J., U. S. Patent 3,136,973.
A sealed resistor is constructed which includes a cylindrical ceramic rod and an outer hermetic shell comprising a hollow ceramic tube.

Kingsley, W. H. and Monroe, D. S., U. S. Patent 3,161,540.
A process is described for forming an insulated wire adapted for use in indirectly-heated electron tubes comprising the steps of depositing a film of a noble metal on a refractory wire, depositing a coating of volatile binder, and aluminum oxide on said film. A volatilization of binder and noble metal follows.

Medwin, A. H. and Luedicke, E., U. S. Patent 3,161,859.
Patent describes a modular structure for a random-access storage device comprising a first sheet of insulating material having an electrically conductive film on one side thereof, and a first plurality of electrically conductive coating substantially parallel on the other side. Devices use transmission lines, tunnel diodes, and resistors.

Bronson, R. W., U. S. Patent 3,142,886.
Describes a method of glass encased electrolytic capacitor assembly and article.

Koenig, J. and Bernard, J., U. S. Patent 3,153,179.
Describes a dielectric composition which consists of zirconium, oxygen, and barium in stoichiometric proportions corresponding to $BaZO_3$ and modified by the substitution of 0.5% to 10% of either the rare earths or zirconium, niobium, or tantalum.

Quinn, R. A., U. S. Patent 3,138,504.
A method is described of partially reducing stoichiometric rutile to change its electrical properties. The procedure comprises sandwiching a thin layer of an alkali and/or alkaline-earth metal halide between a layer of titanium and a surface of stoichiometric rutile, and heating.

Sprague, J. L. and D'Amico, J. F., U. S. Patent 3,149,398.
The method comprises heating a substrate strip in an atmosphere of silicon tetrachloride to dissociate the silicon tetrachloride, depositing a layer of polycrystalline silicon on the substrate, oxidizing the silicon to silicon dioxide, applying metal layer electrodes to the strip and applying lead attachments to the electrodes.

Sprague, J. L. and Wied, O. J., U. S. Patent 3,149,399.
A method of making a capacitor comprises treating at least one surface of a silicon body to provide a thin silicon dioxide dielectric film thereon and applying electrodes to opposed surfaces of the body.

McHugh, J. F., U. S. Patent 3,151,382.
Describes a method of making mica condensers.

Cirkler, W. and Loebl, H., U. S. Patent 3,157,835.
Describes a capacitor exhibiting high voltage stability, high rated voltage, high insulation resistance, and low loss angle. This capacitor comprises a ceramic body made of a mixture of barium titanate and 10% (mole) titanium dioxide.

Bremer, J. W., U. S. Patent 3,158,502.
Describes a method of manufacturing electrically insulated devices. Procedure comprises depositing a very thin layer of silicon monoxide over a superconducting underlayer requiring a higher magnetic field to render it resistive, oxidizing the insulating material, and depositing a second partially-superconducting layer.

Bhogaraju, V. J. and Remington, M., U. S. Patent 3,154,503.
Describes a vitreous enamel adapted to be fired on a ceramic substrate to form an electrical resistor and comprises finely divided palladium, platinum, or rhodium, and a glass frit containing silver, gold, or copper in the ionic state.

Elarde, V. D., Potocki, E. A., and Schneider, M., IEEE Trans. Component Parts, Vol. CP-11, No. 2, 5-8, 1964.
Paper describes the properties of a new material called "moldable precision ceramic." It has low controllable shrinkage. Composition and process are not given.

VIII. Data Compilations

Johnson, V. A., U. S. Govt. Res. Rep., Vol. 39, P. 18A.
This report is a bibliography containing over 300 abstracted references covering electrets, thermoelectrets, photoelectrets, and radioelectrets.

Directory/Encyclopedia Issue of Insulation Magazine, 1964.
This issue presented its annual comprehensive review of electrical properties and applications of mica, ceramic, and glass insulation.

Ireland, R. A. and Tarrants, G., Am. Ceram. Soc. Bull. 43, 333.
A number of compositions were discussed for usage as radomes for future aerospace vehicles. Requirements for lightweight ceramics, and ceramic-to-metal bonding techniques were discussed.

Guyer, E. M., Insulation, Vol. 10, No. 1, 21-26, 1964.
Electrical properties of glasses and ceramics derived from glass are tabulated as a function of frequency and temperature.

Milek, J. T., U. S. Govt. Res. Rept., Vol. 39, P. 67, June 5, 1964.
A compilation of the electrical properties of a wide range of aluminum oxide ceramics is presented. Included are sapphire, sintered single crystal, and polycrystalline material. The crystal structure, applications, and phase diagrams are briefly reviewed.

Sack, W., Nachrichtentech. Fachber. 29, 57-64, 1964.
This paper discusses the preparation and properties of glasses and glass-ceramics formed by the slow crystallization of glasses and sintered glass-ceramics, and inorganic materials such as magnesium and lithium oxides.

Storms, E. K., Govt. Report N-64-31060, W-7405-Eng-36.
The literature concerning the group -4a, -5a, and -6a carbides and nitrides, and the carbides and nitrides of Th, U, and Pu has been reviewed. The following properties have been discussed: phase relationship, lattice parameter and structure, appearance, chemical stability, hardness, resistivity, superconductivity, thermodynamic properties, and vaporization.

Westphal, W. B., U. S. Govt. Res. Rept., Vol. 39, P. 87A, May 1964.
Dielectric properties of high temperature materials for frequencies of 100 cycles per second to 25 kMc and temperatures to 1650°C are described. Microwave losses are due partly to the charge transfer responsible for low-frequency conductivity and to the vibration spectra of infrared absorption.

DiMarino, A., Ceramic Age 80, 34-36, 1964.
Paper describes the properties of glass and ceramics for substrate material in microelectronics. The properties of glass and ceramic materials that affect performance are discussed.

Proc. IEEE 52, December 1964.
The Integrated Electronic Issue includes articles on durability of glass coating, dielectric and resistive films, surface phenomena, thin-film transistors, etc.

CHAPTER VIII

APPLICATIONS

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I. Introduction

Principal interest in the practical application of insulation in 1964, in the United States, was in the area of Extra High Voltage power transmission, at line-to-line voltages of 500 kv. This posed problems in air gap strengths, insulator flashover voltages, radio interference levels, and switching surge stresses. Much of the work involved in tackling these problems was reported in the literature.

Efforts to evolve more realistic thermal endurance tests for insulation, and to better understand the strength properties of impregnated paper insulation systems, also received considerable attention.

II. H.V. Transmission Lines

Leslie, J. R. and O'Beirne, H., IEEE Trans. Power App. & Syst. 83, 495-500, 1964.
Describe the coronaphone, a device for detecting sources of audible corona, which can discriminate between sources spaced three feet apart, at a distance of 100 feet from the detector. It was developed for locating corona sources on power transmission lines.

Boulet, L. and Jakubczyk, B. J., IEEE Trans. Power App. & Stst. 83, 508-12, 1964.
Explain the increase in transmission line corona caused by liquid water in the air (rain, fog), as discharges between raindrop and conductor, and streamers from drops collected on the conductor.

Hylten-Cavallius, N., Annestrand, S., Witt, H., and Madzarevic, V., IEEE Trans. Power App. & Syst. 83, 500-08, 1964.
Discuss insulator requirements, corona losses, and RIV characteristics of dc transmission lines, based on tests up to 250 kv.

Morris, R. M. and Rakoshdas, B., IEEE Trans. Power App. & Syst. 83, 5-14, 1964.
Give results of corona loss and RI measurements on a 400 foot long test transmission line at dc voltages up to 600 kv positive and negative.

Nigol, O., IEEE Trans. Power App. & Syst. 83, 524-33, 1964.
Describes some basic characteristics of corona discharges on high-voltage transmission lines, and establishes a general approach for radio noise analysis based on radio noise meter response characteristics.

Nigol, O., IEEE Trans. Power App. & Syst. 83, 533-41, 1964.
Presents a theoretical method for determining radio noise levels near high-voltage transmission lines.

von Pfaler, C., ETZ-A 85, 261-66, 1964. (German).
Presents a method of relating RI field strength adjacent a transmission line to the measurements on a short single-phase line.

Timascheff, A. S., IEEE Trans. Power App. & Syst. 83, 492-95, 1964.
Theorizes that snow increases corona losses on power transmission lines because of an increase in "apparent" dielectric constant of the atmosphere, which results in increased surface gradients at the conductors.

Schroeder, T. W., O'Neil, J. E., England, G. L., and Pakala, W. E., IEEE Trans. Power App. & Syst. 83, 228-36, 1964.
Report satisfactory RI performance of a wood-pole 340 kv one-mile test transmission line. Leakage current studies were also made to verify the practicability of hot-line maintenance.

Reichman, J. and Leslie, J. R., IEEE Trans. Power App. & Syst. 83, 223-28, 1964.
Review the source and nature of corona discharges and RI measurements on EHV transmission lines, concluding that RI levels on EHV lines should be no greater than with existing HV lines.

Rakoshdas, B., IEEE Trans. Power App. & Syst. 83, 483-91, 1964.
Investigated the pulse and radio-influence voltage characteristics of smooth and stranded conductors energized with dc in a concentric cylinder configuration. He found that RIV from negative conductors occurs at all voltages above onset, but only in a limited voltage range with positive conductors.

Gutman, Y. M., Elekt. Stantsii (USSR) No. 10, 59-64, 1964. (Russian).
Reports the flashover strength of long insulator strings subjected to switching surges up to 2250 kv, varying string length and surface contamination.

Jacottet, P., ETZ-A 85, 257-61, 1964. (German).
Reports tests to determine the effects of frequency and gap distance, on the switching surge strength of rod gaps and insulators. Maximum gap was 1200 mm. Maximum insulator rating was 110 kv.

Udo, T., IEEE Trans. Power App. & Syst. 83, 471-83, 1964.
Reports impulse and switching surge tests on air gaps up to 8 meters long, and on insulator strings, up to 80 units in length. He found that the sparkover voltage of long air gaps with long-tail surges tends to be below the ac value.

Rawls, J. A., Kalb, J. W., and Hileman, A. R., IEEE Trans. Power App. & Syst. 83, 245-50, 1964.
Present the results of surge tests on a full-size laboratory model of an EHV tower-insulator system. Switching surge characteristics are emphasized, including effects of rise-time and bias voltage.

Owens, J. B., IEEE Trans. Power App. & Syst. 83, 263-66, 1964.
Proposes a statistical approach to the determination of switching surge withstand voltages for EHV insulation systems.

Hill, H. L. and Kinyon, A. L., IEEE Power App. & Syst. Supplement 1963: 476-87.
Describe 200-300 x 1000 microsecond switching surge flashover tests on EHV line insulation - air gaps and suspension insulator strings. Positive and negative waves were used under wet and dry conditions.

Hedman, D. E., Johnson, I. B., Titus, C. H., and Wilson, D. D., IEEE Trans. Power App. & Syst. 83, 1196-1203, 1964.
Report an investigation of miniature power systems showing that switching surges from energization and reclosing are most effectively reduced by the use of circuit-breaker contact shunting resistances and controlled pole-closing relationships.

Beehler, J. E., IEEE Trans. Power App. & Syst. 83, 512-20, 1964.
Reports measurements on the decay time for charges trapped on power transmission lines by switching operations. The average dry-weather time constant was 25 seconds. More inclement weather reduces the time constant.

Young, F. S., Clayton, J. M., and Hileman, A. R., IEEE Trans. Power App. & Syst. Supplement 1963: 132-52.
Develop a method of determining shielding requirements for transmission lines, as a function of ground wire height. Shielding angles from 30 to 45 degrees are shown to be satisfactory for lower lines, but angles in the range 10 to 12 degrees are required for ground wires 150 to 160 feet high.

Anderson, J. G. and Barthold, L. O., IEEE Trans. Power App. & Syst. 83, 271-80, 1964.
Propose the use of digital weather models to statistically forecast the insulation performance of EHV transmission lines.

Wagner, C. F., IEEE Trans. Power App. & Syst. 83, 931-44, 1964.
Explores the possibility of utilizing the predischarge currents between the ground wire and conductors on high-voltage transmission lines to improve the lightning performance of the lines.

III. Insulators

Killian, S. C. and Moran, J. H., IEEE Trans. Power App. & Syst. 83, 280-85, 1964.
Present sixty-cycle, impulse, and switching surge strength data from tests on station post insulators from 1300 to 2100 kv BIL's.

Zaazou, A., Khalifa, M., and El-Debeiky, S., Proc. IEE 111, 959-66, 1964.
Report on radio noise from suspension insulators as a function of atmospheric humidity, surface pollution, and form of applied voltage.

Hampton, F., Proc. IEE 111, 985-90, 1964.
Has investigated the flashover mechanism of polluted insulation, measuring the voltage distribution on flat models and looking at arc behavior.

Ely, C. H. A. and Lambeth, P. J., Proc. IEE 111, 991-98, 1964.
Suggest a new criterion of performance of an insulator subjected to pollution: the maximum salinity of the fog in which the insulator will not flash over.

Heuse, E. M., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 9 pp.
Reports tests made to determine the optimum configuration for evaluating the power frequency puncture strength of porcelain.

Zeibig, A., ETZ-A 85, 610-14, 1964. (German).
Proposes a uniform set of test conditions for high-voltage post insulators, to eliminate national variations.

Klǎy, H. ETZ-A 85, 289-93, 1964. (German).
Presents a theory to explain the reduced negative impulse flashover strength of large insulators.

Heise, W. and Kǒthe, H., ETZ-A 85, 861-65, 1964. (German).
Report tests on the flashover strength of contaminated insulators, particularly the variation in strength with the number of insulators in series.

Korbut, E. V. and Merkhalev, S. D., Elekt, Stantsii (USSR) No. 8, 58-62, 1964. (Russian).
Studied the effect of insulator surface profile and washability on the flashover strength of outdoor insulators.

IV. Cables

Blodgett, R. B. and Gooding, F. H., IEEE Trans. Power App. & Syst. 83, 121-28, 1964.
Show that the variation with voltage stress of the loss factor of carbon black paper used as screens in oil paper cables, is principally a surface effect. The indicate that the variation can be reduced but not eliminated.

Gazzano-Priaroggia, F., Occhini, E., and Palmieri, N., IEEE Trans. Power App. and Syst. 83, 137-51, 1964.
Report an investigation on carbon black paper used in oil paper cables, showing its effectiveness in increasing the ac dielectric strength, and present a theory to explain this effect.

Tuzinski, J. R., IEEE Trans. Power App. & Syst. 83, 152-65, 1964.
Presents graphs for several voltage classes, and outlines a computer program for designing high-voltage cable joints, worked at pre-selected stresses.

Bartnikas, R. and d'Ombrain, G. L., IEEE Trans. Power App. & Syst. Supplement 1963: 366-75.
Describe a method for determining the dissipation factor from ionization-discharge-rate and intensity measurements on oil-impregnated paper-insulated power cables. The approach is partly empirical but test results show satisfactory agreement with Schering bridge measurements.

Kojima, K. and Tanaka, S., IEEE Trans. Power App. and Syst. 83, 460-67, 1964.
Investigated the impulse breakdown of oil-impregnated paper and polyethylene in oil, in structures representing cable dielectrics. They found the breakdown of composite solid-liquid insulation to be a function of the breakdown strengths of the solid and the liquid, and the ratios of their thickness.

Balaska, T. A., McKean, A. L., and Oliver, F. S., IEEE Trans. Power App. & Syst. 83, 774-80, 1964.
Report results of an accelerated load cycle test program on high-voltage gas-filled cable to evaluate (leak) tracer gases. Helium was concluded preferable over odorant and halogenated gases. Electronegative gases, SF_6 and C_4F_8, in addition to being traceable, permit lower operating pressures for ionization-free operation than nitrogen.

Kurtz, M. and Kellam, B., IEEE Trans. Power App. & Syst. 83, 804-10, 1964.
Describe a single, universal system for splicing or terminating plastic and elastomeric insulated cables, applicable to polyethylene, butyl rubber, polyvinyl chloride, and cross-linked polyethylene insulations, up to 15 kv. The key material is a self-amalgomating polyethylene tape which is compatible with all available insulants.

IEEE Trans. Power App. & Syst. 83, 1053-57, 1964.
An IEEE Committee report gives the background for a new IEEE Standard in Procedures for Impulse Voltage Testing of Insulated Conductors.

Mosley, K., Conf. of Diel. and Ins. Matls. (London: IEE, 1964), 12 pp.
Reports on the electrical properties of high-temperature cables using compacted magnesia insulation. Variations were noted in resistivity, loss angle, and dielectric constant.

Petry, H., ETZ-A 85, 102-06, 1964. (German).
Reports tests on corona discharges in plastic-insulated cables. A heating process for making voids visible is described.

V. Switchgear

Shaw, A. B. and Whittaker, D., Proc. IEE 111, 193-202, 1964.
Studied spark reignition voltage as a function of gap geometry, electrode material, arc duration, and rate of transverse gas flow. The results are explained on the basis of average gap density as controlled by the temperature.

Salge, J., ETZ-A 85, 417-25, 1964. (German).
Reports observations on the movement of high-current arcs in narrow gaps with walls of insulating materials.

Burghardt, G., ETZ-A 85, 306-11, 1964. (German).
Discusses the non-uniform distribution of restrike voltages in double-break air contactors.

Burghardt, G., ETZ-A 85, 161-66, 1964. (German).
Reports on the effect of arc length and arc energy on the restriking of short ac arcs in air.

Liao, T. W., Schneider, H. N., Skeats, W. F., and Titus, C. H., IEEE Trans. Power App. & Syst. 83, 1213-19, 1964.
Describe a new circuit-breaker testing facility comprising a compound circuit, similar to the Weil synthetic circuit, but with modifications and much higher voltage and current capabilities.

Curtis, T. E., IEEE Trans. Power App. & Syst. 83, 1161-64, 1964.
Describes a vacuum switch interrupter combined with a multiple-circuit disconnecting switch in such a manner that the single interrupter can be used as a load-break switch for any of the multiple circuits. Ratings extend to 138 kv and 1200 Amperes.

Easlay, G. J. and Telford, J. M., IEEE Trans. Power App. & Syst. 83, 1172-77, 1964.
Describe a new line of SF_6 circuit breakers to cover the range 34.5 to 69 kv and 500 to 2500 MVA. Normal pressure is 60 psig. Interrupting and impulse voltage withstand test data are reported. A puffer-type interrupter is utilized.

Low, S. S. and Boehr, J. W., IEEE Trans. Power App. & Syst. 83, 1178-84, 1964.
Describe the equipment and procedure used in obtaining a single-pole circuit-breaker test at 87% of line-to-line voltage, on 34.5 kv breakers.

Johnson, I. B., Phillips, V. E., and Simmons, H. O., Jr., IEEE Trans. Power & Syst. 83, 1187-94, 1964.
Discuss the effects of extra-high-voltage level transmission, 500 kv and up, on circuit-breaker requirements.

Shores, R. B., Beatty, J. W., and Phillips, V. E., IEEE Trans. Power App. & Syst. 83, 1205-12, 1964.
Describe a line of outdoor air blast circuit-breakers for ratings through 700 kv, based on a building-block design utilizing 250 kv interrupter elements. Pre-inserted resistors maintain surge voltage control during closing.

VI. Transformers

Hornsby, E. A., Irving, R., and Patterson, E. A., Conf. on Diel. and Ins. Matls. (London: IEE, 1964) 10 pp.
Report data on the life of insulating oils in transformers operating at top oil temperatures of 100-105°C.

Abetti, P. A., IEEE Trans. Power App. & Syst. 83, 855-58, 1964.
Supplies additional listings to previously published bibliographies on the surge performance of transformer and rotating-machine windings.

Acker, C. R., IEEE Trans. Power App. & Syst. 83, 893-900, 1964.
Presents a loading guide for 65°C rise distribution transformers, based on a normal life expectancy of 30 years at a continuous hot-spot temperature of 120°C.

Committee Report - IEEE Trans. Power App. & Syst. Supplement 1963: 58-63.
Describes experience in thermal endurance testing of oil-immersed distribution transformers rated 15 Kva, 7200 Volts. Aging was accomplished by self-heating at hot-spot temperatures of 220°, 180°, and 160°C.

Committee Report - IEEE Trans. Power App. & Syst. Supplement 1963: 67-71.
Proposes a standard (IEEE) Test Procedure for Thermal Evaluation of Oil-Immersed Distribution Transformers (Insulation). Integral transformers are to be self-heated to a given hot-spot temperature, then periodically subjected to short-circuit and dielectric tests. Failure to pass these tests denotes end-of-life.

Sloat, T. K. and Banevicius, V. A., IEEE Trans. Power App. & Syst. Supplement 1963: 353-64.
Report an investigation on the use of new and reconditioned oils in new and reconditioned distribution transformers. Transformer breathing was found most influential on the result of thermal aging tests.

Stein, G. M., IEEE Trans. Power App. & Syst. 83, 877-91, 1964.
Discusses the initial distribution of voltage when a voltage surge is applied to a transformer with concentric windings. He considers the effects of insulation-grading, line-element shielding, and the limitations of the equivalent-circuit approach to obtain the distribution.

Beavers, M. F., IEEE Trans. Power App. & Syst. 83, 909-13, 1964.
Challenges the present loading guide for oil-immersed distribution transformers, ASA C57.92, as being quite conservative, by a factor of two to six in life expectancy. He proposes that a more realistic guide be based on an Arrhenius loss-of-life relation and a transient-temperature cumulative-aging procedure.

Crawford, C. I. and Wilson, A. F., IEEE Trans. Power App. & Syst. 83, 926-30, 1964.
Describe test methods used to monitor combustible components in the gas spaces of power transformers. Screening measurements are made with a hydrogen-indicating meter. When periodic readings show significant increase in hydrogen content, a gas sample is drawn for mass spectrometer analysis.

Davis, J. H. and Jones, R. T., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 11 pp.
Describe the insulation system for Class C air-cooled transformers.

Tangen, K., ETZ-A 85, 752-55, 1964. (German).
Reports a method for locating discharge points in transformer windings, using short low energy pulses.

VII. Capacitors

Coleman, C. R., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 3 pp. Discusses the effect of chemical composition of Askarels on their electrical properties when used as capacitor impregnants.

Snell, L. J., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 5 pp. Describes procedures for precise measurement of the temperature-coefficient of capacitance of ceramic capacitors.

Bäumlein, G., Degenhart, V., and Döhler, D., ETZ-A 85, 874-77, 1964. (German). Recommend minimum density paper for improved high-frequency behavior of electrolytic capacitors.

VIII. Impregnated Paper

Constandinou, T. E., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 20 pp. Reports non-destructive electrical tests on oil-impregnated, resin-coated, and untreated papers over a range of moisture contents and temperatures.

Kelk, E. and Wilson, I. O., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 25 pp.
Report data on the effects of various physical parameters on the electric strength of impregnated paper. Factors in the paper making process affecting dielectric losses are also brought out.

Kogan, P., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 10 pp. Reports breakdown and discharge inception measurements on oil-impregnated paper with moisture contents ranging from 1-8%.

Scarfe, E. C. R. and Pulsford, R. G., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 7 pp.
Report that the power factor of impregnated paper correlates with the volume resistivity of the impregnant, but not with the power factor of the impregnant.

IX. Insulating Fluids

Goddard, A. W. and Simmons, M. A., Conf. of Diel. and Ins. Matls. (London: IEE, 1964), 13 pp.
Discuss the time variation of dielectric loss and dc conductivity of insulating oils upon introduction into the test cell.

Ryder, D. M. and Edwards, F. S., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 4 pp.
Report power frequency tests on sphere-to-rounded electrode gaps in oil, at voltages up to 800 kv. Observation showed that impurities in the gap caused wide variations in breakdown voltage.

Hornsby, E. A., Irving, R., and Patterson, E. A., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 17 pp.
Report on the influences of temperature and stress on the gassing tendencies of oils.

Sletten, A. M. and Dakin, T. W., IEEE Trans. Power App. & Syst. 83, 457-59, 1964.
Report on a study of the power frequency breakdown voltage of a one-half inch gap in transformer oil. They find that breakdown is initiated at the positive electrode in less pure oil, and usually at the negative electrode in higher purity oil. Photomultiplier observation of the breakdown process disclosed no polarity effect.

Hawley, R., Zaky, A. A., and Zein Eldine, M. E., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 27 pp.
Review recent work on the insulating properties of high vacuums.

George, D. W., Proc. IEE 111, 1619-23, 1964.
Describes tests showing that "seed" impurities from the electrodes are the source of ionization in inert gases at temperatures over 2000°K.

Sharbaugh, A. H. and Watson, P. K., IEEE Trans. Power App. & Syst. 83, 131-36, 1964.
Report dc breakdown tests on FC-75 vapor and SF_6, and mixtures of the two compounds, over a pressure range of 0.8 to 110 psia. Electrodes were one-inch diameter hemispheres.

Schreier, S., IEEE Trans. Power App. & Syst. 83, 468-71, 1964.
Studied the breakdown characteristics of five Freon gases and SF_6 at low pressures, obtaining Paschen curves over a range from 1 to 40 mmHg-mm. He concludes that the gases all lost most of their insulating advantage over air, at low pressures.

X. Thermal Endurance

Walker, H. P., IEEE Trans. Power App. & Syst. Supplement 1963: 858-69.
Cites tests on components and systems (varnished magnet wire) to show the degree of correlation between thermal life tests on materials when tested alone and when tested as parts of a system.

Beavers, M. F. and Lipsey, G. F., IEEE Trans. Power App. & Syst. 83, 902-08, 1964.
Outline tests and procedures for thermally evaluating insulating materials, indicating the importance of testing composite insulation systems rather than components, and at voltage stresses simulating operating conditions.

Day, A. G., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 9 pp.
Finds tensile strength, extension-at-break, and tearing strength suitable rough screening test only, for evaluating thermal endurance of varnished fabrics.

Potthoff, K., ETZ-A 85, 449-54, 1964. (German).
Discusses thermal aging criterion for oil, cellulose, and wire varnish.

XI. Corona Endurance

Olyphant, M., Jr. and McKeown, J. J., IEEE Trans. Power App. & Syst. Supplement 1963: 846-57.
Review test methods for evaluating the corona resistance of materials, comparing data obtained by various methods. It is shown that the test conditions, e.g., voltage stress, sample thickness, ambient humidity, not only affect the corona life of a sample but also its resistance relative to other materials.

Meats, R. J. and Stannett, A. W., IEEE Trans. Power App. & Syst. 83, 49-54, 1964.
Describe corona resistance tests on polyethylene in the presence of several different gases. They find that the time to breakdown is a function only of the product of applied stress and total discharge quantity per cycle.

Edelman, H., ETZ-A 85, 434-39, 1964. (German).
Reports on the aging of polyethylene films under ac gas discharges.

Alston, L. L. and Dawson, P. G., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 9 pp.
Report the effect of voltage waveform on the life of polyethylene samples with artificial voids.

XII. Tracking and Arc Resistance

Parr, D. J. and Scarisbrick, R. M., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 15 pp.
Report tests on the resistance to surface tracking and erosion of a range of synthetic insulating materials, under polluted conditions.

Hayes, R. and Walker, G. B., Proc. IEE 111, 600-04, 1964.
Report an improvement in the surface flashover strength of titania ceramic in a vacuum, by applying a thin lead-borate glaze. The improvement is attributed to the elimination of tracking.

Näcke, H., ETZ-A 85, 361-70, 1964. (German).
Discusses the strength of insulating materials exposed to moisture and arcing.

Näcke, H., ETZ-A 85, 868-73, 1964. (German).
Proposes a new apparatus for determining the arc resistance of plastic materials.

XIII. Corona Measurement

Jolley, H. E. W., Conf. of Diel. and Ins. Matls. (London: IEE, 1964), 25 pp.
Discusses detection of discharges in bushings up to 600 kv, and safe discharge limits.

Melville, D. R. G. and Salvage, B., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 5 pp.
Report a technique of discharge measurement, where the pulses are recorded on magnetic tape for subsequent analysis with a pulse scaler.

Simons, J. S., Conf. of Diel. and Ins. Matls. (London: IEE, 1964), 13 pp.
Describes an instrument for integrating the discharge energy in high-voltage insulation.

XIV. H. V. Testing

Committee Report, IEEE Trans. Power App. & Syst. 83, 520-23, 1964.
Based on observations on rainfall made at eight locations throughout the U. S., shows that one-third of the samples had resistivities less than the standard 7000 ohms-inch used in laboratory tests. The maximum recorded rate of rainfall was less than half the standard laboratory rate of 0.20 inch per minute.

Möller, K., ETZ-A 85, 375-80, 1964. (German).
Discusses the transient ground currents caused by spark breakdowns in a shielded test area.

Schwab, A., ETZ-A 85, 878-79, 1964. (German).
Describes a newly developed divider for measuring high impulse voltages.

XV. Miscellaneous

Salvage, B., Proc. IEE 111, 1162-72 and 1173-76, 1964.
Calculates the electric stresses for gaseous cavities in solid insulation and for conducting surfaces located between plane parallel electrodes.

Black, R. M. and Reynolds, E. H., Conf. on Diel. and Ins. Matls. (London: IEE, 1964), 25 pp.
Report that dielectric materials subjected to high energy ionizing radiation show effects similar to those during stress aging.

Widman, W., ETZ-A 85, 97-102, 1964. (German.
Discusses statistics of breakdown as influenced by the volume under stress.

CHAPTER IX

INSULATING FILMS

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I. Introduction

The references presented in this chapter are concerned with the electrical properties of organic film or fiber insulation. The literature search was based largely on Chemical Abstracts and Science Abstracts. Other sources of relevant information included the 1964 Conference on Electrical Insulation, NAS-NRC; Conference of Dielectric and Insulating Materials (London: IEE, 1964); and the magazine Insulation which provided both original articles and abstracts of the European literature.

The bibliography has been organized by subject matter under the major categories of cellulosics, laminating materials and structures, supported films, plastic films, radiation effects, and applications. A short digest is included with each reference.

Significant developments and trends in insulating films and fibers for 1964 included:

Cellulosic materials continued to receive substantial attention demonstrating sustained importance of this class of insulation. Most of the reports were from European workers and dealt with the properties of dry and impregnated paper, the effects of manufacturing process variables, and aging studies.

Work continued in the field of ultra-thin supported films in which ionizing radiation is used as the means of inducing polymerization. Conduction mechanisms were emphasized.

The literature on enamels consisted primarily of the synthesis of new materials aimed at improved properties over extended temperature ranges.

Three new materials of potential importance to film insulation were announced in 1964. PPO, poly(phenylene oxide), a new high melting thermoplastic was introduced by General Electric. Du Pont announced a new copolymer of polyethylene and polar components, called Surlyn A Ionomer. A third material, ML-1, a thermally deposited thin film of poly(paraxylylene), was announced as a capacitor dielectric by Union Carbide.

Several papers on plastic films dealt with the relationship between the dielectric properties and film morphology and orientation.

The work on radiation effects was concerned primarily with conduction mechanisms with some work on radiation resistance.

In the applications of plastic films to capacitors, several papers were concerned with the use of metalized electrodes and the clearing processes. An excellent piece of work was reported by Henninger and by Kammermaier in which the chemical factors involved in breakdown of self healing films were studied.

II. Cellulosic Materials

Bullwinkel, E. P., 1964 Conf. on Elect. Insul., NAS-NRC Publication 1238, 101-103, 1965.
A device was described which scans large areas of kraft capacitor tissue and locates microscopic areas which fail at voltages below a predetermined level.

Constandinou, T. E., ERA Rept. (GB) Rept. V/T 148, 22 pp., 1962.

Ibid. Rept. 5008, 24 pp., 1963.

Ibid. Rept. 5039, 19 pp., 1964.

Constandinou, T. E., Conf. of Dielectric and Insulating Materials, IEE, 1964, 20 pp.
In a series of four papers Constandinou measured dielectric properties of unimpregnated paper (1962 ref.), oil impregnated paper (1963 ref.), and resin coated paper (1964 ref.) as a function of moisture content between 20 and 100°C. The fourth report summarizes the first three.

Dieterle, W., Bull. Assoc. Suisse Elect. 55, 198-212, 1964. (French).
Present uses for acetylated paper were described and dielectric properties were compared with those of ordinary cable paper.

Fournie, M. R., Le Gall, Y., and Roulet, C., Bull. Soc. Franc. Elect. 5, 321-31, May 1964. (French).
Infrared analysis was used to study the aging of unimpregnated paper and pentachlordiphenyl impregnated paper at elevated temperatures with and without applied voltage.

Fleischer, T. B. and Fergestad, R., Elektrotek. Tidsskrift (Norway) 77, 133-9, 1964. (Norwegian).
The temperature limits of a heat-stabilized transformer insulation paper called INSULDUR, originally developed by Westinghouse, were found to be about 30°C higher than those of ordinary insulating paper.

Gutman, B. B., Loseva, Y. P., Maslennikov, K. V., Renne, V. T., Morozova, M. N., and Gulyaeva, L. M., Bumazhn. Prom. 39, (1), 12-13, 1964.
This paper gave the results of a laboratory study designed to learn the process for preparing Al_2O_3-filled paper previously developed in Finland. The oxide-filled paper was found to have a higher impregnated dielectric strength than unfilled paper.

Hochauz, E., Przeglad Papier 17, 6-10, 1961.
Manufacture of insulating paper filled with carbon black was described. It had high mechanical strength and high chemical purity.

Kahle, M., Wiss. Z. Hochsch. Elektrotech. Ilmenau 9, No. 5, 647-53, 1963. (German).
A structural analysis of cellulose was used to clarify the adsorption mechanism of water vapor and to calculate adsorption isotherms on the basis of multimolecular layers.

Kelk, E. and Wilson, I. O., Conf. of Dielectric and Insulating Materials, IEE, 1964, 20 pp.
The incorporation of synthetic and other types of fiber into soft wood pulp was discussed. The dielectric strength was found to be dependent upon physical properties such as thickness, apparent density and air impermeability, whereas the dielectric losses were found to be dependent upon the chemical constitution and purity of the pulp and water from which the paper was made as well as on its apparent density.

Korchemkin, F. I. and Bobrov, A. I., Bumazhn. Prom. 39 (1), 15-16, 1964.
A comparative study was made of the properties of conventional electrical insulation paper and acetylated paper (Ac content 34.2-37.8%). Acetylation reduced the dielectric loss angle by a factor of 6-10 in 120-hr. tests at 95% relative humidity, and increased the resistivity of paper several hundred times.

Krasucki, A., Proc. IEE, Pt. B 109, Suppl. No. 22, 435-9, 1962.
Processes leading to discharges in oil-impregnated paper were studied.

LePetit, J. P., Proceedings of the Twelfth Colloque Ampere, Bordeaux, 1963, pp. 419-22. (French).
The dielectric anisotropy of blocks of paper with oriented fibers was measured at 3000 Mc.

McLeod, T. S. and Yallup, A. F., Insulation 10, 20 Feb. 1964.
The absorption of moisture in paper was measured with a fringing capacitor. Instruments for measurements on either a static or moving web were described.

Milov, B. G., Proizv. Kondensatorn. Bumagi Sb. 1963, 25-41.
Experimental batches of kraft pulp, characterized by high chemical purity, low dielectric losses, good beatability, uniform fibrillation, and high mechanical strength, were obtained by modifying the conventional pulping variables.

Riaux, E., Proceedings of the Twelfth Colloque Ampere, Bordeaux, 1963, pp. 412-18. (French).
The dielectric characteristics of capacitor papers were measured over a wide range of frequency and temperature. An equivalent circuit was proposed which can be used under certain conditions to derive the electrical properties of an impregnated capacitor.

Scarfe, E. C. R. and Pulsford, R. G., Conf. of Dielectric and Insulating Materials, IEE, 1964, 7 pp.
The effects of ionic and other additives on the power factor of the impregnated paper were investigated. There was no correlation between the power factor of impregnated paper and the power factor of the impregnant, but a definite relationship was found between the power factor of impregnated paper and the volume resistivity of the impregnant.

Shirai, M., Kamiya, T., Kan, T., and Kinozaki, T., Mitsubishi Denki Engr. 5, 31-5, Oct. 1963.
A new heat-stabilized insulating paper for transformers was developed by treatment with dicyandiamide, melamine, or polyacrylamide. Test results indicated increased overload capacity and life.

Stamm, H. and Kahle, M., Wiss. Z. Hochsch. Elektrotech. Ilmenau 9, No. 3, 293-9, 1963. (German).
A theoretical discussion was given of a method of removing inorganic salts absorbed in paper fibers by means of diffusion and electro-osmosis with ion free water.

Stamm, H. and Kahle, M., Wiss. Z. Hochsch. Elektrotech. Ilmenau 9, No. 5, 661-6, 1963. (German).
It was shown that the loss factor of cable and capacitor paper could be improved by a factor of 6 by a suitable system of ion exchange.

Stamm, H. and Kahle, M., Elektrie 17, 392-7, 1963.
The dielectric strength of impregnated and non-impregnated papers was found to be unaffected by prestressing up to 80% of tear strength. The dielectric strength was also measured as a function of mechanical pressure on the paper. Thermal aging tests resulted in no changes in electrical properties after 30 days at 150°C although a change in mechanical properties occurred after a short time at 110°C.

Take, Y., Suzuki, Y., and Matsushita, M., Kogyo Kagaku Zasshi 63 (6), 1061-6, 1960.
The effects of heat on dielectric properties of oil-impregnated paper were investigated. The dielectric loss after heating at 100° decreased more in air than in vacuum, and the values of the dielectric constant at 20° became larger with degradation by heating.

Tomago, A. and Yamaguchi, I., Natl. Tech. Rept. (Matsushita Elec. Ind. Co., Osaka) 9 (4), 326-43, 1963.
This paper continued a series on dielectric characteristics of chlorodiphenyl and chlorodiphenyl-impregnated paper. Parameters affecting the corona start voltage of impregnated capacitors were investigated.

Vaisman, L. M., Proizv. Kondensatorn. Bumagi Sb. 1963, 64-80.
Data were presented on the effect of the nature of pulp organic and inorganic impurities, pulp freeness, conditions of sheet formation and paper finishing, the quality of the process water, and methods used for its purification on the dielectric properties of capacitor paper.

Vaisman, L. M. and Kundzich, G. A., Bumazhn. Prom. 39 (2), 10-12, 1964.
A method was described for evaluating the structure of capacitor paper and relating it to the dielectric strength.

Varshavskii, D. S., Proizv. Kondensatorn. Bumagi Sb. 1963, 81-96.
The quality requirements of capacitor paper were discussed in relation to the use of synthetic impregnating oils.

Venkateswaran, A. and Tiwari, S. T., TAPPI 47, 25-8, Jan. 1964.
Measurements of dielectric constant and dissipation factor of several woods of varying moisture content were made at 1, 2, 5, and 10 kc.

Vyatkina, O. V. and Vyatkin, D. G., Bumazhn. Prom. 38 (12), 7-11, 1963.
Ibid. 39 (1), 7-9, 1964.
These two papers described the upgrading of kraft pulp for insulation paper by the inclusion of hardwoods in the process.

Westinghouse Electric Corp. Brit. Patent 938,479, Oct. 2, 1963, 14 pp.
The thermal stability of kraft paper and other materials used in liquid dielectrics was increased by the use of amide-type stabilizers.

III. Laminating Materials and Structures

Burton, W., Conf. of Dielectric and Insulating Materials, IEE, 1964, 4 pp.
The manufacture and properties of unimpregnated and impregnated Samica mica paper were described and a survey was made of the main applications of this material.

Ketterer, R. J., Insulation 10, 24-32, Aug. 1964.
The properties and applications of mica paper were presented in a state of the art review.

Böning, W., Arch. Elektrotech. 48, No. 1, 7-22, 1963. (German).
In Part I of this paper an equivalent circuit was devised to describe the distribution of air voids in laminated dielectrics. In Part II, the air content and crack distribution were deduced from measurements of the loss factor.

Holt, T. and Simpson, W., Brit. Patent 944,279, Dec. 11, 1963, 4 pp.
Glass-mica tapes impregnated with a 1:1 equivalent mixture of an epoxy resin and a styrene-acrylic acid copolymer (4:1 molar ratio) were used as core windings and cured at 160° to form a superior electrical insulation.

Koyanagi, S., Denki Kagaku 28 (6), 274-7, 1960.
The electrical characteristics of printed wiring boards of melamine-glass, phenol paper, polyester-glass, epoxy-glass, epoxy-Tetoron, and Teflon-glass board were compared.

Moore, E. R., Zimmerman, R. L., and Spiekerman, D. R., Abstracts, T8, 148th Meeting, ACS, Aug.-Sept. 1964.
Laminating resins incorporating decreased amounts of maleic anhydride in a styrene copolymer showed improved electrical properties.

Turnbull, R. B., Conf. of Dielectric and Insulating Materials, IEE, 1964, 5 pp.
Varnished fabrics and the materials used for their manufacture were briefly reviewed, and properties of representative materials quoted.

IV. Supported Films

A. Ultra Thin Films

Bashara, N. M. and Doty, C. T., J. Appl. Phys. 35, 3498-507, 1964.
Further studies of electrical conduction in very thin polybutadiene films formed in a glow discharge were reported, see 1963 Digest.

Bradley, A., Insulation 10, 31-5, April 1964.
The current-voltage relationships of glow discharge polymerized films were discussed. This is a continuation of work reported by A. Bradley and J. P. Hammes, J. Electrochem. Soc. 110, 15, 543, 1963.

Caswell, H. L., 1964 Conf. on Elect. Insul., NAS-NRC Publication 1238, 57-9, 1965.
Techniques for fabricating thin inorganic and organic dielectric films were reviewed.

Chrobak, P., Prace Inst. Tele-i-Radiotech. 7, No. 4 (25), 90-3, 1963. (Polish).
Studies on the methods of preparation and application of lacquer layers for metal-lacquer capacitors were presented. Methods of measuring film continuity and thickness in process were given.

DaSilva, E. M. and Miller, R. E., Electrochem. Technol. 2, 147-50, 1964.
A modified glow discharge using a hot-filament cathode was used to deposit films of polybutadiene. The deposition rate was studied as a function of the glow discharge parameters and a technique was described for depositing large-area, short-free polymer films 500-2000 Å thick.

Gregor, L. V. and McGee, H. L., Proc. Ann. Meeting Electron Beam Symp., 5th, Boston 1963, 211-17.
The formation of thin polymer films of acrolein, methyl methacrylate, and divinylbenzene through ultraviolet irradiation of surfaces with adsorbed monomer vapor was described.

Leturcq, P., C. R. Acad. Sci. 258, No. 7, 2027-30, 1964. (French).
The conductivity of silicone films about 100 microns in thickness was studied as a function of time.

Mann, H. T., J. Appl. Phys. 35, 2173-9, 1964.
The current through silicone polymer films formed by electron-beam bombardment in the thickness range 500-2500 Å was measured as a function of voltage and temperature between 4° and 300°K. The usual theoretical expressions for field emission or Schottky emission did not completely fit the electron transport data, although the logarithm of the current varied as the square root of the field.

Christy, R. W., J. Appl. Phys. 35, 2179-84, 1964.
The current through silicone polymer films formed by electron-beam bombardment in the thickness range 50-150 Å was measured as a function of voltage and temperature between 77° and 300°K. Simple tunneling theory, including the effects of image force and dielectric constant, failed to account for all the data.

McNally, F. X., Insulation 10, 41-3, May 1964.
A technique was described for preparing photo etched organic films for use on printed circuit boards or multilayer microcircuitry.

Stuart, M., Conf. of Dielectric and Insulating Materials, IEE, 1964, 3 pp.
A continuous process was used to produce thin one micron polymer films from styrene vapor subjected to an ac glow discharge. Dielectric losses in such films were investigated, including the effects of various gases present during polymerization.

Zinn, W., Z. Angew. Phys. 16 (2), 115-21, 1963.
The insulating capabilities of thin crosslinked polymer films prepared by electron bombardment of a substrate in the presence of silicone oil vapor were evaluated. The dielectric strength was found to be dependent upon the electrode material.

B. Enamels

Anon, Insulation 10, 31, July 1964.
A new 220°C amide-imide magnet wire enamel based on trimellitic anhydride was described. Electrical and mechanical properties were presented.

Beck, H. J., Schmidt, K., and Rombrecht, H. M., Ger. Patent 1,170,095, May 14, 1964, 2 pp.
Wire enamels made from polyesters of terephthalic acid and mixtures of polyhydric alcohols containing $\geq$ 2OH groups were described in which 1,4-dimethylolcyclohexane was used as part or all of the dihydric alcohol component.

Beck, H. J., Schmidt, K., and Rombrecht, H. M., Ger. Patent 1,158,650, Dec. 5, 1963, 5 pp.
Cresol solvents of polyamide-urea resins containing two different amide components were found to give lacquers with good mechanical properties for insulated magnet wires.

Beck, H. J., Brit. Patent 947,973, Jan. 29, 1964, 6 pp.
Polyurethan lacquers prepared by reaction of an oil-modified polyester with a diisocyanate and a blocking agent which had desirable electrical properties were described.

Chandler, R. H., Paint Manuf. 34 (7), 52-4, 1964.
A review of insulating lacquers was presented which included 43 references.

Furukawa Electric Co., Ltd. Japan, Japanese Patent 7520, 1962, 2 pp.
This patent disclosed electrical insulating wire coatings composed of organic titanate-modified aromatic polyesters.

General Electric Co., Brit. Patent 942,472, Nov. 20, 1963, 6 pp.
Ethylene glycol-glycerol-iso-or terphthalate resins (Brit. Patent 775,081) were modified by total or partial replacement of ethylene glycol by ethanolamine to give polyester-amide resins for insulating conductors.

Gurevich, A. D., Trenke, K. M., and Nemtsov, M. S., USSR Patent 159,887, Jan. 14, 1964.
Electrical insulating lacquers were prepared from poly(vinyl acetal), a solvent consisting of a mixture of dioxane alcohols boiling at ≥ 230°, and a diluent consisting of low-boiling aromatic hydrocarbons or their derivatives.

Hawley, R., Zein Eldine, M. E., and Zaky, A. A., Elect. Rev. 174, No. 5, (Suppl.), 13-15, Jan. 31, 1964.
Possible future trends in the improvement and application of insulating materials, including resins and enamels were discussed in general terms.

Haughney, J. P., Abstracts, T5, 148th Meeting, ACS, Aug.-Sept. 1964.
Thermal aging studies of resinous insulating coatings, such as phenolics, alkyds, and polyesters suggested correlation of changes of dielectric constant and dissipation factor with mechanical properties during aging.

Kurskii, R. M., Kozlov, N. N., Shoikhet, M. G., Maiofis, I. M., Antonova, E. R., and Polyakova, N. P., Lakokrasochnye Materialy i ikh Primenenie 1963 (6), 25-8.
Electrical insulating varnish TL-1 was prepared by transesterification of "Lavsana," a waste product of poly(ethylene terephthalate) and glycerol. Elastic and heat-stable properties were maintained after short exposures to 200°.

Logemann, H., Becker, W., and Kolb, G., U. S. Patent 3,112,223, Nov. 26, 1963, 5 pp.
The patent disclosed a heat-cured acrylonitrile copolymer magnet wire coating.

Lybeck, A. H., U. S. Patent 3,141,850, July 21, 1964, 2 pp.
Wire electrical insulating compositions containing poly(vinyl chloride), triallyl cyanurate, fillers, and flame retardants were patented.

Mehendru, P. C. and Menon, N. S. K., Indian J. Pure Appl. Phys. 2, 184-6, June 1964.
The dielectric constant and loss of six grades of shellacs were measured at 3 cm and 8 mm wavelengths.

Schmidt, K., Neubert, G., and Rombrecht, H. M., Elecktrotech. Zeit. B. 15, 603-7, Oct. 14, 1963.
Wire enamels and varnishes based on imides and esterimides were described.

Sprengling, G. R., Chang, L. S., Sassano, D. R., and Trapp, O. D., Belg. Patent 632, 201, Sept. 2, 1963, 13 pp.
Thermally stable insulating resins were made from the polymerization of a methylol diphenyl ether.

Timmerbeil, F. W. and Klingenberg, G., Ger. Patent 1,156,459, Oct. 31, 1963, 2 pp.
Electrical insulating coating materials especially suitable for voltages > 10 kv were prepared by addition of 15-22% poly(methyl methacrylate) to conventional resin mixtures.

Victorius, C., Belg. Patent 632,700, Nov. 22, 1963, 42 pp.
A 2-stage polymerization process was described for preparation of an aqueous dispersion of an acrylonitrile/acrylic acid/acrylate terpolymer useful mainly for electrical wire coatings, preferably in combination with a water soluble phenol-formaldehyde resin.

V. Plastic Films

A. General

Dulin, C. I., Rubber Plastics Age 45, 405-6, 1964.
Use of plastic films including Mylar, FEP fluorocarbon, and polyimide films for electrical insulation was reviewed.

Killam, D. L., 1964 Conf. on Elect. Insul., NAS-NRC Publication 1238, 125-8, 1965.
Measurements of surface resistivity, volume resistivity, permittivity and dissipation factor were made on samples of 18 common polymeric insulating materials as a function of relative humidity at room temperature.

Mathes, K. N., SPE Journ. 20, 634-7, July 1964.
The electrical and mechanical properties of various polymeric films at cryogenic temperatures were reviewed.

McPherson, A. T., Rubber Chem. Technol. 36, 1230-1302, 1963.
A review of the electrical properties of elastomers and related polymers was given with 234 references.

Nakajima, T., Researches Electrotech. Lab. (Japan) 102 pp, Jan. 1964.
Studies of dielectric properties of various insulating materials at very low frequencies were reported.

Passaglia, E., SPE Trans. 4, 169, July 1964.
The mechanical and dielectric relaxation in crystalline and semi-crystalline polymers was discussed in relation to the degree of crystallinity and the morphology of the polymers. Data were presented for poly(chlorotrifluoroethylene) and polypropylene.

Potthoff, K., Elektrotech. Z. 85, 449-54, July 1964. (German).
The interpretation of thermally accelerated aging of insulating oils, cellulose, and wire varnish was discussed and related to thirty-one references. Refractive index-density-molecular weight analysis, estimation of average degree of polymerization and measurement of dielectric loss were recommended as the clearest indications of aging in oil, cellulose and wire varnish respectively.

Reinsch, H., Elektrizitätsverwertung (Switzerland) 38, 231-3, Sept. 1963. (German).
A brief review was given of the use of plastics in the field of electrical technology.

Skinner, S. M., Lytle, W. J., and Merck, J. W., Dielectrics in Space Symposium (Pittsburgh: Westinghouse Electric Corporation, 1963), 11 pp.
The failure mechanisms of dielectrics under space conditions were discussed and techniques for their investigation in the laboratory were described.

Sprengling, G. R., Dielectrics in Space Symposium (Pittsburgh: Westinghouse Electric Corporation, 1963), 6 pp.
A discussion of the desirable features of dielectric polymers designed to operate at temperature > 300°C was given.

Wurstlin, F., Nachrichtentech. Fachber. 29, 19-24, 1964. (German).
A short review of the dielectric properties of non-polar and polar polymers was presented.

B. Polyolefins

Alston, L. L. and Dawson, P. G., Conf. of Dielectric and Insulating Materials, IEE, 1964, 9 pp.
Polyethylene samples, 0.09 to 0.18 cm thick, with artificial voids were subjected to pulses lasting for some 10^{-6} to 10^{-3} seconds. The results were consistent with life being controlled by the intrinsic electric strength of the polyethylene, and indicated that a space charge may be set up and decay with a time constant of the order of 10^{-3} seconds.

Anon, Materials in Design Engg. 60, 106-7, Sept. 1964; Modern Plastics 41, 98, Sept. 1964.
Electrical and mechanical properties of a new polymer based on polyethylene containing ionic as well as covalent bonds were given in these announcement-type articles.

Artbauer, J. and Griac, J., Electrie 17, 120, April 1963.
The mechanism of breakdown of polyethylene due to electrical discharges was studied. The discharges resulted in a decrease in the dielectric strength which could not be explained by any of the existing theories of corona damage.

Artbauer, J. and Griac, J., Conf. of Dielectric and Insulating Materials, IEE, 1964, 3 pp.
The dc and impulse electric strength of polyethylene were measured as functions of temperature. The decrease of electric strength, typical for plastics above a certain critical temperature, was found to be far less marked when measured with impulse voltage than with dc. Possible explanations of this difference were discussed.

Bouvier, B. and Fallou, B., Rev. Gen. Elect. (France) 73, 295-304, May 1964. (French).
Changes in mechanical and electrical properties of polyethylene and poly(vinyl chloride) with various plasticizers were correlated with rate and extent of plasticizer migration.

Conklin, G. E., J. Appl. Phys. 35, 3228-35, 1964.
A mechanism contribution to the dielectric loss at 55.2 Gc in highly crystalline polyethylene was identified with the vinyl unsaturation content which can orient in the microwave field.

Curtis, A. J., High Polymers 20, Pt. 2, 105-30, Interscience.
Electrical properties of polyolefins were presented along with 51 references.

Edelmann, E., Elektrotech. Zeit. A 85, 434, 1964.
Various methods for measuring the degree of corona damage to polyethylene films were investigated. Infrared spectrography was found to give a qualitative measure of aging and adhesion was used to obtain a quantitative measure.

Esso Research and Engineering Company, Brit. Patent 964,328, July 22, 1964, 12 pp.
Micaceous talcs were found to improve the dielectric strength of olefin polymers and rubbers.

Fava, R. A., Conf. of Dielectric and Insulating Materials, IEE, 1964, 9 pp.
Evidence was presented that the sharp decrease in the dielectric strength of polyethylene above room temperature is due to an electromechanical effect.

Hoffman, J. D., Am. Chem. Soc., Div. of Polymer Chem., Preprints 4 (1), 150-61, 1963.
A survey was made of the dielectric properties of semicrystalline polymers, with poly(chlorotrifluoroethylene) used as an example.

Hor, L. M., Elektrotechnika 57, 129-37, May 1964. (Hungarian).
Internal discharges and associated energy losses of laminated polyethylene with cavities of various sizes were studied.

Ishida, Y., Yoshitaka, U., Shigenori, T., and Masato, M., Kolloid-Z. 199, No. 1, 70, 1964.
Dielectric behavior of isotactic polybutene was reported.

Kocharyan, N. M., Akopyan, A. N., Barsamyan, S. T., Tolapchyan, L. S., and Pikalova, V. N., Dokl. Akad. Nauk Arm. SSR 37 (5), 263-7, 1963.
The dielectric losses, dielectric constant, specific volume resistance and effective dipole moment of chlorinated poly(tetrachlorohexatriene) were measured.

Lacombe, J. and Wrobel, W., Wire Wire Prods. 38 (4), 508ff, 1963.
A comparative discussion of physical, chemical and electrical properties of conventional and chemical cross-linked polyethylenes was presented.

Link, G. L., Abstr., Tl, 148th Meeting, ACS, Aug.-Sept. 1964.
The molecular bases for dielectric losses in polyethylene were reviewed.

Martens, S. C. and Rothenberg, S., U. S. Patent 3,148,169, Sept. 8, 1964, 4 pp.
Curable polyethylene compositions for insulating electrical conductors were patented.

McKeown, J. J., Conf. of Dielectric and Insulating Materials, IEE, 1964, 15 pp.
A technique was developed to measure the 60 cps ac intrinsic electric strength of organic polymers by embedding the film and electrodes in a thermosetting resin to eliminate surface pre-breakdown discharges. Peak 60 cps ac and dc intrinsic electric strengths of polyethylene were found to be equivalent, i.e., 22.9 kv/mil at room temperature.

McMahon, E. J. and Perkins, J. R., Abstr., T2, 148th Meeting, ACS, Aug.-Sept. 1964.
The degradation of polyolefins and fluorocarbon resins subjected to high voltage fields and mechanical strains was reported.

Meats, R. J. and Stannett, A. W., IEEE Trans. Power Apparatus Syst., 49-54, Jan. 1964.
The influence of discharges on polyethylene sheet was investigated in various gases. The time of breakdown was found to depend on the product of electric stress and total discharge quantity per cycle and appeared to be independent of the chemical changes.

Mikhailov, G. P., Lobanov, A. M., Shevelev, V. A., and Orlova, T. P., Plasticheskie Massy 1964 (2), 9-12.
The dissipation factor and dielectric constant of high and low density polyethylene were measured as a function of temperature at 3×10^9 and 4.7×10^8 cps.

Minnesota Mining and Manufacturing Company, Brit. Patent 962,637, July 1, 1964, 6 pp.
High dielectric strength rubber insulating compositions suitable for sheet or tape were disclosed.

Pegoraro, M. and Zelinger, J., Chim. Ind. (Milan) 46 (3), 258-62, 1964.
The dielectric constant and loss factor at 50 cps and temperatures from -35° to the melting point were measured on isotactic polypropylenes, free from chemically bonded oxygen. The use of suitable antioxidants is recommended in polypropylene for electrical purposes.

Reed, J. C., McMahon, E. J., and Perkins, J. R., Insulation 10, 35-8, May 1964.
The effects of high voltage stresses on TFE and FEP fluorocarbons were discussed.

Sazhin, B. I. and Skurikhina, V. S., Vysokomolekul. Soedin, Karbotsepnye Vysokomolekul. Soedin., Sb. Statei 1963, 68-73.
The volume resistivities of low, medium, and high density polyethylene and high and medium density ethylene-propylene copolymers were measured as a function of temperature.

Sistig, E. and Zeil, W., Z. Physik. Chem. 41 (3/4), 236-44, 1964.
Dielectric constant and loss factor were measured for linear and branched polyethylene in the range 7.5-36.3 kMc at room temperature. Within the accuracy of measurement, both parameters were independent of the frequency in this range.

Stetter, G., 1964 Conf. on Elect. Insul., NAS-NRC Publication 1238, 21-4, 1965.
The dc conductivity of polyethylene was studied as a function of stress, temperature, and time.

Verne, S., Conf. of Dielectric and Insulating Materials, IEE, 1964, 18 pp.
Higher melting point polyolefins were examined for use as flexible dielectrics.

Wibbens, R. L., Insulation 10, 46-9, July 1964.
The physical and electrical properties of polypropylene films were reviewed.

Work, R. N., McCammon, R. D., and Saba, R. G., J. Chem. Phys. 41, 2950-1, 1964.
Measurements were reported of the dielectric loss in atactic polypropylene between 4° and 300°K and from 100 cps to 20 kc.

Zeil, W. and Sistig, E., Kolloid-Z. 196 (1), 8-17, 1964.
Dielectric data were given for polyethylene and Plexiglas at 24.3×10^{10} cps at 211°-373°K.

C. Acrylates

D'Errico, M. J. and Fetter, E. J., Belg. Patent 627,195, July 16, 1963, 20 pp.
Films of acrylate and methacrylate polymers were described for use in electroluminescent panels and capacitors.

Dittmer, B., Arch. Elektrotech. 48, No. 6, 387-402, 1964. (German).
Previous work on discharge channels in a point/plane electrode system was extended by observations on poly(methyl methacrylate) and "Araldite" with 50 cps and parts of ac waves. It was concluded that breakdown in solids is initiated by ionizing collisions and electron avalanches, much the same as in gases.

Dyvik, G. K., Bartoe, W. R., and Steck, N. S., SPE Trans. 4, 98-101, April 1964.
A new second order transition temperature relationship for copolymers was proposed. Dielectric measurements on acrylate copolymers showed good correlation with the model.

Haase, J., Sistig, E., and Zeil, W., Z. Naturforsch. 19a, 660-1, May 1964. (German).
The dielectric constant of Plexiglas was determined at room temperature from microwave interferometric measurements of the refractive index. A value of 2.54 was obtained at 36 Gc and a value of 2.55 at 42 Gc in good agreement with results obtained with an impedance method.

Heydemann, P., Kolloid-Z. 195 (2), 122-8, 1964.
Dielectric relaxation of poly(methyl methacrylate) as a function of pressure, temperature, and frequency was discussed.

Ishida, Y., Masato, M., Yoshitaka, U., and Motowa, T., Kolloid-Z. 199, 67, 1964.
Dielectric properties of poly(acrylonitrile) were discussed.

Ishida, Y., Kolloid-Z. 200, 51, 1964.
Dielectric behavior of copolymer and block polymer (methyl acrylate-styrene) was discussed.

Luttinger, M., Sliemers, F. A., Jr., Kircher, J. F., and Leininger, R. L., U. S. At. Energy Comm. BMI 1678, 31 pp, 1964.
Polymerization of methyl methacrylate, beta-cyanoethyl acrylate, ethyl vinyl sulfone, and $F_3CCH_2OCH{:}CH_2$ by radiation and by chemical catalytic methods was investigated. No significant differences were found in the dielectric properties of the polymers made by the two methods.

Murakami, I., Ishii, T., and Yamamura, H., J. Sci. Hiroshima Univ. Ser. A-II, 27 (2-3), 125-32, 1964.
Effects of stretching on dielectric properties of poly(methyl methacrylate) were studied in the frequency range from 10^{-4} to 10^6 cps at temperatures between 15 and 130°C.

Steck, N. S., SPE Trans. 4, 34-8, Jan. 1964.
Dielectric constant and dissipation factor of a series of acrylic polymers were measured over a temperature range of -40°C to 200°C.

Williams, G., Trans. Faraday Soc. 60, 1556-73, 1964.
The complex dielectric constant of poly(methyl acrylate) was investigaged in the frequency range 25-10^5 cps, the temperature range 14.5-90°C and the pressure range 1-3 x 10^3 atm.

D. Vinyls

Barabanov, N. N., Koikov, S. N., Fomin, V. A., and Tsikin, A. N., Elektrotekhnika, No. 12, 15-19, Dec. 1963. (Russian).
The life of styrene, Teflon and Mylar films at 50 cps was determined by accelerated aging at high frequencies within the limited range of voltage for which life x frequency = constant.

Breilmann, W., Elektrotech. Zeit. 85, A, 381, June 12, 1964. (German).
The volume resistivity and long time dc dielectric strength of poly(vinyl chloride) were studied as a function of temperature. Breakdown was explained in terms of a thermal mechanism.

Dokukina, A. F., Kocheshkov, K. A., Koton, M. M., Smirnova, Z. A. Egorova, E. I., Talalaeva, T. V., and Timofeyuk, G. V., USSR Patent 162,964, May 27, 1964.
Polymeric dielectrics with increased heat resistance were obtained by the emulsion copolymerization of styrene or 2,5-dimethylstyrene with halogen-containing styrenes.

Flowers, L. C. and Berg, D., J. Electrochem. Soc. 111, 1239-43, 1964.
Poly(vinyl alcohol) was reacted with acrylonitrile to obtain a series of polymers differing in degree of cyanoethylation. Dielectric constants and dissipation factors were measured as a function of temperature and frequency. DC resistivities were reported for room temperature.

Hara, T. and Ikamoto, S., J. Phys. Soc. Japan 19 (6), 1087-8, 1964.
The effect of molecular weight on dielectric absorption of poly(vinyl acetate) was studied. Apparently, end groups of the polymer contribute to beta-absorption but not to alpha-absorption.

Ishida, Kolloid-Z. 200, 48, 50, 1964.
These papers discussed the dielectric behavior of poly(vinylidene fluoride) and poly(vinyl fluoride).

Ieda, M. and Shinohara, U., Mem. Fac. Engng. Nagoya Univ. 14, 150-9, Nov. 1962.
Dielectric absorption was studied in plasticized poly(vinyl chloride).

Korsun, V. M., Nauchn. Zap. Dnepropetr. Gos. Univ. 77, 54-9, 1962.
The electrical conductivity of polystyrene was studied during illumination with visible light. Illumination first sharply reduced the current through the specimen, but then increased it to a magnitude somewhat exceeding the dark current.

Koppelmann, J., Kolloid-Z. 189, 1-6, 1963.
The relationship between the dielectric and mechanical relaxation times of poly(vinyl chloride) was discussed.

Kryszewski, M., Kurczewska, H., and Szymanski, A., Przeglad Elektron. 5, No. 4, 190-8, 1964. (Polish).
The dc conductivity of polystyrene and Saran was studied as a function of operating conditions and environmental factors. The current-voltage relationahip was found to be in agreement with space charge limited current flow theory.

Razinskaya, I. N., Kozlov, P. V., and Shtarkman, B. P., Vysokomolekul. Soedin. 6 (3), 516-21, 1964.
The temperature and frequency dependences of the dielectric loss of poly(vinyl chloride) plasticized with ethyl stearate, castor oil, and dioctyl phthalage were studied.

Rychtera, M., Slaboproudy Obzor 23, No. 12, 694-6, 1963. (Czech).
The effects of atmospheric exposure on the insulation resistance of poly(vinyl chloride), laminated paper and acetyl wool were investigated.

Sorkin, H., Graessley, W. W., Manson, J. A., and Zufall, J. H., 1964 Conf. on Elect. Insul., NAS-NRC Publication 1238, 34-5, 1965.
The range of the dielectric constants of a homologous series of poly(fluoroalkyl vinyl ethers) was explained in terms of the orientation of polar groups.

Wartman, L. H., SPE J. 20, 254-9, Mar. 1964.
The influence of plasticizer and ionic impurities on the electrical resistance of poly(vinyl chloride) was studied.

E. Polyesters

Aleksandrov, N. V. and Trubachev, S. G., Vestnik Elektroprom., 1963, No. 8, 41-6. (Russian).
Poly(ethylene terephthalate) films of Russian, British, and West-German manufacture were tested to determine their electrical and mechanical properties and aging behavior.

Antonov, S. N., Fainshtein, E. B., and Andrianova, N. V., Plasticheskie Massy 1963 (12), 51-2.
The volume resistivity, electrical strength, and dielectric loss of a poly(ethylene terephthalate) film were measured at 20°-240°.

Gottlieb, M. and Garbuny, M., Rev. Sci. Instrum. 35, 641-2, May 1964.
A technique was described for the measurement of the low frequency dissipation factor of Mylar at liquid helium temperatures.

Ishida, Y., Kolloid-Z. 200, 49, 1964.
The symmetry of the dielectric beta-absorption curve of a polyester was discussed.

Ishida, Y., Masato, M., Yoshitaka, U., and Motowa, T., Kolloid-Z. 199, 69, 1964.
The dielectric behavior of solution-gorwn crystals of polyethylene terephthalate was presented.

Mikhailov, G. P. and Lobanov, A. M., Vysokomolekul. Soedin., Geterotsepnye Vysokomolekul. Soedin. 1964, 175-80.
The dielectric properties were determined for poly(4,4'-isopropylidenediphenol sebacate), a polar amorphous polymer, over the frequency range 200 to 10^{10}cps and the temperature interval -150° to 200°.

F. Polycarbonates

Hara, T. and Okamoto, S., Japan J. Appl. Phys. 3, 499-500, 1964.
Dielectric measurements on poly(bisphenol-A carbonate) and poly(tetrachlorobisphenol-A carbonate) at temperatures from -170° to 250°C were reported. The positions of three dielectric loss peaks were determined and their origins discussed.

Woboditsch, W., Elektrie 17, Oct. 1963.
The resistance of polycarbonate and cellulose acetate butyrate films to surface discharges was discussed.

G. Other Materials

Barker, R. E., Jr. and Thomas, C. R., J. Appl. Phys. 35, 3203-16, 1964.
The effects of moisture and high electric fields on conductivity in alkali-halide-doped cellulose acetate were discussed.

Bartenev, G. M. and Zelenev, Yu. V., Dokl. Akad. Nauk SSSR 154, 661-4, 1964. (Russian).
Low temperature relaxation processes in rubbery polymers were studied by measuring the mechanical and electrical losses between -180° to 25°C.

Filbert, W. H., Insulation 10, 38-9, Mar. 1964.
The influence of filler loading and thickness on dielectric strength of silicone rubber insulation was discussed.

Hay, A. S., Fr. Patent 1,322,152, Mar. 29, 1963, 51 pp.
This patent described a new class of high melting thermoplastic polymers useful in insulation applications.

Anon., Chem. and Engg. News 42, 57-8, Dec. 7, 1964; Modern Plastics 42, 95-7, Dec. 1964; Plastics Technology, Dec. 1964.
In these announcement-type articles, general dielectric and mechanical properties were given for the new high melting thermoplastic, polyphenylene oxide, disclosed in the above patent by Hay.

Mikhailov, G. P., Lobanov, A. M., Shevelev, V. A., and Orlova, T. P. Vysokomolekul. Soedin. 6 (5), 868-70, 1964.
The dielectric constant and dissipation factor of poly(tetrafluoroethylene) were measured as a function of temperature at 4.7×10^8 cps. The effects of annealing, hardening, elongation, and pressure treatment on the dissipation factor were investigated.

Peterlin, A., Abstracts, T6, 148th Meeting, ACS, Aug.-Sept. 1964.
Dielectric measurements were made on polyoxymethylene films between -63° and +3°C with frequencies from 30 to 10^5 cps. A significant difference was observed between oriented cold drawn and unoriented quenched samples.

Petrosyan, V. P. and Dzhanbaryants, A. V., Izv. Akad. Nauk Arm. SSR, Khim Nauki 16 (5), 421-8, 1963. (Russian).
Dielectric permeability and dielectric loss of polychloroprene were measured between -60° and +20° and 500 to 1.2×10^7 cps.

Petrosyan, V. P., Karapetyan, N. G., Boshnyakov, I. S., and Zhamkochyan, S. G., Izv. Akad. Nauk Arm. SSR, Khim. Nauki 16 (5), 429-36, 1963. (Russian).
The variation of the dielectric permeability, loss angle, and specific volume resistance with temperature and frequency was investigated for amorphous as well as for partly crystalline polychloroprene in a study of effect of structure on dielectric properties.

Wetzler, I., Fr. Patent 1,370,046, Aug. 21, 1964, 8 pp.
Adhesives for electrical insulating papers and films were patented. An example was given for the lamination of paper to a polyester film.

VI. Radiation Effects

Adamec, V., Internat. J. Appl. Radiation Isotopes (GB) 15, 477-83, 1964.
Measurements of the volume resistivity of poly(tetrafluoroethylene), polystyrene, polycarbonate, poly(ethylene terephthalate), polypropylene and acetobutyrate under the exposure to X-ray radiation were described.

Adamec, V., Conf. of Dielectric and Insulating Materials, IEE, 1964, 4 pp.
The nature of the anomalous conductivity in polymeric insulating materials was studied by measurement of transient conductivity after application of dc voltage both with and without irradiation.

Adamec, V., Nature 200, 1196, Dec. 21, 1963.
The dissipation factor of poly(tetrafluoroethylene) increased under X-ray irradiation but the permittivity was only slightly affected.

Adamets, V., Elektrichestvo, 1964, No. 4, 76-80 (April). (Russian).
The influence of ionizing radiation on the electrical properties of organic insulation was discussed. Changes in the dielectric constant and loss angle of 20 organic insulating materials after exposure to various doses in a reactor were reported.

Asch, G., Felix, M. C., and Ongaro, R., Compt. Rend. 258 (16), 3982-5, 1964. (French).
The effects of irradiation time, polarization time and voltage, time interval between irradiation and polarization, and discharge by short circuiting were observed in a study of the electrification of polystyrene previously subjected to gamma radiation.

Black, R. M. and Reynolds, E. H., Conf. of Dielectric and Insulating Materials, IEE, 1964, 25 pp.
A study of the chemical changes produced by exposure of dielectric materials to high energy ionizing radiation has shown the effects produced are similar to those involved in electrical deterioration during stress aging and when ionization has taken place in the dielectric.

Campbell, F. J., Abstracts, T3, 148th Meeting, ACS, Aug.-Sept. 1964.
Changes in volume conductivity, dielectric constant, and dissipation factor of thin films of Mylar subject to gamma radiation were studied.

Craig, C. L. and Rogers, J., 1964 Conf. on Elect. Insul., NAS-NRC Publication 1238, 120-4, 1965.
The radiation resistance of various insulating materials to a mixed gamma ray and neutron environment was determined.

Fallah, E., Ind. Plastiques Mod. 15 (9), 37-41; (10), 25-8, 1963.
Samples of low density polyethylene were irradiated in a reactor and by a cobalt 60 source, and the conductivity was then measured under X-ray irradiation.

Frisco, L. J., Muhlbaum, A. M., and Szymkowiak, E. A., Dielectrics in Space Symposium (Pittsburgh: Westinghouse Electric Corporation, 1963), 21 pp.
Some effects of a simulated space environment consisting of X-ray and UV irradiation at 10^{-6} Torr on the electrical properties of dielectrics were presented.

Harrison, S. E., Coppage, F. N., and Snyder, A. W., Conf. of Dielectric and Insulating Materials, IEE, 1964, 12 pp.
Measurements were made to study the character of photoconduction in organic insulating solids exposed to cobalt gamma radiation and neutrons from a reactor. Materials studied included Teflon, polyethylene, poly(vinyl chloride), polystyrene, Kel-F, and nylon.

Ieda, M., Kosaki, M., Yamada, Y., Shinohara, U., 1964 Conf. on Elect. Insul., NAS-NRC Publication 1238, 29-33, 1965.
The volume resistivity of polyethylene was measured after exposure to gamma ray and high energy electron irradiation.

Linnebom, V. J., Insulation 10, 21-6, Mar. 1964.
A state of the art review of radiation effects on insulation was given.

Nakai, T. and Sakakibara, T., Denki Gakkai Zasshi 83 (894), 263-71, 1963.
The effects of gamma ray irradiation on electric properties of Mylar and Mylar capacitors were investigated.

Pascale, J. V., Herrmann, D. B., and Miner, R. J., Mod. Plastics 41, 239 ff, Oct. 1963.
The effects of ionizing radiation on the mechanical and electrical properties of 45 plastics were determined. Styrene polymers and polyethylenes were most resistant to radiation, while acrylics, cellulosics, and fluorocarbons were least resistant.

Posselt, K., Elektrie 18 (5), 145-9, 1964.
Cross-linking induced by irradiation was found to improve the properties of polyethylene and several other insulating materials.

Snyder, A. W., Dielectrics in Space Symposium (Pittsburgh: Westinghouse Electric Corporation, 1963), 1 p.
Data were presented on gamma ray and neutron induced conductivity and photoconductivity in dielectrics.

Wicklein, H. W., Nutley, H., and Ferry, J. M., IEEE Trans. Nuclear Sci. NS-10, 131-8, Nov. 1963
Gamma, Electron and X-ray induced transient conductivity was measured in Mylar, Vitamin Q, fixed paper, ceramic, tantalum, and mica capacitors.

Yahagi, K., Shinohara, K., and Mori, K., Electrical Engineering in Japan 83, Mar. 1963.
This paper presented experimental values of insulation resistance and a theoretical analysis of the results of exposing polyethylene and Teflon fluorocarbon polymer to gamma radiation and electron-beam bombardment.

Yahagi, K. and Shinohara, K., 1964 Conf. on Elect. Insul., NAS-NRC Publication 1238, 25-8, 1965.
Conduction currents were measured in high and low density polyethylene which had been irradiated with high energy electrons.

VII. Applications

Ackmann, W., Nachrichtentech. Z. 16, 513-16, 1963. (German).
Accelerated life test methods were evaluated for metallized paper capacitors. The insulation resistance was found to be a significant parameter for the evaluation of failures.

Black, R. M., Ann. Rept. Prog. Rubber Technol. (W. Heffer Sons Ltd., Cambridge, Eng.) 27, 81-9, 1963.
Use of natural and synthetic rubber for cables and insulation was reviewed. 78 references.

Coleman, C. R., Conf. of Dielectric and Insulating Materials, IEE, 1964, 3 pp.
The effect of chemical composition on the electrical properties of askarels was described with reference to their use in impregnated paper capacitors, particularly at low ambient temperatures.

Henninger, P., Frequenz 17, 319-28, Sept. 1963. (German).
The development of a self healing metalized polystyrene capacitor was described. See related work in following reference by Kammermaier.

Kammermaier, J., Frequenz 18, 145-50, May 1964. (German).
The decomposition gases produced during breakdown in metalized capacitors were analyzed using gas chromatography and infrared spectroscopy. Films of cellulose triacetate, cellulose, poly(ethylene terephthalate), and polystyrene were investigated.

Horii, K. and Wada, H., Bull. Electrotech. Lab 27, 447-54, June 1963. (Japanese).
Corona detection and corona pulse counting at 50 cps (or 300 cps in accelerated life tests) was used for evaluation of non-inductively wound miniature polyethylene, Mylar, and polycarbonate capacitors which had been oil-immersed in vacuum.

Huraux, C., Rev. Gen. Elect. 72, 535-50, Nov. 1963. (French).
Properties of papers used in the manufacture of metalized capacitors and the effects of the metal coating, zinc in particular, were described.

Kuchinskii, G. S., Elektrichestvo, July 1964, No. 7, 39-42. (Russian).
Low loss, low inductance 50 kv discharge capacitors with capacitance of 0.1µf at 3 Mc have been developed with polyethylene film insulation alternating with sheets of capacitor paper.

Leda, L., Przeglad Elektron. 5, No. 2, 93-5, 1964. (Polish).
Technological problems and electrical parameters of lacquer-metal capacitors manufactured in Western Europe were reviewed.

Lukasiewicz, T., Prace Inst. Tele-i Radiotech. 7, No. 4 (25), 94-5, 1963. (Polish).
A process was described for etching aluminum foil covered with a dielectric lacquer layer for the production of metal-lacquer capacitors.

Ludanyi, J., Hiradastechnika 15, 108-14, April 1964. (Hungarian).
The influence of thermal cycling and humidity on the capacitance of protected and unprotected polystyrol capacitors was investigated.

McMahon, W. and Weke, W. G., Insulation 10, 28-32, Oct. 1964.
The electrical properties of miniature metalized polycarbonate lacquer film capacitors were presented.

Pereselentsev, I. F., Elektrotekhnika, June 1964, No. 6, 48-50. (Russian).
The effects of the vacuum heat treatment process on the electrical characteristics of paper power capacitors were described.

Petley, B. W., ERA Rep., Rep. L/T 412, 13 pp, 1961.
The ac working voltage of polystyrene capacitors was greatly increased by indenting the film and impregnating the capacitor with liquid paraffin.

Proskurnin, V. P., Pereselentsev, I. F., Baev, I. F., and Ivannikov, P. N., Elektrotekhnika, 1964, No. 8, 18-21 (Aug.). (Russian).
The electrical characteristics of liquids based on chlorinated hydrocarbons were examined for use in capacitors and transformers.

Przybyl, E., Przeglad. Elektron. 4, No. 10-11, 616-24, 1963. (Polish).
Results of life tests on paper, mica, and styroflex capacitors were presented for a range of temperatures and voltages.

Valley, D. J. and Wagener, J. S., IEEE Trans. Compon. Pts. CP-11, 205-11, 1964).
Capacitors with stable capacitance and high and stable Q's over a wide temperature and frequency range have been developed from a new polymeric material, ML-1 which is applied to aluminum foil in the manufacturing. Full details of electrical characteristics were given.

CHAPTER X

THE BREAKDOWN OF DIELECTRICS

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I. Introduction

As in previous years there has been much activity in the field of electrical breakdown during 1964. In the section dealing with gas breakdown, work pertaining to phenomena outside the normal range of gas discharges has not been included. Thus, high energy ionization processes and plasma physics are not included, although in some cases the discharges required to form the plasma are of interest. Several important books relating to gas breakdown have been published. Physics of Atomic Collisions by Hasted contains a good account of atomic collisions and other phenomena associated with the study of ionized gases. The appearance of Raether's book Electron Avalanches and Breakdown in Gases will be welcome to all who are working directly in this field or are only interested in a general way. In this volume is contained a summary of the theoretical and experimental work on single electron avalanches as well as the processes leading to a succession of avalanches, and ultimately to breakdown. Much of this material has not been published in English before. The various techniques for observing the development of avalanches are considered in detail; and the results obtained for diffusion coefficients, carrier statistics, electron and ion drift velocities, ionization, and attachment coefficients from these measurements are given. Space charge effects in avalanches of high carrier density are of particular interest. The generation of successions of avalanches resulting from photon and ionic secondary mechanisms is then considered, and the development of a discharge through either the Townsend or streamer mechanism is discussed in detail. A chapter is devoted to applications such as spark chambers and counters; and finally in an appendix, the theories of the transient current build-up are described.

In the field of liquid breakdown there has not been any notable advances in an understanding of the mechanism or processes involved. Perhaps the most outstanding point is the growing realization of the importance of surface layers on the electrodes. This includes natural oxide layers as well as artificial layers. Gallagher and Lewis (Brit. J. Appl. Phys. 15, 491-8, 1964), for example, report that the static electric strength of liquid argon is strongly dependent on the oxidation condition of both anode and cathode when small amounts of oxygen are present in the argon. Kao (Brit. J. Appl. Phys. 15, 1247-9, 1964) has found that the breakdown strength of CCl_4 is increased when one electrode is covered by an insulating layer, and Zaki, Zein Eldine, and Hawley (Nature 202, 687-8, 1964) have found similar results using coated electrodes in transformer oil. In all cases, these results are interpreted in terms of space charge effects, showing that space charge is of much greater importance in liquid breakdown than is frequently imagined. The possible role of positive ions in causing enhanced cathode emission has long been realized but many of the space charge effects recently investigated are due to negative ions accumulating in the region of the anode, a process which has not been considered as particularly important.

The breakdown of solid dielectrics continues to receive attention, because of the practical significance of such insulating systems as well as the academic problems associated with an understanding of the mechanisms. A very useful book entitled, The Theory of Dielectric Breakdown of Solids by O'Dwyer has been published, dealing with both the theoretical and experimental aspects of the subject. The classification of breakdown into intrinsic, thermal, and avalanche is discussed, and it is pointed out that only experiments performed under carefully controlled experimental conditions are considered, in which such things as discharges in the ambient medium, faulty samples or inhomogeneous fields are eliminated. Failure due to surface discharges is not considered. The theories of the three types of breakdown mentioned above are discussed in detail and the experimental results available are collected together and considered in terms of these theories. Attention is centered on the alkali halides because it is with these relatively simple solids that most work has been done and it is with these that there is the best hope of obtaining a theoretical understanding of the breakdown process.

There has been growing realization that the "intrinsic" electric strength of polyethylene as determined using recessed test specimens is possibly influenced by electromechanical effects (Fava, Conf. on Dielectric and Insulating Materials, 1964). By means of a new technique for holding the sample which eliminates discharges and minimizes electromechanical effects McKeown (Conf. on Dielectric and Insulating Materials, 1964) has been able to show that the dc and peak ac electric strengths of polyethylene are identical. This is a particularly significant experiment since the lower ac strength usually found has been attributed to dielectric heating, whereas in some instances, it is now more probable that electromechanical effects were significant.

The practical importance of failure of insulating as a result of corona discharges has prompted a considerable amount of work in this area. In particular, a wide variety of organic materials have been tested, but they all exhibit about the same corona resistance and are far inferior to mica and the silicones. Various test methods have been employed in an attempt to understand the mechanism of corona failure. Of particular note is the work of Meats and Stannett (IEEE Trans. PAS-83, 49-54, 1964) who measured the rate of erosion and decomposition products for polyethylene subjected to corona discharges in a variety of gases. The life of the material was found to depend on the product of stress and the total quantity of charge per cycle, but to be independent of the gas used. The development of discharge trees in materials has also been examined but it is still not at all clear how these grow. Some authors have suggested that intrinsic breakdown at the end of the branches causes propagation (Bolton, Cooper, and Gupta, Conf. on Dielectric and Insulating Materials, 1964) while avalanche breakdown has also been proposed as the mechanism of growth (Dittmer, Arch. Elektrotech. 48, 387-402, 1964).

Surface flashover, particularly of insulator strings, has been investigated primarily with a view to finding how pollution affects the breakdown voltage and also by what means the adverse effects can be reduced. Of the more basic papers, that of Hampton (Proc. IEE 111, 985-90, 1964) has indicated the conditions necessary in order that breakdown should propagate along the surface. A number of papers dealing with avalanche breakdown in semi-conductor materials is included in the bibliography because of the relationship between this process and avalanche breakdown of insulators.

II. Breakdown of Gases

A. Prebreakdown and Fundamental Collision Phenomena

Asundi, R. K. and Craggs, J. D., Proc. Phys. Soc. (London) 83, 611-18, 1964.
Ionization and attachment coefficients have been measured in SF_6 and C_7H_{14}. The maximum values of the attachment cross-sections for electron energies below 1 ev were about 10^{-15} cm^2 for SF_6 and 10^{-14} cm^2 for C_7H_{14}. The attachment process is a resonant process, within a very narrow energy range (less than 1 ev).

Barna, S. F., Edelson, D., and McAfee, K. B., J. Appl. Phys. 35, 2781-2, 1964.
The first Townsend ionization coefficient has been measured in H_2 and D_2 for $17 < E/P < 100$ V/cm mmHg.

Bowe, J. C., Phys. Rev. 134, A355-61, 1964.
A theoretical analysis is given for the drift velocity of electrons in noble gases in terms of the cross-sections for inelastic collisions near the threshold energy.

Brambring, J., Z. Physik 179, 532-8, 1964.
The electron current of an avalanche in a homogeneous electric field is calculated taking into account the influence of the diffusion of electrons and the boundary effect of the anode. The ionization rate is assumed to be proportional to the current density. The results are significant in measurements of electron diffusion and electron drift velocities.

Brambring, J., Z. Physik 179, 539-43, 1964.
Drift velocities of electrons in pure argon are derived from measurements of transit times in a homogeneous electric field. The avalanches are initiated by the light pulse of a spark, and the current of electrons is observed. Effects of diffusion are taken into account.

Breare, J. M. and von Engel, A., Proc Roy. Soc. A282, 390-402, 1964.
The ultraviolet signals resulting from excitation and ionization of gas molecules by an electron swarm are observed, and electron drift velocity, diffusion coefficient, and degree of radiation quenching are derived. The agreement with other data is moderate.

Breton, C., Compt. Rend. 258, 3648-51, 1964. (French).
The rate of ionization of hydrogen in a pulsed discharge is examined for the cases where various dissociative reactions of the hydrogen molecule are followed. Effective cross-sections are calculated for each reaction. Estimates of the electronic temperature may be in error if the dissociation is neglected.

Brink, G. O., Phys. Rev. 134, A345-6, 1964.
The absolute values of the cross-sections for ionization by electron impact of Na, K, Rb, and Cs were measured by a modulated crossed beam technique. The values were observed to increase with atomic number.

Brion, C. E., J. Chem. Phys. 40, 2995-9, 1964.
The ionization of oxygen by electrons has been examined by a mass spectrometer

with an electron-velocity selector. Five ionization potentials of molecular oxygen were obtained, which were in good agreement with spectroscopic data.

Brueckner, K. A., J. Chem. Phys. 40, 439-44, 1964.
The three-body recombination rate for molecular ions is calculated at low density, including the effect of dissociative collisions on the molecular complex initially formed by the recombination process. The rate is markedly reduced from the predicted value of the Thomson theory by this effect, as it is by an increase of ionic mass due to attachment of neutral molecules to the ion.

Bydin, Yu, F., Zh. Eksperim. i Teor. Fiz. (USSR) 46, 1912-18, 1964. (Russian).
Translation: Soviet Physics JETP 19, 1091-5, 1964.
The resonance charge exchange of 900 to 2400 ev Na^-, K^-, Rb^- and Cs^- ions was studied. The cross-section for the process is $\sim 10^{-14}$ cm^2, and increases with decreasing ion velocity.

Carlton, T. S. and Mahan, B. H., J. Chem. Phys. 40, 3683-7, 1964.
The rate constants for bimolecular recombination of gaseous ions in three different systems have been determined. The results suggest that the recombination rate constant is not particularly sensitive to the chemical identity of the ions, and that ion-atom complexes are important even at pressures below 10 mmHg.

Cavalleri, G., Gatti, E., and Principi, P., Nuovo Cimento 31, 318-24, 1964.
The diffusion coefficient for thermal electrons in pure neon is measured by an electron-density sampling method. The value obtained (1670 ± 50 cm^2/sec) is in agreement with that deduced from the collision probability for momentum transfer of thermal electrons.

Cavalleri, G., Gatti, E., and Principi, P., Nuovo Cimento 31, 302-9, 1964.
A new method of measuring attachment cross-sections and diffusion coefficients for thermal electrons in gases is described which uses a gas-amplified scintillation chamber. The operation of this chember is based on the decay of excited states caused by secondary electrons obtained by Townsend local multiplication of primary electrons due to an ionizing particle.

Chanin, L. M. and Rork, G. D., Phys. Rev. 135, A71-5, 1964.
Electron ionization coefficients were measured in He - H_2 and Ne - H_2 mixtures over an extended range of E/P. The results for these mixtures are similar with respect to H_2 concentration to that previously obtained for Ne - Ar mixtures.

Chanin, L. M. and Rork, G. D., Phys. Rev. 133, A1005-9, 1964.
The first Townsend ionization coefficient was determined for E/P in the range 3-300 V/cm mmHg in cataphoretically cleaned helium. Good agreement is found with other work.

Comes, F. J. and Lessmann, W., Z. Naturforsch. 19a, 65-70, 1964. (German).
The photoionization of N_2 up to a photon energy of 28.6 ev is described. Highly excited states of N_2 molecules are observed and the ionization potential is measured. Below 511Å N^+ ions are formed by dissociation. Under

certain circumstances, N^+ ions are formed by dissociation of N_2^+ when in collision with a N_2 molecule. Cross-sections for the ionization processes are given.

Davidson, P. M., Proc. Phys. Soc. 83, 259-73, 1964.
The statistical problems associated with ionization currents in gases are treated theoretically. In addition to certain prebreakdown phenomena, the probable time for the occurrence of a spark, due to statistical fluctuations, using maintained illumination and a potential less than the sparking potential is evaluated.

Davies, D. K., Llewellyn-Jones, F., and Morgan, C. G., Proc. Phys. Soc. 83, 137-44, 1964.
Ionization currents have been measured in helium between plane parallel electrodes ($d=0.817$ cm) for $5.07 \leq P_o \leq 38.51$ mmHg, in the range $8.61 \leq E/P_o \leq 38.08$ V/cm mmHg, for overvoltages up to 6%. The significant secondary ionization process at higher pressures is delayed photoelectric emission, with a cross-section of 3×10^{-20} cm^2. At lower pressures positive ion incidence becomes more important, contributing up to 75% of the secondary emission at $P=5.07$ mmHg.

Davis, A. J., Evans, C. J., and Llewellyn-Jones, F., Proc. Roy. Soc. (London). Ser A, 281, 164-83, 1964.
The spatio-temporal growth of ionization between plane parallel electrodes is investigated theoretically taking account of space charge distortion of the field. Agreement with experiments in H_2 is obtained if allowance is made for a variation in the secondary ionization coefficients with the area of the discharge.

Dawson, P. H. and Tickner, A. W., J. Chem. Phys. 40, 3745-6, 1964.
Several complex ions such as NH_4, NH_3, $NH_4 \cdot 2NH_3$, etc. which are probably formed by a clustering process were observed in the ammonia glow discharge. The results indicate the ready formation of ion-molecule clusters at pressures below 1 mmHg.

Demkov, Yu. N., Zh. Eksperim. i Teor. Fiz. (USSR) 46, 1126-35, 1964. (Russian). Translation: Soviet Physics - JETP 19, 762-8, 1964.
The detachment of electrons in slow collisions between negative ions and atoms is examined theoretically. The energy distribution of the emitted particles (electrons) is obtained and the probability that the system remain in the bound state (no detachment) is determined.

Derwish, G. A. W., Galli, A., Giarindi-Guidoni, A., and Volpi, G. G., J. Chem. Phys. 40, 5-12, 1964.
Ion-molecule reactions in methane, in methane-methane-d_4 mixture, and in ethane have been studied up to a pressure of 0.08 mmHg in the ion source of a mass spectrometer. Ionization-efficiency curves, appearance potentials, and pressure-dependence studies have allowed the parent-daughter ion relationship and the cross-sections of the pertinent reactions to be determined.

Devins, J. C. and Wolff, R. J., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 43, 1965.
Ionization and attachment coefficients are reported for CF_4, C_2F_6, C_3F_8, C_4F_{10}, C_6F_{14}, cyclic C_4F_8 and olefinic C_3F_6. The attachment coefficients are related to molecular structure in a very complex fashion.

Dutton, J. and Williams, E. M., Proc. Phys. Soc. 84, 171-5, 1964.
The drift velocity and diffusion coefficient for selected species of neon ions were measured for $3 < E/P < 45$ V/cm mmHg. Two species of ion with zero field mobility of 4 and 7.5 cm^2/V sec were observed. The diffusion coefficient of the slower ion increased from a constant value at low E/P and tended to the form $D \alpha (E/P)^{1/2}$ at high E/P.

Edelson, D. and McAfee, K. B., Rev. Sci. Instr. 35, 187-94, 1964.
A new apparatus and technique is described which minimizes the errors involved in the determination of ionization and attachment coefficients and ion mobility by means of a pulsed discharge. Recent theoretical results incorporating the effects of diffusion and finite duration of the initial impulse are presented together with a method for obtaining the parameters of interest from the experimental data.

Edelson, D., Morrison, J. A., and McAfee, K. B., J. Appl. Phys. 35, 1682-90, 1964.
The equations for the pulsed Townsend discharge involving two ions interacting through the γ process have been solved for the ion densities as a function of time and position. The single ion case can be derived similarly. Negative ions are a special case with $\gamma = 0$. The temporal increase of ion flux close to the Townsend breakdown condition is shown.

Freely, J. B. and Fisher, L. H., Phys. Rev. 133, A304-10, 1964.
Prebreakdown currents in oxygen are reported for $32 < E/P < 100$ V/cm mmHg, and in oxygen-helium mixtures for $16 < E/P < 36$. Ionization and attachment coefficients were evaluated. Secondary ionization coefficient was about 10^{-6} at $E/P = 46$, using a molybdenum or nickel cathode, but increased to 10^{-5} for $E/P = 100$.

Galli, A., Giardini-Guidoni, A., and Volpi, G. G., Nuovo Cimento 31, 1145-64, 1964.
Charge exchange processes between Ar, Kr, Xe ions and some molecules were investigated in the energy range (~ 15 - 100) ev, for singly charged primary ions and (~ 80 - 200) ev for doubly charged primary ions. Their cross-sections were measured both for formation of secondary parent ions and for fragments.

Govinda, Raju, G. R., Harrison, J. A., and Meek, J. M. Proc. IEE 111, 2097-9, 1964.
Photon absorption coefficients have been measured for radiation produced in a wire-cyclinder discharge in oxygen at pressures between 1 and 50 mmHg. Between 10 and 50 mmHg the absorption coefficient/pressure ratios were 0.03 $(cm\ mmHg)^{-1}$ and 0.01 $(cm\ mmHg)^{-1}$. Below 10 mmHg pressure μ/P increased with decreasing pressure.

Harris, F. M., Brit. J. Appl. Phys. 15, 439, 1964.
The accuracy with which the initial externally maintained photoelectric current can be measured in various electronegative gases is discussed and is shown to depend on the relative magnitude of the coefficients of ionization and attachment and of backscattering.

Hasted, J. B., Physics of Atomic Collisions, Butterworth, 1964.
The book provides a good introduction to the study of ionized gases, atomic collisions, and associated phenomena. It covers the basic principles as well as the recent experimental material.

Hubert, P. and Crémieu-Alcan, E., 6th Int. Conf. Ionization Phenomena in Gases, Volumes 1 - 4 , Paris, 1963.
These volumes contain many papers concerned with all aspects of gas discharge phenomena.

Jones, F. L., Radio Electronics Engr. 28, 219, 1964.
Initiatory cold cathode emission in gas discharges.

Van Lint, V. A. J., IEEE Trans. NS-11, 266-71, 1964.
A beam of high energy electrons (20-30 Mev) was used to produce a uniform and known concentration of ionization in a gas. A microwave field is then used as a probe to determine electron density and collision frequency. In N_2, electron-ion recombination is found to be anomalous in that the apparent recombination coefficient depends on the initial ionization intensity, possibly as a result of metastables.

Lucas, J., J. Electron. Control. 17, 43-8, 1964.
Amplification and transit time of an electron avalanche while crossing a gap are calculated in terms of ionization coefficient and electron drift velocity. Allowance must be made for electron diffusion and electrode effects or considerable error can be introduced.

Mahan, B. H. and Person, J. C., J. Chem. Phys. 40, 2851-9, 1964.
An analysis of the mechanisms of three-body recombination of ions is given. The results show how mass, relative velocity, and nature of deactivating species affect the magnitude of the recombination rate.

Mahan, B. H. and Person, J. C., J. Chem. Phys. 40, 392-401, 1964.
The rate at which gaseous ions neutralize each other has been measured in a variety of gases over a relatively wide pressure range. Neutralization occurs by simultaneous binary and ternary collision processes. The ternary process is sensitive to the nature of the inert gas in which recombination occurs.

Marmet, P., Canad. J. Phys. 42, 2102-20, 1964.
The difference between the idealized ionization probability curves which would be obtained with monoenergetic electrons and the experimental curves are explained in terms of the electronic space charge.

McDowell, M. R. C., Atomic Collision Processes, (Amsterdam: North-Holland Publishing Co., 1964).
Contains the papers presented at the Third International Conference on the

Physics of Electronics and Atomic Collisions. Group headings were as follows. Slow electron scattering by atoms; resonances; polarization of radiation emitted on electron impact, excitation and ionization of atoms by electron impact, electron-molecular collisions, recombination, negative ions, photoprocesses, inelastic heavy particle collisions, elastic heavy particle collisions, collisions with molecules and other topics, theory (mainly electron-atom collisions). 140 papers.

Morgan, C. G. and Williams, W. T., Radio Electronics Engr. 28, 223, 1964.
The temporal growth of ionization in hydrogen.

Petropoulos, G. M., Brit. J. Appl. Phys. 15, 169-76, 1964.
It is observed photographically and by current recordings that for non-uniform fields the predischarge channels grow in steps which result from the constriction of corona streamers.

Prowse, W. A. and Nicholls, J. M., Proc. Phys. Soc. (London) 84, 545-55, 1964.
The growth of current due to collision ionization in H_2 with a 100 Mc field applied is measured in the pressure range 3-10 mmHg. From these measurements, and an assessed value of the electron lifetime, ionization coefficients are calculated which are in fair agreement with accepted values.

Rork, G. D. and Chanin, L. M., J. Appl. Phys. 35, 2801-2, 1964.
The first Townsend ionization coefficient has been measured in deuterium for $20 < E/P < 100$ V/cm mmHg.

Sinnott, G., Phys. Rev. 136, A370-6, 1964.
The mobility of positive ions in H_2 is reported for E/P between 0.6 and 110 V/cm mmHg. At low field strengths the mobility was 10.2 cm^2/V sec at room temperature. At E/P = 10 the mobility increased to a maximum of 14.3 cm^2/V sec at E/P = 60. The low field mobility remained at about 10 for temperatures between 77°K and room temperature, but rose sharply to 11.5 at 375°K.

Sukhum, N., Brit. J. Appl. Phys. 15, 509-12, 1964.
Formulae are derived to give ionization and attachment coefficients from prebreakdown current measurements as a function of I_0, I_1 and I_2. I_0 is the photocurrent, I_1 and I_2 are the currents at gaps d and 2d. The results give current characteristics within 3% of the observed results.

Tholl, H., Z. Phys. 178, 183-8, 1964. (German).
Drift velocities in N_2 were measured for $34 < E/P < 49$ V/cm mmHg, and in CH_4 for $33.5 < E/P < 42$ V/cm mmHg.

Wagner, C. F., IEEE Trans. PAS-83, 931-44, 1964.
The relationship between pre-discharge currents and flashover when lightning strikes overhead lines is considered, and it is shown that the pre-discharge currents can be used to advantage in order to make the line substantially lightning proof.

Wagner, C. F. and Hileman, A. R., Conf. Int. Grands Réseaux Elec. a Haute Tension, (CIGRE) No. 320, 1964.
Pre-discharge currents in parallel pipe electrode gaps are investigated. Current magnitude is approximately proportional to gap, length of lines, and number of elements forming each electrode. The lightning performance of transmission lines can be improved using these properties.

Wagner, C. F. and Hileman, A. R., IEEE Trans. PAS-83, 1236-42, 1964.
Pre-discharge current characteristics of parallel pipe electrode gaps.

Wagner, K. H., Z. Naturforsch. 19a, 716-21, 1964. (German).
The decay of radiation from avalanches stopped in mid-gap was investigated in Ar, N_2 and $N_2 + CH_4$ and found to be exponential and pressure dependent. Lifetimes of the excited states were measured to be 36×10^{-9}sec for N_2, 1.5×10^{-8} and 2×10^{-8}sec for Ar. CH_4 is very effective in quenching radiation in N_2.

Wagner, K. H., Z. Phys. 178, 64-81, 1964. (German).
Spacial and temporal development of avalanches in pulsed discharges in N_2, Ar, Xe and N_2+CH_4 were investigated using image-intensifier and photomultiplier techniques. Drift velocity and mean energy of the electrons is obtained. The mean energy did not change much with E/P in ranges investigated.

B. Spark and Corona Breakdown

Allen, K. R. and Phillips, K., Proc. Roy. Soc. A278, 168-87, 1964.
Using submicrosecond impulses, first visible discharges in a uniform field were observed using high speed streak photography. Filamentary discharges, believed to be streamer discharges, occur with larger electrode spacings, while at smaller spacings a broad diffuse Townsend discharge is observed. Gases studied were air, N_2, O_2, Ar, and H_2.

Allen, K. R. and Phillips, K., Proc. Roy. Soc. A278, 188-213, 1964.
Formative time lags have been measured for Pd values up to 3000 cm mmHg. Evidence is given for the transition from a Townsend to streamer discharge in air and O_2. This transition was not seen in H_2, N_2 or Ar.

Bazelyan, E. M., Zh. Tekh. Fiz. (USSR) 34, 474-83, 1964. (Russian).
Translation: Soviet Physics-Tech. Phys. 9, 370-6, 1964.
The distribution of charge in the initial stages of a long spark is examined by employing a spherical electrode divided into a number of segments. The charge on each segment is recorded as a function of time. It is proposed that the main mass of charge actually moves together with the ionization front leaving behind neutrals or a weakly ionized medium.

Bazelyan, E. M. and Stekolnikov, I. S., Dolk. Akad. Nauk. SSSR 155, 784-7, 1964. (Russian). Translation: Soviet Physics - Doklady 9, 308-11, 1964.
Space charge is introduced into a long air gap (200 cm) by an auxilliary pulse, and the breakdown voltage of the gap is found to increase by as much as 20% over that measured without the space charge.

Bortnik, I. M., Zh. Tekhn. Fiz. (USSR) 34, 1683-7, 1964. (Russian).
Translation: Soviet Physics-Tech. Phys. 9, 1965.
The positive corona discharge in helium was investigated using a coaxial discharge chamber with a central molybdenum wire. The effects of distance of electrodes, field, cathode material, and gas pressure were investigated.

Caruso, A. and Cavaliere, A., Brit. J. Appl. Phys. 15, 1021-9, 1964.
A simplified model for the low pressure discharge is given where the finite mean free path of the neutral atoms for ionization is taken into account. On this basis, the spacial distribution of the potential and particle densities are computed for strong ionization, and two mechanisms leading to the limitation of the current are discussed.

Cizek, R. and Kohoutova, D., Elektrotech. Obzor 53, 380-5, 1964. (Czech.).
Detailed results are given of a two-year investigation on the influence of humidity upon surge flashover voltages of long air distances. Rod-rod and rod-plate spark gaps are used.

Csernátony-Hoffer, A., Schweiz. Tech. Z. (Switzerland) 61, 229-35, 1964. (German).
Experimental breakdown potentials as a function of the geometrical electrode arrangement, the electrode separation, the surrounding gas, and the electrode polarity are presented in graphical form.

Dmitriev, A. V., Zh. Tekhn. Fiz. (USSR) 34, 1504-10, 1964. (Russian).
Translation: Soviet Physics-Tech. Phys. 9, 1163-8, 1965.
The statistical theory for the breakdown of air at atmosphere pressure in a uniform field is examined for the case where a streamer discharge is unlikely to occur. A cathode fall region occurs at local spots near structural defects on the electrode surfaces.

Driver, C., Z. Naturforsch. 19A, 1327-8, 1964. (German).
Observation of electron avalanches with large electrode spacings (15 cm) in room air.

Forman, R., J. Appl. Phys. 35, 261-4, 1964.
Breakdowns in high-pressure thermionic diodes occur at voltages lower than the ionization potential of the gas. This breakdown seems to be associated with the first excitation potential of the gas. Process occurs in a limited pressure range only, and an explanation is put forward on the assumption that electrons traversing the cathode-anode space can pick up almost all the energy of the applied voltage.

Fuller, D. W., Radio and Electronic Engr. 28, 229, 1964.
Statistical and formative time lags in cold cathode tubes.

George, D. W., Proc. IEE 111, 1619-23, 1964.
An unexpectedly high electrical conductivity is observed in inert gases at high pressures above 2000°K. The effects of electrode geometry and supply frequency are examined, and gas pressure is reduced down to high vacuum level. The presence of "seed" impurities from the electrodes is observed.

Gorin, B. N., Zh. Tekhn. Fiz. (USSR) 34, 1511-20, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 1169-76, 1965.
Experiments are described on the neutralization of excess space charge around a corona electrode when the voltage is reduced. This neutralization, or reverse corona, is most appreciable when the voltage cutoff is negative and high overvoltages are applied; then up to 80% of charge is neutralized.

Hara, J., Nitta, T., Kawane, K., and Yamada, N., Mitsubishi Denki Lab. Rep. (Japan) 5, 189-205, 1964.
Breakdown of air in non-uniform fields with step function voltages is examined. Non-uniformity is produced by a hemispherical projection on one electrode of a plane-parallel gap. A reduced breakdown voltage is observed with projection on anode for all gaps. With projection on cathode, breakdown voltage approaches that for uniform field at long gaps. Current pulses are also studied.

Heylen, A. E. D., Nature 203, 745, 1964.
The propagation of a gaseous discharge over a surface in a crossed magnetic field is considered, taking into account secondary ionization processes at the cathode due to incident positive ions. It is concluded that the velocity should be somewhere intermediate between the electron velocity component along the surface and the positive ion velocity component along the surface.

Ieda, M., Sawa, G., and Shinohara, U., Japan. J. Appl. Phys. 2, 813-4, 1963.
Negative point-plane corona is investigated with an insulating film on the plane. This film disturbs the negative space charge.

Kher, G. V. and Ayachit, V. G., Physica. 30, 702-12, 1964.
The starting voltage for an ac discharge in air at pressures around the Paschen minimum increases to about 2.6 times the dc value as the frequency is increased from 20 to 20,000 c/s. The results are explained in terms of the statistical time lag.

Klyarfel'd, B. N., *Investigations into Electrical Discharges in Gases*, Oxford: Pergamon Press, 1964.
Contains twelve original papers by Russian scientists. The first six deal with the breakdown of gases in certain practical conditions, the spread of a discharge plasma, and discharge after-effects. The last six are concerned with various aspects of mercury ac rectifiers and devices.

Köhrmann, W., Z. Naturforsch. 19a, 245-53, 1964. (German).
The growth of current in a Townsend discharge in the presence of space charge is calculated by elimination of the space coordinate from a series of simultaneous equations. The method allows a variety of boundary conditions to be applied.

Köhrmann, W., Z. Naturforsch. 19a, 926-33, 1964. (German).
The current-time characteristic for a Townsend discharge in H_2 is calculated, taking space charge into account. Usual primary and secondary processes are considered.

Kostin, V. N. and Tkachenko, V. M., Zh. Tekhn. Fiz. (USSR) 34, 883-7, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 680-3, 1964.
The influence of a uniform magnetic field on a stationary corona discharge

is examined using a probe. The velocity of the particles moving in the direction of the electric field is slightly reduced by the action of the magnetic field.

Kostin, V. N. and Tkachenko, V. M., Zh. Tekhn. Fiz. (USSR) 34, 1252-8, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 968-72, 1965.
The effect of a magnetic field on the volt-ampere characteristic of unipolar corona discharges between coaxial cylindrical electrodes is studied for pressures between 1 and 70 mmHg in H_2, Ar, and air. Onset voltage, current and ion mobility are evaluated as a function of magnetic field strength.

Kravchenko, V. D., Levitov, V. I., and Popkov, V. I., Elektrichestvo (USSR) No. 5, 7-12, 1964. (Russian).
Describes investigation of corona on loaded 400-500 kv lines in operating conditions. Mean corona power loss was found to increase from 1 kw/km in good weather to 10 kw/km in bad weather.

Krisch, H., Z. Naturforsch. 19a, 1136-7, 1964. (German)
A fast and slow component of current in an argon discharge is observed. The fast is associated with secondary electrons, the slow appears to be due to the release of secondary electrons by the decay of metastables.

Krisch, H., Z. Phys. 178, 354-64, 1964. (German).
The influence of metastable atoms in the static breakdown of argon is examined. At static breakdown, 25% of the secondary coefficient, is due to metastables. The mean life-time of the metastables at 1.1 mmHg and an electrode spacing of 1 cm is 2.2 m sec which is mainly due to de-exciting collisions at the electrodes.

Legler, W., Z. Naturforsch. 19a, 481-3, 1964. (German).
The distribution function for the carrier numbers of series of electron avalanches is calculated which is valid for the case where the avalanche distribution function is given by $V(n) = (1/\bar{n}) \exp(-n/\bar{n})$. The influence of electron attachment is also investigated.

Lemke, E., Wiss. Z. Tech. Univ. Dresden 12, 1893-9, 1963. (German).
Presents the calculations of the impulse characteristics of non-uniform field spark gaps using 1/50 µs positive impulses.

Maddison, R. C., Gozna, C. F., and Davies, D., Nuovo Cimento (Suppliment) 1, 742, 1964.
The effects of cathode material and surface nature on the work functions and sparking potentials in hydrogen are reported.

Mesyats, G. A., Usov, Yu. P., and Korshunov, G. S., Radiotekhn. i Elektron. (original reference not given) 1964. (Russian). Translation: Radio Eng. Electron. (USSR) No. 5, 717-21, 1964.
A procedure for investigating time lags in air using nanosecond pulses is discussed. The effect of intensity and duration of light for pulses of rise time 1 nsec is investigated. For higher intensities the statistical lag is reduced to zero and the formative lag is measured directly. Gap length, pressure and electrode material are varied.

Miller, H. C., J. Appl. Phys. 35, 1745-8, 1964.
The effectiveness of cataphoretic purification of Ne was investigated in conjunction with work on breakdown potentials in Ne below the Pashen minimum. Making use of the Penning effect for Ar in Ne, it was possible to detect argon concentrations as low as $1:10^7$.

Miller, H. C., Physica 30, 2059-67, 1964.
The breakdown potential of Ne has been measured for $0.2 < pd < 15$ cm mmHg, with gap lengths from 0.75 to 34.6 mm.

Minck, R. W., J. Appl. Phys. 35, 252-4, 1964.
Electrical discharges in air have been initiated by focusing a beam from a Q-spoiled ruby laser. The spark is initiated at the focus but quickly grows to a volume several mm in length and 1 mm in diameter. The maximum power density carried through the air is found to be 7×10^{11} W/cm^2 as long as the electron mean free path is small compared to the beam diameter.

Nelson, P., Veyrie, P., Berry, M., and Durand, Y., Physics Letters 13, 226-8, 1964.
The breakdown of air by the action of a focused laser beam is examined experimentally and theoretically. It is believed that breakdown is due to a multiphotoelectric process followed by a multiphoton inverse bremsstrahlung effect.

Nesterikhin, Yu. E., Komel'kov, B. S., and Meilikhov, E. Z., Zh. Tekhn. Fiz. (USSR) 34, 40-52, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 29-39, 1964.
Time lags were measured in gases with uniform and non-uniform fields for various pressures and gap lengths. Very short rise-time pulses were employed. The time lag increased with gap width and decreased with increasing ratio of field to gas pressure.

Obenaus, F. and Zimmermann, W., Conf. Internat. Grands Reseaux Elect. (CIGRE) Paper 302, 1964.
All breakdowns of point-plate spark gaps with gaps of several meters, and all flashovers on insulators in air at very high voltages are preceded by spark-type predischarges. These are examined.

Pennell, P. M., Conf. on Dielectric and Insulating Materials IEE (London), 1964.
The dielectric strength of mixtures of N_2 and SF_6 between concentric cylinders was measured for total gas pressures up to 17 atmospheres. Electrode material was important, and the addition of SF_6 to N_2 resulted in a marked increase of strength.

Penney, G. W., Nygren, S. F., and Voshall, R. E., IEEE Trans. 83, 203-8, 1964.
Photoionization as a secondary mechanism in a Townsend discharge is examined, and it is concluded that photoionization is a plausible mechanism for breakdown of gaps of the order of 1 cm at atmospheric pressure. For overvoltages, photoionization is greatly increased and can account for very rapid breakdown.

Perry, F. R., Internat. J. Elec. Engr. Educ. 1, 425-43, 1964.
Brief account of Townsend and Streamer theories of breakdown is given. Effects of parameters such as humidity, polarity of voltage, electrode geometry, irradiation, and proximity of nearby objects are considered in detail.

Raether, H., *Electron Avalanches and Breakdown in Gases*, Butterworth, Washington, 1964.
This book gives an excellent survey of the experimental and theoretical work on single avalanches in gases, and describes also the relationship between the development of these avalanches and breakdown. For a fuller discussion of the content of this book, see the introduction to this chapter.

Rakoshdas, B., IEEE Trans. **PAS-83**, 483-91, 1964.
The corona current pulse and radio-influence voltage characteristics of smooth and stranded transmission lines are determined in terms of polarity and conductor size for high dc stresses. Corona pulse shape, amplitude, energy, and repetition rate were determined.

Richter, K., Z. Phys. **180**, 489-515, 1964. (German).
A study of avalanches with number of carriers between 10^6 and 10^8 shows space charge effects in reducing the ionizing power of the electrons. Electron energy and electrostatic repulsion are also discussed. Above 10^8 carriers, the average ionization increases rapidly.

Ryzko, H., Arkiv Fysik **25**, 481-507, 1964.
The transition from avalanche to streamer breakdown has been investigated for uniform fields without irradiation. Statistical lag is eliminated by using light emission from the avalanche to trigger the oscilloscope, which gives formative lag; while the statistical lag itself can be measured on a second scope. At pd = 600 cm mmHg the transition was investigated in humid air and found to occur at a lower overvoltage than in dry air.

Schreier, S., IEEE Trans. **PAS-83**, 468-71, 1964.
The dielectric strengths of five Freon gases and SF_6 were determined at low pressures between parallel plates in order to determine the Paschen minimum. The advantages of these gases at atmospheric pressure and above are not maintained at low pressures.

Schwab, A., Z. Angew. Phys. **17**, 52-3, 1964. (German).
Secondary electrons in a corona discharge from a pointed cathode are produced by photons and positive ions. Contrary to the usual assumption that at low pressure positive ions and at high pressure photons are dominant it was found that the proportion of each mechanism was not influenced by pressure changes between 50 and 740 mmHg.

Sharbaugh, A. H. and Watson, P. K., IEEE Trans. **PAS-83**, 131-6, 1964.
The breakdown strength of perfluorocarbon vapor (FC-75) and mixtures of the vapor with SF_6 is given for the pressure range 40-5700 mmHg at 180°C with gaps up to 25 mil. The effects of UV radiation was also investigated. It was found that this radiation reduced the mean strength at room temperature but was not effective at 180°C.

Stekolnikov, I. S., Priroda-Moscow, No. 5, 40, 1964. (Russian).
The nature of a long electric spark. (No abstract available).

Tholl, H., Z. Naturforsch. **19a**, 346-53, 1964. (German).
The development of electron avalanches in N_2 is investigated with pulsed

uniform fields. The influence of positive ion space charge on the development of the discharge current is demonstrated. Streamers are formed at high overvoltages (> 20%). In the region of 17% overvoltage both streamer and generation mechanisms occur simultaneously.

Tholl, H., Z. Naturforsch. 19a, 704-15, 1964. (German).
The transition of electron avalanches into cathode- and anode-directed streamers was investigated with pulsed fields in N_2. Velocities of both streamers were measured.

Timascheff, A. S., IEEE Trans. PAS-83, 492-5, 1964.
The large corona loss from power lines during snow storms is attributed to change in the dielectric constant of the atmosphere. Calculations show that during heavy snowfall the surface potential may increase by as much as 20%.

Usov, Yu. P., Izv. Vysshikh Uchebn. Zavedenii-Fiz., Jan.-Feb., 81, 1964. (Russian).
The paper is concerned with the delay to breakdown of a non-irradiated spark gap at high overvoltages. (No abstract available).

Wagner, K. H., Z. Phys. 180, 516-22, 1964. (German).
The local and temporal development of electron avalanches in a homogeneous field into the weakly ionized streamer channels is investigated by the simultaneous application of image intensifier and image converter streak shutter techniques. Velocity of anode directed streamers was several 10^7 cm/sec, while that of cathode directed streamers was about 10^8 cm/sec.

Waidmann, G., Z. Phys. 179, 102-10, 1964.
Positive and negative streamer lengths were measured in point-to-plane impulse corona in air at atmospheric pressure. The streamer tip velocity was measured using impulse voltages. Velocities of $\sim 10^8$ cm/sec were found.

Waters, R. T. and Jones, R. E., Phil. Trans. Roy. Soc. A256, 185-234, 1964.
The impulse breakdown voltage and time-lag characteristics of long gaps in air are discussed for both the positive and the negative discharge. Rod-rod, rod-sphere, and rod-plane gaps were employed at atmospheric pressure.

Wright, J. K., Proc. Roy. Soc. A280, 23-36, 1964.
A theory for the propagation of positive impulse corona is presented assuming photoionization and impact ionization in the high fields near the corona filament tip. Reasonable agreement is obtained with experiment. Propagation velocity, electron density, and filament radii are computed in terms of fundamental cross-sections.

Wright, J. K., Proc. Phys. Soc. 84, 41-6, 1964.
The theory of gas breakdown by focused radiation from a laser is presented, assuming that an electron acquires energy from the radiation field by inverse bremsstrahlung absorption.

C. Glow Discharge and High Frequency Breakdown

Adamov, I. Yu., Dushin, L. A., Konoenko, V. I., and Pavlichenko, O. W., Atomnaya Energiya (USSR) 16, 99-103, 1964. (Russian).
Describes experiments and results of microwave radiation from a discharge in a system without electrodes. The microwave radiation is correlated with X-ray radiation. The X-rays confirm the presence of high energy electrons.

Banège-Nia, A., Basquin, F., and Morand, G., Compt. Rend. 258, 4521-4, 1964. (French).
Voltage-current characteristics have been measured for luminous discharges in air at 13 mmHg between a nickel cathode and the surface of a solution of HCl or H_2SO_4. A Paschen minimum was observed at 15 mmHg cm and V = 340 v.

Banège-Nia, A., Kaspar, D., and Morand, G., Compt. Rend. 258, 4726-9, 1964. (French).
Potential and charge distributions in a luminous discharge in air between a metallic cathode and a solution of HCl are described. Results are given for gap lengths between 2 and 7 mm.

Barber, P. B., Looms, J. S. T., Swift, D. A., and Tozer, B. A., Plasma Phys-Accelerators-Thermonuclear Res. (GB) 6, 29-38, 1964.
The discharge between coaxial electrodes in N_2, at pressures between 4 and 4×10^{-3} mmHg, was found to always develop initially in one or more radial columns and never in a continuous ring. Peak currents were 10-60 ka.

Barber, P. B., Looms, J. S. T., Swift, D. A., and Tozer, B. A., Brit. J. Appl. Phys. 15, 665-72, 1964.
The spread of an impulsive discharge in the region between short coaxial electrodes is described using currents of 20 ka peak and of 20 μsec period. Air and N_2 were used at pressures between 0.1 and 4 mmHg.

Bletzinger, P. and Garscadden, A., J. Electron. Control 16, 169-73, 1964.
Presents the method and some results of image converter measurements on striations in a neon hot-cathode discharge. The structure of the striations and the importance of metastable atoms are indicate.

Bochkova, O. P. and Razumovskaya, L. P., Optika i Spektroskopiya 17, 16-23, 1964. (Russian). Translation: Optics and Spectroscopy 17, 8-11, 1964.
The transition region from "weak" to "strong" hf discharges in He, Ne and Ar was studied spectroscopically. Frequency of 6 Mc was employed.

Borisov, M., Stainov, G., and Martinov, N., Compt. Rend. Acad. Bulgare Sci. 17, 9-12, 1964. (Russian).
Describes experiments used to verify current theories of plasma oscillations in the cathode region of a glow discharge. Results are presented for current as a function of frequency over a range of pressures. Al, Cu and Fe cathodes were used in He and Ne.

Bulkin, P. S., Ponomarev, V. N., and Solntsev, G. S., Zh. Tekhn. Fiz. (USSR) 33, 1222-6, 1963. (Russian). Translation: Soviet Physics-Tech. Phys. 8, 911-14, 1964.
The SHF discharge in H_2 formed in a tube which is coaxial with the wave guide

at 9470 Mc shows two states - the normal and the anomalous. The normal is developed simultaneously along the entire length of the tube. The anomalous discharge propagates at 10^7- 10^8cm/sec as it forms in the direction of the SHF wave. Very high electron concentrations are indicated.

Chiplonkar, V. T. and Joshi, S. N., Physica 30, 1746-56, 1964.
The radial distribution of positive ions on the cathode surface of a cold cathode glow discharge in H_2 was determined over a wide range of discharge parameters. (5×10^{-1} - 3×10^{-2} mmHg, 0.5 - 6 mA). For high pressures the distribution is flat, edge effects becoming important at lower pressures. For low pressures the distribution is Gaussian.

Deb, S. and Goswami, S. N., Brit. J. Appl. Phys. 15, 1501-10, 1964.
Describes the theory of electrical breakdown in a high-frequency electrodeless discharge at low pressure in a steady transverse magnetic field.

Demirkhanov, R. A., Kadish, I. Yu., and Khodyrev, Yu. S., Zh. Eksperim. i Teor. Fiz. (USSR) 46, 1169-77, 1964. (Russian). Translation: Soviet Physics-JETP 19, 791-6, 1964.
The skin effect in a stationary high frequency discharge was studied at frequencies of 0.9, 4.6, and 5.6 Mc. It was shown that the character of penetration of the field in the plasma depends on the relationship between field frequency and electron mean free path. Near the axis of the discharge an anomalous increase of field occurs as it penetrates the plasma.

Dmitriev, A. V., Zh. Tekhn. Fiz. (USSR) 34, 1494-1503, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 1155-62, 1965.
The glow discharge between electrodes covered by one or two dielectric layers is investigated. The current is greatly reduced by the layers. Secondary processes on the dielectric surface result from the cathode fall region, but other emission mechanisms are present. Electron avalanches occur in the cathode fall region, where the field is almost equal to the breakdown value between conducting electrodes.

Dunbar, A. S., J. Appl. Phys. 35, 3047-8, 1964.
The pulsed power breakdown of air at 3.2 cm wavelength in rectangular wave guides between 1 and 10^{-3} mmHg pressure is investigated.

Dyson, J., Williams, R. V., and Young, K. M., Plasma Phys-Accelerators-Thermonuclear Res. 6, 105-22, 1964.
The electron density in a high-current discharge was measured using an optical interferometric method. Mean densities of the order of 10^{14} cm^{-3}were measured.

Emeleus, K. G. and Ahmad, N., Nature 201, 485, 1964.
The spectral emission from the negative end of the positive space charge of the cathode dark space was observed in N_2, P, As, Se, and I vapor in a spiral cathode glow discharge tube. In all cases, there was a preferential development of the spectra of the neutral atom of the particular gas species, suggesting some neutralization process at the cathode surface.

Fishkova, T. Ya., Shpak, E. V., and Yavor, S. Ya., Zh. Tekhn. Fiz. (USSR) 34, 53-9, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 40-44, 1964.
The loss of charged particles across a magnetic field from a discharge with reflected electrons is studied. The degree of ionization of the plasma on the axis was > 50% for argon at pressures from 5×10^{-4} to 1×10^{-3} mmHg. The electron current to the anode and ion current to the wall probe were measured with various magnetic field strengths.

Gilden, M. and Pergola, J., IEEE Trans. MTT-12, 26-33, 1964.
Microwave breakdown near a hot surface in a wave guide system was studied to determine its dependence upon the thickness of the adjacent film of hot gas and its associated temperatures. Although the breakdown threshold of the wave guide system is lowered by the hot surface, a sufficiently rapid flow of the bulk gas tends to restore the threshold due to a reduction in the hot gas film thickness.

Golant, V. E., Krivosheev, M. V., and Privalov, V. E., Zh. Tekhn. Fiz. (USSR) 34, 953-60, 1964. (Russian). Translation: Soviet-Physics-Tech. Phys. 9, 737-43, 1964.
The discharge with a heated cathode in a uniform magnetic field up to 2500 Oe was investigated in the pressure range 3×10^{-3} to 1 mmHg. With discharge current densities of about $50A/cm^2$, a pressure of 0.1 mmHg in argon, and a magnetic field of 2500 Oe, a charged particle density of 10^{15} cm^{-3} was obtained in the plasma.

Gold, L., Nature 203, 855, 1964.
The basic elements of a theory of stationary striations are set out.

Hantzsche, E., Beitr. Plasma Physik. 4, 165-208, 1964. (German).
A one-dimensional theory for the cathode fall region of the glow discharge is developed, based on Boltzmann equations for electrons, ions, and neutral molecules, and on simple empirical relationships for collision cross-sections and secondary coefficients. Numerical solution is given for two particular cases.

Hirsch, E. H., Brit. J. Appl. Phys. 15, 1535-44, 1964.
It is confirmed that the Penning discharge in its normal mode is governed by a thin electron sheath, situated close to the anode. Electron transport to the anode does not involve molecular collisions.

Imazu, S., Uesaka, Y., Sukegawa, T., and Nakano, Y., J. Phys. Soc. Japan 19, 418, 1964.
Measured characteristics of E vs B curve hysteresis in the positive column in a magnetic field show such hysteresis effects near the critical magnetic field above which the positive column becomes unstable. Typical curves for increasing and decreasing B are shown.

Kagan, Yu. M. and Lyagushchenko, R. I., Zh. Tekhn. Fiz. (USSR) 34, 821-7, 1964. (Russian). Translation: Soviet-Physics: Tech. Phys. 9, 627-32, 1964.
The energy distribution function for electrons in the positive column is examined, taking into account inter-electronic interactions, elastic collisions with atoms, and inelastic collisions. Particular cases for Ne and Ar are discussed.

Kagan, Yu. M. and Lyaguschenko, R. I., Zh. Tekhn. Fiz. (USSR) 34, 1873, 1964. (Russian).
On the radial properties and contraction of a positive discharge column in noble gases at intermediate pressures.

Kaganskii, M. G., Kaminskii, D. L., and Klyucharev, A. N., Zh. Tekhn. Fiz. (USSR) 34, 1050-6, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 815-20, 1964.
Two regimes of operation are distinguished in the high frequency Penning discharge with a cold cathode. At pressures of 10^{-4} mmHg and below, there is a weak form of discharge with a current density less than $1A/cm^2$. Increasing pressure to 10^{-3} mmHg results in a sharp transition to an intense discharge with current densities of several $amps/cm^2$. Regular oscillations of current are observed.

Kreindel, Yu. E. and Ionov, A. S., Zh. Tekhn. Fiz. 34, 1199-1205, 1964. Translation: Soviet Physics: Tech. Phys. 9, 930-4, 1965.
Some characteristic features of low-pressure discharges in Penning tubes are discussed. The behavior of the ion and electron components of the output beam was studied in varying magnetic fields.

Labuda, E. F. and Gordon, E. I., J. Appl. Phys. 35, 1647-8, 1964.
The electron density in the positive column of a dc excited He-Ne discharge is a linear function of the discharge current, but the average electron energy is independent of the current in the range 5-100 mA. A microwave technique is used for the measurements.

Lakatos, G. and Bito, J., Acta.Phys. Acad. Sci. Hung. 16, 327-32, 1964.
Using probe techniques, the cathode fall in ac low pressure mercury vapor discharge tubes is examined, with oxide cathodes. Dimensions of cathode fall and cathode dark space are calculated.

Lakatos, G. and Bito, J., Acta. Phys. Acad. Sci. Hung. 17, 271, 1964.
The processes involved in the moving striations in a low pressure discharge are investigated as a function of temperature.

Lustig, C. D., Phys. Letters 9, 315-17, 1964.
Resonances were detected in the noise spectrum of a dc discharge in Kr and Xe at pressures of a few microns. Electron temperature was 3.5 eV. The resonances agreed with that expected from the Tonks-Dattner theory.

Lustig, C. D., Appl. Phys. Letters 4, 194-6, 1964.
Noise resonances in the micro-wave emission spectra of discharges in rare gases in the range 2-4 Gc have been observed. Frequency of this noise is sensitive to tube geometry, but amplitude is sensitive to changes in electron density and to a weak magnetic field. Origin of noise spectrum is not known.

Müller, K. G. and Tenschert, G., Z. Phys. 178, 319-34, 1964. (German).
The radial distribution of current density is computed on a two-dimensional theory of the glow discharge. This allows for radial diffusion. The difference between the normal and minimal cathode fall is explained on this theory.

Muly, E. C. and Frerichs, R., Proc. IEEE 52, 202, 1964.
Describes investigations using microwaves and Langmuir probes of a hollow cathode discharge in a copper cavity with two external anodes. The tube possesses two sustaining voltages for identical tube currents and also exhibits a region of high negative resistance.

Nakata, J., Takenaka, E., and Masutani, T., J. Phys. Soc. Japan 19, 143-4 1964.
The wave length and frequency of moving striations in a low pressure argon-mercury discharge are found to be inversely proportional. This is contrary to many earlier experiments, but no theory is presented.

Paik, S. F., Shapiro, J. N., and Gilbert, K. D., J. Appl. Phys. 35, 2573-7, 1964.
Using a pulsed microwave technique the properties of a moving striation in the positive column of a glow discharge are investigated. The is a large degree of variation of both electron temperature and density within one cycle of the striation.

Paik, S. F. and Gilbert, K. D., IEEE Trans. NS-11, 232-6, 1964.
The variations of charge density in the positive column of a dc discharge due to moving striations is investigated using a microwave method. Some results are presented which are contrary to previous observations of the striations.

Pfau, S. and Rutscher, A., Beitr. Plasma Physik 4, 11-20, 1964. (German).
The dependence of the characteristics of moving striations on percentage composition of Ne-H_2 mixtures was studied for discharges at low currents and at a pressure of 1.8 mmHg. As little as $10^{-2}\%$ H_2 caused a change in the striations while at ~10% H_2 a damping occurred giving a homogeneous column. For higher H_2 concentrations negative moving and undamped stationary striations appeared in addition to this column.

Rugge, H. F. and Pyle, R. V., Phys. Fluids 7, 754-9, 1964.
The instability of the ac positive column in a magnetic field is studied experimentally in H_2, D_2, He, Ne, and Ar at frequencies up to 70 kc using dc and half-wave rectified - current discharges and in square and sinusoidal ac glow discharges. The instability in the ac discharges was suppressed by increasing the frequency.

Rutscher, A. and Wojaczek, W., Beitr. Plasma Physik 4, 42-59, 1964. (German).
The available data on the limiting conditions of current, pressure and tube diameter is collected and interrelated in order that self excited running striations should be avoided. Discharges in noble gases, metal vapors, molecular gases,and gas mixtures are each considered.

Ryutov, D. D., Zh. Eksp. Teor. Fiz. 47, 2194-207, 1964. (Russian).
Theory of breakdown of noble gases at optical frequencies.

Severn, P. J., J. Electron. Control 16, 381-91, 1964.
The radio frequency impedence of a gas discharge is derived. This is particularly of interest in the study of the ionic properties of the cathode fall region. It is shown that the modulated electron current, the ac component of the ion density times dc velocity current, and the vacuum displacement current are the pertinent currents flowing in this frequency region.

Sicha, M., Vesely, V., Novak, J., and Pekarek, L., Czech. J. Phys. B14, 247-55, 1964. (German).
The relaxation time of the electron temperature in the positive column of an electric discharge is evaluated.

Sicha, M., Vesely, V., Studnicka, J., and Prostejovsky, J., Brit. J. Appl. Phys. 15, 199-201, 1964.
The propagation of moving striations in the positive column of a glow discharge in Ne has been examined, and the results are in agreement with the hypothesis that the moving striations propagate towards the anode. For self-excitation feedback through the external circuit is essential.

Silberg, P. A., J. Appl. Phys. 68, 2264-6, 1964.
A standing-wave discharge was formed in air around a Lecher wire shorted to half wavelength. A 105 Mc supply was used. The discharge did not show any sphericity and the phenomenon of ball lightning was not reproduced.

Sturges, D. J. and Oskam, H. J., J. Appl. Phys. 35, 2887-94, 1964.
The anode fall region of a hollow cathode discharge in He and Ne was eliminated using two cathode plates and a movable anode. The transition from plane cathode to hollow cathode discharge is found to be a smooth function of cathode plate separation. Other properties are also measured and discussed.

Subertova, S. and Karcik, J., Czech. J. Phys. B14, 72-3, 1964. (German).
Low frequency sound (2.7 kc/sec) was established in a glow discharge tube at pressures between 0.1 and 1 mmHg. By increasing pressure to 5 mmHg, the sound amplitude was reduced to a very small level.

Tikoo, P. K., Phys. Letters 10, 165, 1964.
The proximity of the walls of the containing tube to an ac discharge in iodine vapor at 0.47 mmHg exerts a marked influence on the sign and magnitude of the Joshi effect, the current varying almost instantaneously when the tube is illuminated externally. This effect is absent with large diameter tubes.

Vorobeva, N. A., Kagan, Yu. M., and Milenin, V. M., Zh. Tekhn. Fiz. (USSR) 34, 828-32, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 632-4, 1964.
The velocity distribution function for electrons in the positive column of a discharge in mixtures of Hg vapor with Ne, Ar, He, and Xe is investigated. At low pressures, the distribution is Maxwellian but deviations occur at higher pressures.

Young, R. A., Sharpless, R. L., and Stringham, R., J. Chem. Phys. 40, 117-19, 1964.
The density of atomic nitrogen produced from very pure nitrogen in a microwave discharge was increased from 2×10^{13} cm^{-3} to 1.2×10^{15} cm^{-3} by the addition of $\sim 5 \times 10^{12}$ cm^{-3} of SF_6 molecules to the gas before the discharge. Much larger amounts of nitric oxide or oxygen are needed to produce the same effect.

Zager, B. A. and Tishin, V. G., Zh. Tekhn. Fiz. (USSR) 34, 297-306, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 234-41, 1964.
The mechanism of a high frequency resonance discharge and the effect of a

constant displacement voltage on the conditions for its excitation are described. Means of suppressing the discharge are considered.

D. Post-breakdown Studies

Court, G. R. and Sayers, J., Brit. J. Appl. Phys. 15, 923-7, 1964.
By measurement in the afterglow of a helium + approximately 1% NH_3 mixture, the electron-ion recombination coefficient for NH_3^+ was obtained over a range of electron temperatures between 1000°K and 2600°K. This coefficient was $(9.4 \pm 0.5) \times 10^{-7} cm^3 sec^{-1}$ at 2150°K. The coefficient did not depend on total or ammonia pressure.

Court, G. R. and Sayers, J., J. Sci. Instr. 41, 462-4, 1964.
Probe measurements of electron temperatures in afterglows are influenced by the variation of plasma potential with probe current. By using a heated tungsten filament as an electron source in the afterglow, it was found that reliable measurements could be made. The electron source maintained the afterglow electron temperature at a value close to the source temperature. By varying source temperature and gas pressure, afterglow electron temperatures have been obtained in NH_3-He mixtures.

Collins, C. G. and Robertson, W. W., J. Chem. Phys. 40, 2202-8, 1964.
Spectroscopic investigation of a flowing helium afterglow revealed the presence of strong lines of neutral helium. Observations were made at times from 50-250 μsec into the afterglow. The diffusion half-life for He^+ was about 100 μsec, the ion density $5 \times 10^{12} cm^{-3}$ and the maximum electron temperature about 0.15 eV.

Collins, C. B. and Robertson, W. W., J. Chem. Phys. 40, 2208-11, 1964.
Strong bands of He_2 were observed spectroscopically in a flowing helium afterglow. The dominant reaction populating the excited molecular states is the collisional-radiative recombination of He_2^+.

Dawson, P. H. and Tickner, A. W., Brit. J. Appl. Phys. 15, 1597, 1964.
It is suggested that the ion-electron recombination coefficient reported by Court and Sayers (Brit. J. Appl. Phys. 15, 923, 1964) may be the ion NH_4^+ rather than NH_3^+.

Hackam, R. and Lennon, J. J., Proc. Phys. Soc. 84, 133-9, 1964.
An X-band (3 cm) microwave cavity method has been used to measure the electron loss rate in the afterglow of a pulsed discharge in helium. Positive ion mobility, from ambipolar diffusion coefficient, was found to be 16.7 ± 0.5 cm^2/v sec within the pressure range 4-83 mmHg. Ion is assumed to be He_2^+. At lower pressures He^+ appears with mobility 10.6 cm^2/V sec.

Johnson, P. D., Rautenberg, T. H., and Harris, B., J. Appl. Phys. 35, 1128-30, 1964.
The afterglow following pulsed dc excitation of neon can be explained by the requirement that the electron temperature must decrease before electron-ion recombination followed by radiative transitions can occur. This is supported by the suppression of the afterglow by simultaneously applied r.f. power.

Niles, F. E. and Robertson, W. W., J. Chem. Phys. 40, 2909-14, 1964.
During the early afterglow of a dc pulsed helium discharge at pressures between 5 and 30 mmHg, the spectral emission was predominantly molecular light due to collision-radiative recombination. The ambipolar diffusion coefficient was 710 ± 10 cm^2/sec, corresponding to a mobility of 16.4 ± 0.2 cm^2/V sec.

Niles, F. E. and Robertson, W. W., J. Chem. Phys. 40, 3568-71, 1964.
Spectral emission from the afterglow of a pulsed dc discharge in He for pressures between 5 and 20 mmHg is examined. Atomic and molecular bands are present. The rate of conversion of He^+ to $He_2{}^+$ is found to be 109 ± 6 sec^{-1} $mmHg^{-2}$

Niles, F. E. and Robertson, W. W., J. Chem. Phys. 41, 1523-4, 1964.
Spacial distribution of intensity and thus of ion concentration in a cylindrical discharge cell was measured. The emission is attributed to a volume process in the afterglow or the helium discharge and not the result of radiative processes from neutralization at the wall.

Oskam, H. J. and Mittelstadt, V. R., Physica 30, 2021-30, 1964.
From a study of the afterglow in H_2, a mobility of 13.3 ± 0.5 cm^2/V sec was calculated from the ambipolar diffusion coefficient. This is believed to be due to $H_3{}^+$ ions moving in molecular H_2. With long plasma excitation, a mobility of 16.4 cm^2/V sec is observed, attributed to H^+ ions moving in a mixture of atomic and molecular hydrogen.

Prince, J. F., Collins, C. B., and Robertson, W. W., J. Chem. Phys. 40, 2619-26, 1964.
The excitation of electronic spectra of gases by inelastic collisions with energetic species in an argon afterglow is investigated. The observed states of excitation as well as the conditions of the discharge indicate that the exciting species are the argon metastables $^3P_2$and $^3P_0$. Fourteen different gases were employed.

Rogers, W. A. and Biondi, M. A., Phys. Rev. 134, A1215-25, 1964.
The nature of the electron-ion recombination process in low-pressure, pure helium afterglows at 300°K and 77°K was investigated. It is believed that He^+ ions and electrons are created by the collisions of pairs of He metastables. The three-body conversion of He^+ ions to $He_2{}^+$ ions, the ambipolar diffusion of He^+, $He_2{}^+$ and electrons, and the diffusion of metastables to the walls are also believed to be important. Dissociative recombination is believed to account for afterglow line broadening.

Young, R. A., Sharpless, R. L., and Stringham, R., J. Chem. Phys. 40, 251-2, 1964.
EPR techniques indicate that less than 10% of the total atom concentration in the pink afterglow of nitrogen exist in the form N (^6S).

E. Lightning Discharges

Bruce, C. E. R., Nature 202, 996, 1964.
The large, stable diameter of ball lightning is explained in terms of the escape of a jet of hot gas from points of bending in the lightning channel.

The field deficiency on the outside of a bend in the main channel will permit the ejection of charged gas as the return stroke retraces the leader. This gas could form a ring or a ball since it moves across a magnetic field.

Fleagle, R. G. and Businger, J. A., An Introduction to Atmospheric Physics, New York and London; Academic Press, 1963.
Chapter 3 contains a discussion of the generation of charge in clouds and the lightning discharge.

Finkelstein, D. and Rubinstein, J., Phys. Rev. 135, A390-95, 1964.
A discussion of the plasmoid theory of ball lightning is given and it is concluded that this model is not possible. A new model is examined in which the high dc fields associated with lightning storms are invoked as energy source. The model is thus a low current glow discharge in an atmospheric dc field.

Gorin, B. N. and Stekol'nikov, I. S., Dokl. Akad. Nauk. SSSR 158, 324, 1964. (Russian).
Recurrent charges and their application to lightning.

Hill, R. D., J. Geophys. Res. 68, 6261-6, 1963.
A search for high-energy electrons and radioactivity from lightning showed no effects.

Malan, D. J., Physics of Lightning, London, English Universities Press, 1963.
This book contains a discussion of various types of thunderclouds and lightning discharge. The earth discharge is examined in detail. Charge generation is also discussed, as are the optical spectrum and frictional static charges.

Meinel, A. B. and Salanave, L. E., J. Atmos. Sci. 21, 157-60, 1964.
Measurement of the strength of N_2^+ bands in a lightning discharge shows that errors due to the method of observation have occurred. It is believed that the molecular emission occurs at some distance from the stroke, probably in terminal streamers inside the cloud.

Salanave, L. E., Advances in Geophysics 10, 83, 1964.
Article entitled "The Optical Spectrum of Lightning."

Uman, M. A., J. Atmos. Terrest. Phys. 26, 123-8, 1964.
The peak temperature of a lightning stroke is shown to be less than 10% greater than the average value deduced on an assumption of constant temperature during the time of the stroke.

Uman, M. A., J. Atmos. Terrest. Phys. 26, 1215, 1964.
The conductivity of lightning is examined.

Uman, M. A., Orville, R. E., and Salanave, L. E., J. Atmos. Sci. 21, 306-10, 1964.
The density, pressure, and particle distribution in the lightning stroke near the peak temperature is given. The electron density is about 4.8×10^{18} cm^{-3}, and at 24,000°K the mass density of the stroke is 0.1 of the mass density of air at STP.

Uman, M. A., Salanave, L. E., and Orville, R. E., J. Geophys. Res. 69, 5423, 1964.
The mass density, pressure, and electron density in three lightning strokes near peak temperature is determined.

Uman, M. A. and Orville, R. E., J. Geophys. Res. 69, 5151-54, 1964.
Electron densities between 10^{17} and $0.5 \cdot 10^{18}$ cm^{-3} are found by comparing stark-broadened H α lines with theoretical line profiles for three lightning strokes.

Wallace, L., Astrophys. J. 139, 994-8, 1964.
A re-examination of the lightning spectrum in the region 3150-9800 Å has revealed that some of the lines of OI and NI are Stark-broadened. Also unidentified absorption features have been observed in the interval 6100-6280 A.

F. Vacuum Breakdown

Akishin, A. I. and Doktorov, Yu. A., Zh. Tekhn. Fiz. 34, 352-3, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 277-8, 1964.
Describe the emission of charged particles from electrodes when bombarded by metallic microparticles in vacuum under the influence of a high electric field. The number of particles released is related to the mass of the microparticles and to the field strength. Vacuum of about 10^{-5} mmHg was obtained.

Alpert, D., Lee, D. A., Lyman, E. M., and Tomaschke, H. E. J. Vacuum Sci. and Tech. 1, 35-50, 1964.
A review of the theories of the initiation of vacuum breakdown is given. Predischarge currents and breakdown initiation are related through a critical field strength at the cathode surface. This field strength, 6.5×10^{7} v/cm for tungsten, is independent of gap spacing or electrode geometry.

Bennette, C. J., Swanson, L. W., and Strayer, R. W., J. Appl. Phys. 35, 3054-5, 1964.
The emission of blue light from localized spots on a metal anode preceding breakdown of vacuum has been interpreted before as the ionization of anode surface materials (DeGeeter, J. Appl. Phys. 34, 919, 1963). It is suggested that transition radiation is responsible for the observed emission due to electrons passing from vacuum to metal.

Brodie, I., J. Appl. Phys. 35, 2324-32, 1964.
Studies of field emission and breakdown with nickel cathodes and a cylindrical projection tube are presented. The currents preceding breakdown in vacuum are due to field emission from protruding whiskers. These whiskers can disrupt leaving pools of molten metal on the cathode. The rupture of the whiskers may be the origin of Cranberg's clumps.

Brodie, I. and Weissman, I., Vacuum 14, 299-302, 1964.
A cylindrical projection tube is described which can be used to study prebreakdown emission from protrusions on extended surfaces when subject to very high electric fields.

Gurov, S. V., Dzhafarov, T. A., Malinin, A. A., Osadin, B. A., and Tainov, Yu., Zh. Tekhn. Fiz. (USSR) 34, 868-72, 1964. (Russian). Translation: Soviet Physics: Tech. Phys. 9, 665-70, 1964.
A low-voltage high-current pulsed discharge in a vacuum was obtained between the faces of coaxial electrodes separated by fluoroplastic insulators. Vacuum was 2-5 x 10^{-5} mmHg. High speed photography showed the emission of electrode material during the discharge in the form of micro-plasmoids moving with velocity 1-2 x 10^6 cm/sec.

Hawley, R., Proc. IEE 111, 1373, 1964.
A discussion is given of various ways of improving the breakdown strength of insulator surfaces in vacuum, particularly with reference to Hayes and Walker (Proc. Inst. Elec. Engrs. (London) 111, 600, 1964).

Hawley, R., Zaky, A. A., and Zein Eldine, M. E., Conf. on Dielectric and Insulating Materials. IEE, London, 1964.
Paper gives a review of the insulating properties of high vacuum. Prebreakdown phenomena and the influence of electrode contamination are considered. Parameters affecting the breakdown and the current theories are also discussed. Surface breakdown in vacuum is also considered.

Hayes, R. and Walker, G. B., Proc. IEE 111, 600-4, 1964.
A method of improving the vacuum breakdown strength of ceramic surfaces is described. Titania ceramic discs were coated with a thin layer of a lead-borate glaze. An improvement was noted for both static and microwave fields.

Jedynak, L., J. Appl. Phys. 35, 1727-33, 1964.
The high-voltage performance of a vacuum gap can be improved by coating the cathode surface with a thin insulating film. Coatings on anode are detrimental. A good cathode film has resistivity at least 10^{11} Ω cm, dielectric constant 1.5 to 4, dielectric strength at least 10^6 V cm^{-1}, film thickness between 10 and 25 μ. Mechanically, the film should be hard with no bubbles.

Kalatskii, I. I. and Kassirov, G. M., Zh. Tekhn. Fiz. (USSR) 34, 348-51, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 274-6, 1964.
The pulse electric strength of a 1 mm vacuum gap increases as the strength (tensile) of the anode material increases. Electrodes of graphite, lead, copper, aluminum, and steel were used with pulse durations of 0.1 to 3 μsec. The breakdown voltage-pulse duration characteristic depends on cathode material.

Kassirov, G. M. and Koval'chuk, B. M., Zh. Tekhn. Fiz. (USSR) 34, 484-7, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 377-9, 1964.
Time lags in the breakdown of vacuum gaps have been measured for gap widths of 0.1 to 1.0 mm and for various overvoltages. For small gaps the time lag depends only weakly on overvoltage. For gaps greater than 0.5 mm the lag becomes very voltage dependent. At a constant overvoltage the time lag increases nonlinearly with gap length.

Kassirov, G. M. and Mesyats, G. A., Zh. Tekhn. Fiz. (USSR) 34, 1476-81, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 1141-5, 1965.
Breakdown of vacuum gaps up to 1 mm length is investigated using pulses of

duration 0.3 μsec, rise time 4 nsec and magnitude up to 60 kv. The delay time is measured for a range of overvoltages, and is found to increase non-linearly with increasing gap length.

Llewellyn-Jones, F. and Owen, W. D., Proc. Phys. Soc. 83, 283-91, 1964.
Prebreakdown currents in nitrogen and vacuum (10^{-5} mmHg) have been measured for field strengths in the range 4×10^4 to 9×10^4 V cm^{-1}. These currents did not obey field or field-aided thermionic emission laws. It is postulated that gas released from the electrodes during bombardment by prebreakdown currents permits ionization to occur which leads to breakdown.

Mazeau, J. and Goldman, M., Compt. Rend. 258, 2774-7, 1964. (French).
Prebreakdown effects at very low pressures were studied optically and electrically. A continuous current was observed and was attributed to field emission. Luminous spots on the anode or on both electrodes accompanied this current, but the breakdown channel often formed outside these spots.

Miller, H. C., Physics Letters 12, 184-5, 1964.
Further evidence is presented indicating a transition in the mechanisms of breakdown of vacuum as the gap length is increased. It is noted that for electrodes of radius of curvature R the breakdown voltage V at a given gap length is given by $V = V(R^{Ka})$ where a is positive and K varies from - at short gaps, through zero to + at large gaps.

Rabinowitz, M., Dissertation Abstracts 25, No. 64-9649 (Physics-Electronics and Electricity) 1964.
The effects of curvature and area of electrodes and also polarity on the breakdown of vacuum in the range 0-60 kv are described. Material transfer, particle inertia, protrusion formation, erosion deposits, and micro-arcs also effect the results. A new hypothesis is introduced in which the energy required to initiate breakdown is equal to a fraction of the capacity energy stored in the electrodes.

Reykhrudel, E. M. and Sheretov, E. P., Radio Engineering and Electronic Physics 9, 589-94, 1964.
Conditions for the sparking of a spontaneous discharge in a cold-cathode cylindrical magnetron in high vacuum are examined. The magnetic field strength required for spontaneous discharge initiation is calculated.

Smith, O. E., Rev. Sci. Instr. 35, 134, 1964.
A high voltage spark gap is described, which requires zero energy to trigger. The system switches currents greater than 250 ka in 0.8 μsec.

Sudan, R. N. and Gonzalez-Perez, F., J. Appl. Phys. 68, 2269-70, 1964.
The current between two copper crystal electrodes was measured for field strengths from 1.5 to 3.0×10^5 V/cm and for a vacuum of 10^{-6} mmHg after the gap had been broken down. Enhanced emission occurred from microprojections due to anode material deposited on the cathode.

Tarasova, L. V. and Kalinin, V. G., Zh. Tekhn. Fiz. (USSR) 34, 666-75, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 514-20, 1964.
The effects of electrode shapes and electrode materials on the breakdown of

high vacuum have been investigated in the voltage range 20-300 kv. Pulses of duration 10^{-7} to 9×10^{-5} sec were used, and the breakdown strength was independent of gap length. Time lags of several microseconds were observed, but in general the lag was almost zero.

Vibrans, G. E., J. Appl. Phys. 35, 2855-7, 1964.
Breakdown in vacuum is described by a thermal instability of a field emitter protrusion taking account of the temperature dependence of field emission and of resistivity. The instability can occur when the emitter tip is only several hundred degrees hotter than the bulk of the cathode.

Woolston, J. R. and Honig, R. E., Rev. Sci. Inst. 35, 69-74, 1964.
The energy distribution of ions formed by the pulsed rf discharge in vacuum is measured for various materials and sparking conditions. Wide energy spreads are usually obtained (1000 ev to 5000 ev), with 20 kv voltage applied.

G. Miscellaneous

Andreae, S. W., Kerns, Q. A., Kirsten, F. A., Mack, D. A., Nunamaker, T. A., and Perez-Mendez, U., IEEE Trans. NS-11, 317-20, 1964.
Use is made of a vidicon camera tube as a means of directly viewing spark chamber events.

Badareau, E., Popescu, I., Ghita, C., and Zamfir, O., Brit. J. Appl. Phys. 15, 1171-8, 1964.
Mercury was added to a conventional caesium neutralized diode. A pronounced Penning effect is observed. The effect of increased scatter of electrons due to the mercury is offset by the low cross section at 0.17 ev due to the Ramsauer effect.

Bartholomew, C. Y. and LaPadula, A. R., J. Appl. Phys. 35, 2570-2, 1964.
The penetration depth of Kr ions into a molybdenum cathode in a glow discharge is shown to increase with time of operation of the discharge but reaches a steady state condition after sufficient time. At 150 V the depth was about 10^4 Å after 24 hours.

Becker, E. W. and Klingelhöfer, R., Z. Naturforsch. 19a, 813-4, 1964. (German).
By means of a high potential field an electric discharge was established in a beam of condensed gas, produced by cooling. A thin cylinder of plasma was thus obtained.

Binns, D. F., Hood, R. J., and Dargan, C. L., Rev. Sci. Instr. 35, 365-7, 1964.
A digital technique has been developed for the rapid measurement of time lags, and has been applied to the breakdown of SF_6 - air mixtures.

Bortnick, I. M., Zh. Tekhn. Fiz. 34, 731-6, 1964. (Russian). Translation: Soviet Physics: Tech. Phys. 9, 559-63, 1964.
Peek's equation, which is based empirically on a large number of observations is derived theoretically from the known functional form of the Townsend first ionization coefficient.

Boulet, L. and Jakubczyk, B. J., IEEE Trans. PAS-83, 508-20, 1964.
Discusses corona around a conductor in the presence of water. The behavior of water drops in an electric field is analyzed and the mechanism of streamer formations shown. Water influence, causing corona increase, has two components: (1) discharges between conductor and passing drops and (2) streamers produced by water on the conductor.

Broadbent, T. E., Brit. J. Appl. Phys. 15, 97-9, 1964.
A high-voltage triggered spark gap was constructed from a trigatron type of spark gap and a hot-wire gap combined into a single device in which a trigger spark is produced near the neated filament at the sparking surface of one main electrode. The range of voltage operation can be controlled by varying the wire temperature.

Broadbent, T. E., Elliott, C. T., and Shlash, A. H., Brit. J. Appl. Phys. 15, 1118-9, 1964.
The initiation of the electric spark in trigatrons with gap spacings of 0.8 - 4.8 cm has been investigated. A corona burst initiates breakdown, followed by one or more leader strokes of velocity about 10^8 cm/sec.

Chotia, B. L. and Bhatawdekar, M. G., J. Phys. Soc. Japan 19, 1222-5, 1964.
The Joshi effect (photodiminution of discharge current) is attributed to photo emission from an absorption-like electrode layer formed on the discharge tube wall. Using an RCA 868 tube this hypothesis is substantiated.

Christensen, J. H., Clark, A. R., and Cronin, J. W., IEEE Trans. NS-11, (No. 3) 310-6, 1964.
A brief review of the spatial accuracy of spark chambers using various techniques for data extraction is presented. The accuracy obtainable using photography of spark chambers is discussed, making use of the results of two spark chamber spectrometers.

Ciobanu, G. and Popescu, I., J. Electron. Control. 16, 59-64, 1964.
A kinetic analysis is given for the movement of positive ions through the positive space-charge sheath for plane, cylindrical and, spherical geometries. Expressions are derived for the positive ion relaxation time, concentration, drift velocity, mean kinetic energy, and electric field in the sheath.

Greaves, C. and Kerry, D. C., Brit. J. Appl. Phys. 15, 177-83, 1964.
Space charge compensation is studied in experimental auxiliary discharge thermionic generation devices containing Ne, Ar, Kr, Xe and mixtures of Ne-Ar, Ne-Kr, Ne-Xe, at pressures between 0.25 and 5.0 mmHg. Gas mixtures show no advantage over single gases. Compensation is improved when auxiliary discharge is produced away from emitter-collector region, and when auxiliary cathode temperature is reduced.

Grieder, P. K. F., Helvetica Physica Acta. 37, 469, 1964.
Some properties of air spark chambers.

Hancox, R., Proc. IEE 111, 203-11, 1964.
Low pressure gas discharge switches are considered and several are described which are capable of passing 50 ka to 2 ma at voltages up to 100 kv.

Harraway, R. A., J. Sci. Instr. 41, 399, 1964.
An atmospheric spark gap triggered by an exploding wire and operating between 0.5 and 6 kv is described.

Hull, A. W., J. Appl. Phys. 35, 490-6, 1964.
A basic theory of the mercury cathode spot is presented which is based on field emission of electrons from the surface of the cathode. The electron current density is about 10^7 A cm^{-2} and the field at the cathode surface 2.7×10^7 V cm^{-1}. Temperatures do not exceed 400°C. Retrograde motion is explained as a space charge effect of slow electrons moving in the magnetic field.

Il'enko, O. S., Zh. Tekhn. Fiz. (USSR) 34, 1132-6, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 881-3, 1964.
The inverse motion of the cathode spot of an arc in a magnetic field is associated with the Hall effect. Effects of temperature, pressure, type of gas, electrode material, nature of electron emission, ionization potential, arc length, etc., are in qualitative agreement with the theory.

Ionov, N. I., Zh. Tekhn. Fiz. 34, 769-87, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 591-604, 1964.
Article gives a review of the multielectrode probe study of gas discharge and cosmic plasmas. The inherent disadvantages of single electrode probes and the superior performance of two, three, and four electrode probes are discussed.

Ishikawa, T., J. Phys. Soc. Japan 19, 367-75, 1964.
The mechanism of trigger action in a double electrode spark gap was investigated. The plasma jet, ejected with the trigger spark, increases the field between jet and anti-electrode. The main spark is initiated in this space.

Lavoie, L., Parker, S., Rey, C., and Schwartz, D. M., Rev. Sci. Inst. 35, 1567-71, 1964.
A spark chamber pulser is described which employs an air spark gap whose trigger electrode is surrounded by barium titanate. Pulses up to 25 kv with 1 nsec risetime are obtained. Over-all delay is 17-65 nsec, jitter times less than 3 nsec.

Muhlenfeld, E., Z. Angew. Phys. 17, 76-80, 1964. (German).
The optimum working conditions for corona anemometers and for the elimination of side effects are found through the results of current-voltage curves at various gap sizes. Two- and three-cathode probes are discussed.

Nagaev, E. L., Zh. Tekhn. Fiz. (USSR) 34, 745-52, 1964. (Russian).
Translation: Soviet Physics-Tech. Phys. 9, 569-74, 1964.
The relationship between current, voltage and interelectrode distance is investigated for a weakly ionized gas operating under conditions where electron-atom collisions occur but where the interelectrode spacing is less than the distance required for equilibrium to be established. Large potential changes are assumed near to the cathode.

Neale, D. M., Radio Electronic Engr. 27, 87-97, 1964.
Article gives a survey of cold cathode discharge tubes including a discussion of the leading characteristics of each class of tube currently available.

Parker, A. B. and Poole, D. E., Brit. J. Appl. Phys. 15, 1011-9, 1964.
The dielectric recovery of high current spark gaps using hydrogen and argon as dielectric is investigated with particular emphasis on gas temperature.

Phillips, N. J., Proc. Phys. Soc. 83, 275-81, 1964.
The growth of electron populations in regions remote from the main discharge of an intense electrical breakdown is discussed. Two theories are presented, one relying on photoionization from the discharge as a source of radiation, the other considering the electric field effects remote from a typical azimuthal type discharge.

Rau, K. L., Nachrtech. Z. 17, 636-40, 1964. (German).
Discusses recommended specifications for the breakdown strength of reed relay contacts and concludes that tests with dc or low frequency voltages applied over a long period to a static system are not representative of operative conditions, during which voltage peaks and impulses can occur.

Roberts, A., IEEE Trans. NS-11, 302-9, 1964.
Recent advances in spark chamber techniques are described.

Schrank, G., Henry, G., Kerns, Q., and Swanson, R., Rev. Sci. Instr. 35, 1326-31, 1964.
A spark-gap trigger system is described capable of discharging 5000 A at 30 kv. Approximately 57 nsec were needed from the passage of the initiating event to complete breakdown of the gap.

Shaw, A. B. and Whittaker, D., Proc. IEE 111, 193-202, 1964.
Spark reignition voltage characteristics have been measured for gaps between stationary electrodes for various controlled speeds of gas flow following dc pulsed arc discharges.

Thomas, J. B., Rev. Sci. Instr. 35, 170-2, 1964.
A coaxial corona voltage regulator operating in air is described. By controlling the gas temperature in the vicinity of the wire by resistive heating of the wire, an order of magnitude improvement in stabilization over passive corona regulators is achieved.

Vorobyev, G. A., Golynskii, A. I., and Mesyats, G. A., Zh. Tekhn. Fiz. (USSR) 34, 2153-5, 1964. (Russian).
Investigation of the influence of pressure on the formation of conductivity in the spark of different gases.

Witalis, E. A., J. Appl. Phys. 35, 3617, 1964.
The voltage limit of a thermally ionized gas discharge is explained as a consequence of the thermal effect of the electrodes on the field distribution.

Zemtsov, Yu. K., Pis'mennyi, V. D., and Podgornyi, I. M., Dokl. Akad. Nauk. SSSR 155, 312-15, 1964.
Theoretical reasons for the relatively low (20 ev) electron temperature compared with the ion temperature (200 ev) in a powerful pulsed discharge are discussed.

Izv. Akad. Nauk. SSSR-Fiz. 28, 1402-1545, 1964. Transactions of the 10th All-Union Conference on Cathode Electronics; translation: Columbia Technical Translations, estimated publishing date September 1965.
Contains paper on secondary electron emission, cathode sputtering, thermionic emission, energy conversion.

III. Breakdown of Liquids

Bucklow, I. A. and Drain, L. E., J. Sci. Inst. 41, 614-7, 1964.
Fine metal powders with particle range 100 Å - 500 Å are produced by spark erosion in liquid argon. By using this inert gas contamination is avoided.

Coleman, C. R., Conf. on Dielectric and Insulating Materials. IEE, London, 1964.
The effect of chemical composition on the electrical properties of askarels is described with reference to use as an impregnant for paper capacitors.

Gallagher, T. J. and Lewis, T. J., Brit. J. Appl. Phys. 15, 491-8, 1964.
The static electric strength of liquid argon depends on the surface conditions of both anode and cathode when 20 parts per million of oxygen are present. The anode effect disappears when the O_2 is removed. There is no anode effect, and no O_2 effect for low concentrations if microsecond pulse voltages are used. Negative O_2 ions are believed to be responsible for the anode effect.

Gallagher, T. J. and Lewis, T. J., Brit. J. Appl. Phys. 15, 929-34, 1964.
The impulse breakdown of liquid argon is explained on a statistical basis. Cathode oxidation and positive ions play an important role in the breakdown process. The formative time lag appears to be about 0.1 μsec while statistical lags greater than 20 μsec are seen at stresses above 1.7 Mv/cm.

Gosling, C. H. and Tropper, H., Conf. on Dielectric and Insulating Materials. IEE, London, 1964.
The electric strength of purified transformer oil has been examined with gaps up to 0.2 mm for uniform and non-uniform fields. Gas content of the oil was important. Negative point gave higher strength than positive point. The strength of degassed oil decreased from 1300 kv/cm for a gap of 0.028 mm to 700 kv/cm for a gap of 0.2 mm.

Ibrahim, M., Pakistan J. Sci. Industr. Res. 7, 61-70, 1964.
Describes a technique for measuring the thickness of oil film between lubricated loaded surfaces which involves the electrical breakdown of the oil film. A theory is given.

Kao, K. C., Brit. J. Appl. Phys. 15, 1247-9, 1964.
The breakdown voltage of air and CCl_4 measured between point and plane electrodes is increased when the plane electrode is covered with a thin dielectric solid. Space charge accumulation at the surface of the solid is considered to be important.

Kao, K. C. and Calderwood, J. H., Conf. on Dielectric and Insulating Materials. IEE, London, 1964.
Conduction currents in N-C_8H_{14}, CCl_4, and transformer oil are dependent on field, purity, and temperature; but independent of hydrostatic pressure up to

10 atmospheres and at 90% of normal breakdown voltage. Ionic conduction and a Schottky-type emission are considered important.

Kaplan, D. A. and Kuchinskii, G. S., Elektrotekhnika (USSR) No. 5, 30-3, May 1964. (Russian).
The effect of the moisture content on the electric strength of transformer oil was measured in the range 1-10^4 parts per million of water by weight. Same results were obtained for ac or dc, and effect of water became less at greater gap widths.

Klein, N., Amariglio, Y., and Burstein, E., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 5-7, 1965.
Cavitation in transformer oil when subjected to electrical stress is measured, using a novel cell, as a function of field, pressure, and frequency. The number of bubbles increased with field and with decreasing pressure. Causes of cavitation are discussed.

Lipshtein, R. A. and Shtern, E. N., Elektrotekhnika No. 3, 15-18, March 1964. (Russian).
Experimental results on the conduction and breakdown of oil support the thermal theory of electrical breakdown. Effects of moisture, saponification, spirits, acids, resinous substances, and various container materials were also investigated.

Melnikov, N. P., Ostroumov, G. A., and Stoyak, M. Yu. Zh. Tekhn. Fiz. 34, 949-51, 1964. (Russian). Translation: Soviet Physics-Tech. 9, 730-3, 1964.
The electrical breakdown in aqueous NaCl solution is investigated using high speed photography. The mechanism of breakdown depends on the concentration of electrolyte and on the field configuration. The formation of gas bubbles in which the discharge develops also depends on the concentration of electrolyte.

Murooka, Y., Nagao, S., and Toriyama, Y., Brit. J. Appl. Phys. 15, 1585-96, 1964.
Using high speed photography the growth of bubbles in a liquid-filled bubble chamber with voltage applied between two needle electrodes is examined. It is concluded that electron emission from the cathode occurs during prebreakdown phenomena.

Rudenko, N. S. and Tsvetkov, V. I., Zh. Tekhn. Fiz. (USSR) 34, 1079-82, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 815-20, 1964.
The electric strengths of tap water, distilled water, glycerine, and ethyl alcohol were measured with pulses of 0.1 to 10 μsec duration and for gap widths of 5 to 500 microns. The strength increases for decrease of gap length and pulse duration, and varies inversely with conductivity.

Ryder, D. M. and Edwards, F. S., Conf. on Dielectric and Insulating Materials, IEE, London, 1964.
The breakdown strength of transformer oil at power frequency with voltages up to 800 kv was measured between a sphere and a rounded electrode. Low breakdowns were correlated with visible impurities in the gap.

Sakr, M. M. and Gallagher, T. J., Brit. J. Appl. Phys. 15, 647-51, 1964.
The electric strength of liquid methane is found to depend to a marked degree on the nature of both the cathode and anode metals and on the degree of surface oxidation. Under certain conditions, the strength is comparable with that of the higher n-paraffin liquids.

Sletten, A. M. and Dakin, T. W., IEEE Trans. PAS-83, 457-9, 1964.
The statistical distribution of power frequency breakdown for non-uniform field gaps in transformer oil was measured and found to correspond closely to an extreme value distribution. Light emission from the gaps was observed prior to breakdown using photomultiplier detectors.

Toriyama, Y., Sato, T., and Mitsui, H., Brit. J. Appl. Phys. 15, 203-4, 1964.
Using Lichtenberg figures in insulating oil, it is shown that a purely electronic process occurs, which is independent of pressure above the oil, and that a vapor phase discharge can also occur, which does depend on the hydrostatic pressure.

Widmann, W., Elektrotech. Z. A85, 94-102, 1964. (German).
The relationship between breakdown strength and volume or area is calculated, assuming a distribution of weak spots which lead to failure. The theory is verified experimentally. The derived law permits conclusions to be drawn from small scale experiments and applied to actual test objects.

Zaky, A. A., Zein Eldine, M. E., and Hawley, R., Nature 202, 687-8, 1964.
The electric strength of transformer oil was measured with electrodes coated with 0.25 mm of a polyether. Coating either anode or cathode resulted in an increase of electric strength, but coating both did not further increase the strength. Results are interpreted in terms of space charge.

Zein Eldine, M. E. Zaky, A. A., Hawley, R., and Cullingford, M. C., Nature 201, 1309-11, 1964.
Using a movable probe, the potential distribution between electrodes in oil is measured. Coating either or both electrodes results in large changes in the potential distribution. Space charge accumulation at both electrodes is indicated.

Zein Eldine, M. E., Zaky, A. A., Hawley, R., and Cullingford, M. C., Conf. on Dielectric and Insulating Materials, IEE, London, 1964.
The conduction current in air-saturated transformer oil is measured using electrodes coated with a thin insulating layer. Coating one or both electrodes reduced the current, but coating the anode gives results which indicate that negative space charges play an important role in controlling the current flow.

IV. Breakdown of Solids

A. Electric Strength

Allyn, J. B., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 96-98, 1965.
By exploding wires within various casting resins, resistance to mechanical

shock was measured through the extent of internal fracture. Comparing these results with electrical pulse data yielded a correlation opposite to that expected.

Artbauer, J. and Griac, J., Conf. on Dielectric and Insulating Materials. IEE, London, April 1964.
The decrease of electric strength of polyethylene above a certain temperature is much more pronounced with dc than with impulse voltages. Possible reasons are discussed.

Barney, W. H., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 99-100, 1965.
The dielectric strength of several glasses was measured, and good agreement obtained for calculated values. The square of the strength is found to be proportional to the product of the electrical resistivity and the thermal conductivity.

Barrett, H. H., J. Appl. Phys. 35, 1420-5, 1964.
Pulse and dc electric strength measurements for single crystals of strontium titanate are given for temperatures between -195°C and +100°C. The dc breakdown at 100°C is thermal. At room temperature and -40°C the breakdown is intrinsic, but at -80°C and -195°C the strength depends strongly on sample configuration. It is postulated that electron trapping centers are formed by the high stresses.

Breilmann, W., Electrotech. Z. A85, 381-2, 1964. (German).
The breakdown instability of insulating materials when subjected to high dc stresses is considered. For PVC it is concluded that failure is due to a thermal breakdown with space charges forming at the electrodes.

Fava, R. A., Conf. on Dielectric and Insulating Materials. IEE, London, 1964.
The intrinsic electric strength of polyethylene decreases sharply above room temperature, and it is shown that this decrease is largely the result of electromechanical compressions.

Forlani, F. and Minnaja, N., Phys. Status Solidi 4, 311-24, 1964.
On the basis of the theory of avalanche breakdown, the dependence on thickness of breakdown phenomena in thin dielectric films is considered. It is assumed that breakdown occurs when the current at some point reaches a critical value. Tunnel-effect injection at the cathode is considered the source of carriers. Electron-lattice interaction is the mechanism assumed for energy loss. Satisfactory agreement is obtained with published data.

Greisukj, M. A., Kaplan, D. A., Kuchinskii, G. S., and Messerman, G. T., Elektrotekhnika (USSR) No. 4, 33-5, 1964. (Russian).
The impulse strength of structures with pronounced edge effects, such as capacitor bushings composed of oiled paper enclosing conducting layers, is presented. A 1 mm thick layer of oiled paper failed at about 85 kv, irrespective of pulse length (2 μs-0.2 s). Surface flashover voltage decreased with increased pulse duration. Effects of dc were also examined.

Heuse, E. M., Conf. on Dielectric and Insulating Materials. IEE, London, 1964. The influence of sample shape on the electric strength of porcelain at power frequencies was investigated. The best and most consistent results were obtained with an 8 cm disc having a spherical depression in one face, using fired-on silver electrodes on a ground surface.

Howard, L. F. and Smith, A. W. H., IEEE Trans. CP-11, 187-93, 1964. Dielectric breakdown in solid electrolyte tantalum capacitors is attributed to a thermal mechanism. The leakage current is examined in the early stages of breakdown, and self-healing is also considered.

Kalyatskii, I. I. and Kasserov, G. M., Zh. Tekhn. Fiz. (USSR) 34, 1471-5, 1964. (Russian). Translation: Soviet Physics-Tech. Phys. 9, 1137-40, 1965. The breakdown strength of various solid dielectrics in a vacuum is investigated with pulses of 0.1-3 μsec duration and sample thicknesses up to 20 mm. The strength increases with reduced pulse duration. There is a linear relationship between breakdown voltage and thickness and electrode conditions are not important. The pulse strength is increased by increasing the cathode non-uniformity of the field.

Kelk, E. and Wilson, I. O., Conf. on Dielectric and Insulation Materials. IEE, London, 1964. The effects of thickness, apparent density, and air impermeability upon the impulse strength of impregnated paper are studied. The electric strength of composites of soft-wood pulp and synthetic fibers depends on the same properties. Loss depends on chemical constitution and purity.

Koenig, J. and Jaffe, B., J. Amer. Ceram. Soc. 47, 87-9, 1964. The electrical properties of $BaZrO_3$ containing 2-6% La were investigated. The presence of La^{3+} raises the volume resistivity by several orders of magnitude. The breakdown strength of specimens 10 mil thick was as high as 680 V/mil.

Kojima, K. and Tanaka, S., IEEE Trans. PAS-83, 460-7, 1964. The impulse breakdown mechanism of dielectrics used in oil-filled cables is investigated. Oil-impregnated paper, paper and polyethylene, and polyethylene alone were examined. Tape thickness and butt-space size were varied with constant total thickness. Oil in the butt-gap did not affect the results. Strength of paper varied inversely with tape thickness, but that of polyethylene did not.

McKeown, J. J., Conf. on Dielectric and Insulating Materials. IEE, London, 1964. Employing a new technique of holding the sample which eliminates discharges onto the surface and also eliminates, or reduces, electromechanical effects, the ac intrinsic electric strength of a number of hydrocarbon and fluorocarbon polymers was measured. Contrary to previous work, the dc and peak ac electric strengths of polyethylene were identical at 9.0 Mv/cm.

Milton, O., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 89-92, 1964. The electric strength of a diallylphthalate thermoset plastic has been measured with embedded Rogowski-profile electrodes. Breakdowns occur in the uniform field region.

Milton, O., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 89-92, 1965.
The number of pulses required to breakdown for a resin sample cast about a sharp point electrode is used as an indication of pulse life. This differs markedly from results obtained with ASTM test D149-61.

Morton, J., Conf. on Dielectric and Insulating Materials. IEE, London, April 1964.
The time lag to breakdown of glass was measured as a function of stress up to 7.5 Mv/cm. The effects of temperature were investigated.

O'Dwyer, J. J., The Theory of Dielectric Breakdown of Solids, Oxford University Press, London, (1964).
Gives a survey of dielectric breakdown of solids, both theoretical and experimental (see introduction).

Rhodes, R. G., Wootton, R. E., and Nugent, H., Conf. on Dielectric and Insulating Materials. IEE, London, 1964.
Using tapes of high and low density polyethylene, and of an ethylene-butene copolymer, the impulse strength of gas/plastic composites was evaluated. The effects of temperature, tape thickness, registration, and gas filling were examined. Discharge inception and life tests were also carried out.

Seligman, L. J., 1964 Annual Report Conf. on Elect. Insul, NAS-NRC Publication 1238, 82-4, 1965.
A test cell is described which permits the electric strength of materials to be measured between -10°C and +210°C. Circulation liquid maintains thermal uniformity.

Seligman, L. J., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 93-5, 1965.
The effect on the electric strength of adding solid glass spheres ranging in diameter from 10 μ to 840 μ to an epoxy resin is measured. Certain combinations of epoxy and filler show enhanced dielectric characteristics when measured with pulse voltages.

Ueda, I., Takuichi, M., Ikegami, S., and Sato, H., J. Phys. Soc. Japan 19, 1267-73, 1964.
The temperature dependence of breakdown field, time lag distribution,and high field dielectric constant were studied on polycrystalline $BaTiO_3$. The dc strength is almost constant in range 20 to 150°C, while the pulse strength changes markedly near the Curie temperature (120°C). The time lag is statistical. Breakdown is assumed to be of the avalanche type.

Vermeer, J., Conf. Internat. Grands Reseaux Elect. (CIGRE), Paper 225, 1964.
Breakdown measurements using ac, dc, and impulse voltages are reported for polymer-oil systems for extra-high voltage cables. Results using a new low-loss polymer are discussed. Impulse strengths in excess of 200 kv mm^{-1} are obtained with normal cable oil as impregnant.

Veverka, A., Elektrotech. Obzor. 53, 370-3, 1964. (In Czech.)
Assuming an exponential temperature dependence for loss in a dielectric, the temperature increase with time is calculated for a plane parallel capacitor

system. The limit of thermal stability is determined. Good agreement is obtained between theory and experiment.

Vorobev, A. A., Vorobev, G. A., Kocherbaev, T. K., Kostrygin, V. A., and Nekrasova, L. G., Fiz. Tverd. Tela. 6, 1560-2, 1964. (Russian). Translation: Soviet Physics: Solid State 6, 1226-8, 1964.
Electric strength of NaCl crystals is independent of cathode material when metals are used but is increased by the use of aqueous cathodes. Annealing of NaCl, KCl, KBr, and KI crystals reduced the average strength, indicating the importance of dislocations.

Vorobev, G. A. and Lisetskaja, Fiz. Tverd. Tela. 6, 3493-9, 1964. (Russian).
A study of discharge development in rock salt in homogeneous field.

Vorobyev, G. A. and Kocherbayev, T. K., Radiotekhn. Elektron. 9, 557, 1964. (Russian). Translation: Radio Eng. and Electronic Physics 9, 442 and 454-5, 1964.
By using electrodes of graphite and aqueous NaCl, it is shown that the impulse strength of NaCl crystals depends markedly on cathode material. The NaCl solution appears to be a poor emitter.

Wentz, J. L., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 85-8, 1964.
Current-time and voltage-time traces during electrical breakdown of transparent-epoxy resins have been obtained in non-uniform fields. By supplementary optical means, streamer behavior is correlated with field, electrode material, and temperature.

Yesikov, Yu. G., Elektrichestvo (USSR) No. 8, 67-70, 1964. (Russian).
Refutes the view that sectionalizing the insulation of high voltage cylindrical insulation equalizes the field strength. From test results, no increase occurs in the breakdown voltage due to sectionalizing, since breakdown occurs at the point of maximum field strength.

B. Corona Discharges

Alston, L. L. and Dawson, P. G., Conf. on Dielectric and Insulating Materials. IEE, London, 1964.
Polyethylene samples, 0.09 to 0.18 cm thick with artificial voids were subjected to pulses of 10^{-6} to 10^{-2} sec duration, with voltages between 0.2 and 0.9 Mv/cm. The life was independent of frequency in the range 1 to 4/sec but was longer at 50 pulses/sec. The results are consistent with intrinsic failure resulting from space charge.

Bashara, N. M. and Green, F. M., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 41-2, 1965.
The accumulation of charge on a dielectric surface under corona discharge bombardment was investigated, and it is concluded that a net positive charge accumulates on the surface.

Black, R. M. and Reynolds, E. H., Conf. on Dielectric and Insulating Materials. IEE, London, 1964.
The chemical changes produced by exposure of dielectric materials to high

energy ionizing radiations are similar to those involved in electrical deterioration during stress aging and ionization in the dielectric. It is suggested that techniques for protection of dielectrics against radiation may also be effective for electrical discharge deterioration.

Bolton, B., Cooper, R., and Gupta, K. G., Conf. on Dielectric and Insulating Materials. IEE, London, 1964.
The growth of trees in perspex from a point electrode using impulse voltages shows a random development. Propagation occurs by intrinsic breakdown at the end of the hollow, non-conducting tubes in which a discharge is formed.

Bullwinkel, E. P., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 101-3, 1965.
A technique for locating the weak spots in draft capacitor tissue is described which does not result in breakdown through the weak area.

Dakin, T. W. and Works, C. N., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 109-13, 1965.
The charge associated with corona pulses is investigated for a number of configurations of internal and external voids. Distribution of pulse charge magnitudes are discussed as is the area of insulation involved in corona discharges.

Dittmer, B., Arch. Elektrotech. 48, 287-96, 1963. (German).
The discharge channels which formed in a number of polar and non-polar plastics, in glass, sodium chloride, and resin-bonded paper when 0.01/25 μsec impulses were applied to point-plane electrodes were measured as a function of voltage. Strong polarity effects were noticed, and the nature of the channels depended on the material.

Dittmer, B., Arch. Elektrotech. 48, 387-402, 1964. (German).
The growth of discharge channels in a point/plane electrode system was observed in polymethylmethacrylate and "Araldite" with 50 c ac waves and parts of ac waves. Results of this and earlier work are interpreted in terms of field distortion due to space charges and it is concluded that breakdown is initiated by ionizing collisions and avalanches, as in gases.

Heinrich, O. X., IEEE Trans. CP-11, 299-316, 1964.
Discusses generally corona measuring techniques and their use in insulation system evaluation.

Heller, B., Acta Tech. CSAV 9, 1-16, 1964. (German).
The physics of corona discharges in solid dielectrics is discussed. It is shown that the anomalies observed by Boning [Arch. Electrotech (Germany) 48, 7-22, 1963] can be explained without the use of additional hypotheses when the influence of the charges produced by the discharges on the behavior of the equivalent circuit is considered. Fair agreement is obtained between theory and experiment.

Hendron, J. A., Groble, K. K., Gruetzmacher, R. W., McClurg, G. D., and Retsky, M. W., Materials Evaluation 22, 311-4, 1964.
Corona and microwave methods for the detection of voids in glass-epoxy structures are discussed. The microwave method depends on the change in phase and

amplitude observed in a microwave beam when passing through a dielectric containing a discontinuity as compared to that in a homogeneous dielectric system.

Hor, L. M., Electrotechnika (Hungary) 57, 129-37, 1964. (Hungarian).
Discusses internal discharges, associated energy losses, and a method of investigation by an equivalent circuit for insulating materials. Corona starting voltage is determined in an insulating material with cavities and the theory of surface ionization explained. Loss angle increase due to cavities is also examined.

Jolley, H. E. W., Conf. on Dielectric and Insulating Materials. IEE, London, 1964.
Various forms of discharge tests are described and compared. The problem of establishing safe discharge limits for bushings is considered on a basis of actual test results.

Kogan, P., Conf. on Dielectric and Insulating Materials. IEE, London, 1964.
Time to breakdown and discharge inception of wet paper impregnated with transformer oil and subject to electric stress vary between a few seconds and several hundreds of hours, and to depend on moisture content, temperature, stress, and impregnant. Moisture content was varied between 1 and 8% and temperature between 20 and 80°C. Gas evolution was measured.

McMahon, E. J. and Perkins, J. R., IEEE Trans. PAS-83, 1253, 1964.
Evaluation of polyolefin high voltage insulating compounds; dendrite (tree) formation under highly divergent fields.

Meats, R. J. and Stannett, A. W., IEEE Trans. PAS-83, 49-54, 1964.
The rate of erosion, chemical changes, products of decomposition and time to breakdown were measured at 100°C for polyethylene sheet subjected to discharges in various gases. Cross-linking, increase in saturation and H_2 evolution occur. The rate of change depends on the total energy of the discharge. The life depends on the product of stress and total discharge quantity per cycle.

Melville, D. R. G. and Salvage, B., Conf. on Dielectric and Insulating Materials. IEE, London, 1964.
A new technique for detecting and measuring discharges in gaseous cavities is described which involves the recording of the voltage pulses on magnetic tape. An example of a cylindrical air-filled cavity in polyethylene is given.

Mitra, G., Sakr, M. M., and Salvage, B., Conf. on Dielectric and Insulating Materials. IEE, London, 1964.
Using a bridge circuit and a pulse transformer, internal discharges in a solid dielectric are displayed on an oscilloscope. Results are given for a cylindrical void in polyethylene.

Müller, U., Conf. Internat. Grands Reseaux Elect. (CIGRE), paper 209, 1964.
Breakdown of impregnated paper cables is attributed to corona failure. A large number of cable samples was analyzed and it was observed that the corona damage was in the neighborhood of the 50% equi-potential surface in the coaxial cylindrical field of a round cable insulation. Using thinner tapes in the 50% region than in the remainder resulted in an increase of impulse strength.

Olyphant, M. and McKeown, J. J., 5th NEMA-IEEE Electrical Insulation Conference, 100-4, 1963. Also IEEE Trans. Power App. Systems, Special Supplement, 1964, 846-57.
A review of corona resistance testing is given, and the various methods of test are discussed. Many factors which influence the life measurement are considered.

Petry, H., Elektrotech. Z. (ETZ) A85, 102-6, 1964. (German).
Describes tests on a single core polyethylene insulated cable and the study of the discharges in small voids. High frequency oscillations are correlated with corona discharges.

Simons, J. S., Conf. on Dielectric and Insulating Materials. IEE, London, 1964.
The integrated discharge energy in high voltage insulation is measured using a dielectric loss analyzer with loop-trace display.

Starr, W. T. and McGowan, E. J., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 133-7, 1965.
Techniques for differentiating between thermal or corona breakdown are described and applied to ceramics at 10 kc for temperatures between 200° and 500°C and to butyl rubber insulated cable between 25° and 125°C over a range of frequency.

Starr, W. T. and Agrios, J. P, IEEE Trans. CE-70, 88-98, 1964.
A new test method is described for cables which relates corona to life and reliability of polyethylene insulated cable. Life with corona is 7×10^8 cycles or less, while required life is 10^{11} cycles. In the absence of corona 10^{11} cycle life can be obtained with very high stresses.

Suhr, H., Nachrichtentech. Fachber 29, 91-5, 1964. (German).
The mechanism of the frequency dependence of the threshold voltage for internal electrical discharges is discussed. Results are given for frequencies between dc and 10 Mc.

Veverka, A. and Hon, A., Conf. Internat. Grands Reseaux Elect. (CIGRE), paper 130, 1964.
Describes a method of embedding metal foils in the stator insulation to suppress corona in coil ends.

Veverka, A. and Hon, A., Acta Tech. CSAV 9, 208-16, 1964. (German).
The number of discharges in an artificial void in plexiglass is measured and found to depend on whether the dielectric is laminated or the layers are thermally connected. The influence of surface resistivity and interlayer material are important.

Veverka, A. and Hon, A., Elektrotech. Obzor. 53, 14-18, 1964. (In Czech.).
Results for the number of discharges in gaps in laminated dielectrics is explained by the effect of the boundary between the layers of the dielectric. An equivalent circuit is also given.

C. Surface Breakdown

Aleksandrov, G. N. and Ivanov, V. L., Elektrichestvo (USSR) No. 6, 44-9, 1964. (Russian).
Reviews published literature on flashover of line and substation insulation. Test results indicate that an important role is played by space charges. It is deduced that surges at low frequencies are the most dangerous.

Aleksandrov, G. N. and Kizevetter, V. E., Elekt. Stantskii (USSR) No. 4, 70-3, 1964. (Russian).
The flashover of polluted insulation is investigated on a statistical basis. The probability of flashover is obtained for a range of voltages.

Baatz, H., et al., Conf. Internat. Grands Reseaux Elect. (CIGRE), paper 212, 1964.
Field experience with outdoor insulators in pollution areas is described, and the performance of insulation under conditions of pollution is discussed.

Ely, C. H. A. and Lambeth, P. J., Proc. IEE A111, 991-7, 1964.
Surface breakdown of insulators subjected to pollution is examined. By varying the salinity of a saline fog the maximum value of voltage at which the insulator will not flash is determined. By comparison, this is found to be a valid guide to the performance of insulators in service.

Gregoire, C., Conf. Internat. Grands Reseaux Elect. (CIGRE), paper 211, 1964.
Outlines work being done and results so far obtained in the investigation of insulator pollution in Belgium.

Gutman, Yu. M., Elekt. Stantsii (USSR) No. 10, 59-64, 1964. (Russian).
Describes the results of a series of tests on the flashover voltage of long strings of insulators under switching surges. In particular, it was found that polluted insulators did not flashover at voltages less than clean insulators for long strings, but the effect did become important for short strings.

Hampton, B. F., Proc. IEEE 111, 985-90, 1964.
The mechanism of flashover of polluted insulation is discussed. The formation of dry bands due to the passage of current and the subsequent growth of discharges on the surface is studied by scanning the voltage distribution along the strip at high speed. It is found that the condition for arc propagation over a resistive surface is that the surface voltage gradient exceed that in the arc column.

Jacottet, P., Elektrotech. Z. (ETZ) A85, 257-61, 1964. (German).
The influences of frequency and sparkover distance on the breakdown strength of rod gaps and insulators when stressed by switching surges are examined.

Kelnar, O., Elektrotech. Obzor. 53, 252-4, 1964. (In Czech.).
Insulators were subjected to current of 10 ka for times of 0.3 to 0.6 sec. These events did not damage insulators sufficiently to endanger operation of the line. When one chain link is punctured, there is a high probability of a cascade flashover.

Kläy, H., Elektrotech. Z. (ETZ) A85, 289-93, 1964. (German).
The breakdown voltage of insulators suspended in air is lower for negative pulses than for positive pulses, especially in rain. This is explained in terms of two different conduction mechanisms, the discharge being uniform with positive voltages, but streamers forming with negative voltages.

Kopeliowitch, J., Conf. Internat. Grands Reseaux Elect. (CIGRE), paper 228, 1964.
The effects of climate and pollution on the performance of insulators on hv networks in Israel are discussed. A number of parameters are considered.

Many, A. and Goldstein, Y., Surface Sci. 2, 114-9, 1964. (Physics and Chemistry of Solid Surfaces Conf., Providence, 1964.
Surface breakdown of germanium occurs with fields at the surface of 10^4 V/cm. Breakdown occurs by quantum tunneling between slow surface states and semiconductor bulk.

Maxwell, W., Elect. Rev. (England) 174, 949-50, 1964.
Describes a detector which senses the amount of pollution on an insulator and operates a washing system when a predetermined level is reached.

Näcke, H., Elektrotech. Z. (ETZ) A85, 361-70, 1964.
Deterioration of insulators due to impurity accumulation on the surface is reviewed. Moisture or arcing on the contaminated surfaces accelerates degradation either by direct surface flashover or by thermal degradation with the material due to increased conductivity.

Ouyang, M. and Clowes, R. J., ERA Report (England) S/T 110, 2-30, 1964.
Flashover tests using 1/μsec impulses on the S.E. Asian wood Keruing are compared with Douglas fir and pine. Moisture effects and the effects of flashovers are discussed.

Parnell, T. M., Inst. Engrs. Austral., Elect. Mech. Engrg. Trans. EM-6, No. 1, 1-6, 1964.
The origin and effects of transients resulting from insulation flashover at power frequencies are discussed. Test results are given.

Parr, D. J. and Sarisbrick, R. M., Conf. on Dielectric and Insulating Materials· IEE, London, 1964.
The surface tracking resistance and erosion resistance of a range of synthetic insulating materials have been measured under polluted conditions. A theoretical explanation is attempted.

Rashkes, V. A., Elekt. Stantsii (USSR) No. 2, 66-8, 1964. (Russian).
The effect of natural rain on insulator strings is reported for areas containing large amounts of heavy industry. After rain began, test voltage was applied to insulator at about 2.5%/sec up to flashover. For light drizzle flashover occurred either close to the dry-flashover voltage or to wet-flashover voltage as a result of deposits. The wide spread of results for similar conditions shows that care is required when applying correction factors.

Reynolds, S. I., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 104-8, 1965.
Flashover studies on cylindrical glass rods are described. The flashover is triggered by discharges in a small air gap between rod and electrode. The magnitude of the discharge required to trigger main gap does not seem to depend on gap size.

Starr, W. T., 1964 Annual Report Conf. on Elect. Insul., NAS-NRC Publication 1238, 114-9, 1965.
The problems of insulator design are discussed. Design considerations for maximum flashover voltage in vacuum and in electronegative gases are given. Insulator material and electrode effects are considered.

Thienpont, J. and Sie, T. H., Conf. Internat. Grands Reseaux Elect. (CIGRE), paper 125, 1964.
Surface flashover of the stator insulation is discussed and the steps taken to avoid breakdown are reviewed.

Udo, T., IEEE Trans. PAS-83, 471-83, 1964.
Describes tests for large gaps and long insulator strings using impulse voltages and long tail surges.

Vose, F. C. and Nichols, F. S., Elect. Engrg. 82, 684-8, 1963.
Points out the need for a better insulating element than porcelain for suspension insulators. Describes a modified epoxy-type polymer with a fiberglass core which has been used for suspension insulators.

D. Miscellaneous

Conwell, E. E., Phys. Rev. 135, A1138-40, 1964.
Expressions are derived for the rates of loss of high-energy electrons in a many-valley band structure to acoustic and optical modes. Evaluating these for germanium, the rate of loss to acoustic modes is greater than that to optical modes for electron energies of the order of the energy gap. This is significant in avalanche breakdown.

Davies, D. K., Nature 203, 290-1, 1964.
Using a rotating system by which the surface of an insulator is charged and the charge then measured, trapping parameters are determined for NaCl, KCl, and some polymeric plastics.

Efendiev, A. Z. and Dzhamalov, A. S., Izv. Vysshikh. Uchebn. Zavedenii-Fiz. 124, May-June 1964.
Describes the pulsed electrical breakdown of copper oxide rectifiers.

Goetzberger, A. and Finch, R. H., J. Appl. Phys. 35, 1851-4, 1964.
The uniform avalanche breakdown of silicon p-n junctions shows a reversible reduction of breakdown voltage when mechanical stress is applied. It is suggested the effect is due to a reduction of the energy gap.

Goetzberger, A. and Finch, R. H., Solid-state Electronics 7, 543-5, 1964.
The scratching of diodes which exhibited uniform avalanche effects appeared to introduce about 2.5 x 10^{17} donors into the space charge layer. The breakdown voltage in the damaged region increased for n^+p junctions but decreased for P^+n junctions.

Granger, R., Compt. Rend. 258, 1464-6, 1964.
Capacitance and I/V characteristics of p-n indium arsenide junctions were measured at 77°K. If the junction width is <50 μ a large tunnel effect hinders measurements. For widths >50 μ there is a small tunnel effect and a reverse breakdown field of 5 x 10^4 V/cm is obtained.

Huber, H. J., Rev. Sci. Instr. 35, 1067-9, 1964.
The breakdown of a thin solid dielectric film by means of electrically exploded wires embedded therein is used as a wide voltage range high energy switch. Delay times of 0.1 - 0.3 μsec are found with a jitter of ~0.05 μsec.

Kawamura, N., Phys. Rev. 133, A585-6, 1964.
The breakdown field strength of uncompensated n-type germanium with a donor concentration of 10^{16} cm^{-3} is found to exhibit distinct crystal anisotropy.

Kossov, O. A. and Tsokanov, V. V., Elektrichestvo (USSR) No. 5, 34-40, 1964. (Russian).
The conditions for thermal breakdown of large transistors are considered. In common emitter transistors the breakdown voltage is independent of temperature gas and base circuit impedance.

Leite, R. C. C. and Yariv, A., Proc. IEEE 52, 191-2, 1964.
Diodes of p-n GaAs, which showed spectral narrowing due to stimulated emission at current densities of 2000 A/cm^2 underwent a limited voltage breakdown when forward biased 1.47 v. Experiments were performed at < 20°K.

Melchior, H. and Strutt, M. J. O., Z. Naturforsch. 19a, 563-72, 1964. (German).
The large noise fluctuations observed in silicon diodes in the breakdown region are investigated. The fluctuations are explained by the thermal fluctuations of the breakdown carriers heated by the high field in the transition region of a p-n function. Under certain conditions, fluctuation of the ionization breakdown increases the noise temperature to 10^6 - 10^7 °K.

Morrison, S. R. and Billette, R., Solid-state Electronics 7, 563-74, 1964.
The use of a variable breakdown device as a solid state inductance and for other electronic functions is discussed.

Sakr, M. M. and Salvage, B., Proc. IEE 111, 1176-9, 1964.
An electrolytic tank is used to investigate equipotentials and electric stresses in the analogues of elliptic cylindrical and oblate spheroidal gaseous cavities in solid systems. Good agreement is obtained between theory and experiment.

Sakr, M. M. and Salvage, B., Proc. IEE 111, 1179-81, 1964.
The electric stresses at conducting surfaces located in the field between plane parallel electrodes are investigated using an electrolytic tank.

Salvage, B., Proc. IEEE 111, 1162-72, 1964.
The electric field strengths in cavities between two infinite electrodes are calculated. Expressions are obtained for the field strength on the minor and major axes of the cross-section of an elliptical cylindrical cavity and on the axis and radius of an oblate spheroidal cavity for both dc and ac.

Salvage, B., Proc. IEE 111, 1173-6, 1964.
The maximum electric stresses at conducting surfaces of elliptic cylindrical and oblate spheroidal shape are calculated. The conducting objects are located between plane parallel electrodes.

Strukov, I. A. and Etkin, V. S., Radio Engineering and Electronic Physics 9, 615-8, 1964.
The anomolously high negative currents observed in semiconductor instruments operating in microwave fields when biased close to the region of forward conduction is examined. Premature breakdown only occurs when frequency is less than carrier lifetime.

Tager, A. S., Fiz. Tverd. Tela. 6, 2418, 1964. (Russian).
Current fluctuations in a semiconductor (dielectric) under conditions of impact ionization and avalanche breakdown.

Zschauer, K. H., Z. Naturforsch. 19a, 653-5, 1964. (German).
The breakdown voltage of planar and mesa silicon diodes is calculated assuming an avalanche breakdown process and accounting for field distortion at the edges of structures. Good agreement is obtained with experiment.

V. General Breakdown References

Anderson, C. J., Dielectrics, London: Chapman and Hall, 1964.
This volume covers the whole field of dielectric phenomena. Chapter 8 - Dielectric Breakdown - considers intrinsic breakdown of solids, thermal breakdown, discharge (or corona) breakdown, and the breakdown of liquids.

Hampel, C., (Editor), Encyclopedia of Electrochemistry, Reinhold Publishing Company, 1964.
Contains short articles on the dielectric properties of vacuum, gaseous and liquid dielectrics, and ceramic insulation.

Miller, H. N., Nondestructive High Potential Testing, Hayden Book Company, New York, 1964.
Discusses briefly the theories of breakdown of solids, liquids, and gases.

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3/24/67	NBS-Mrs. Luckett	Stop 3[illegible]
Library		