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Solid State Physics in the People's Republic of China

A Trip Report of the American Solid State Physics Delegation

Edited by ANNE FITZGERALD and CHARLES P. SLICHTER

Submitted to the Committee on Scholarly Communication with the People's Republic of China

National [illegible] Council

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PREFACE

The U.S. Solid State Physics Delegation visited China in September 1975 under the auspices of the Committee on Scholarly Communication with the People's Republic of China (CSCPRC), a group jointly sponsored by the National Academy of Sciences, the Social Science Research Council, and the American Council of Learned Societies. The topic of solid state physics was first suggested by the CSCPRC in the fall of 1974 during negotiations for the 1975 exchange program with China, whereupon China's Scientific and Technical Association (the Committee's counterpart organization) proposed a reciprocal exchange. As a result of this agreement, the Committee hosted a delegation of Chinese physicists in March and April 1975. During their 5-week visit, which took them to universities, companies, and government laboratories, as well as to the American Physical Society's annual March meeting in Denver, the Chinese met many American scientists, some of whom were to appear in China just 6 months later.

Two important considerations influenced the selection of the American delegation members. First, the choice of research areas in the People's Republic of China is closely linked to potential applicability. Second, in recent years Chinese universities have been making major innovations in their system of education. Accordingly, the American delegation was chosen to include solid state physicists who were familiar with basic research and with applications, with the education of solid state scientists, and with their work after graduation.

Four members of the delegation have spent their careers solely in academics, but with close ties to industry. The other six have worked both in industry and in universities. (Four are currently in industry and two in universities.) In addition to these ten, the delegation included an historian of China, a staff member of the CSCPRC, and an American foreign service officer stationed in Peking.

In selecting members of this delegation, an important criterion was the wide range of scientific interests of each individual. Although each delegation member was interested in seeing work in his own area of expertise, be it low temperature physics, semiconductors, theoretical physics, lasers, biophysics, or other topics, the main purpose of this visit was to learn about work in the areas that are of major interest to Chinese solid state scientists. The delegation's general expectations were to gain an understanding of China's approaches to science education and basic science and its applications.

With little previous knowledge of solid state physics in China, we planned the trip by relying on a few published accounts of recent visits to China, on consultation with several physicists who had recently visited China, and on suggestions provided by the Chinese delegation that visited the United States. Taking as a base the institutions represented by the Chinese group, we drew up a suggested itinerary that was sent to China in July. With the exception of visits to the Fukien Institute of Matter Structure and to the Shanghai Institute of Metallurgy, all of these requests were met. Moreover, our hosts in China understood the spirit of our advance letter (Appendix A), which emphasized our desire to concentrate on scientific and technical matters and to promote in-depth discussion by dividing into small groups and visiting only a small number of institutions, with 2 or 3 days at each.

The trip began in Peking with visits to the Institute of Physics, the Institute of Semiconductors, the Institute of Biophysics, Peking University, Tsinghua University, and a semiconductor equipment factory. A 2-day excursion to Sha Shih Yu brigade in Tsun Hua county, 3 hours from Peking by car, provided an opportunity to see a commune and small-scale industries in a rural area. In Sian we visited Chiaotung University, and in Nanking, Nanking University. After a sightseeing stop in Wuhsi, we proceeded to Shanghai, where we visited the Institute of Optics and Fine Mechanics, the Institute of Ceramics

(Silicates), Futan University, and the Shanghai Number One Machine Tools Factory, which inaugurated the system of July 21 schools, or technical colleges. The details of the itinerary appear in Chapter Two and in Appendix B. A list of our Chinese hosts may be found in Appendix D.

At each institution that we visited, we provided several copies of both a short and a long version of a biographical statement about all members of the delegation. The long version may be found in Appendix C. It was our hope that the long version would be of interest to our hosts since it demonstrates how the American solid state physicists couple academic work with industry and government, and basic research with applications. Both versions included pictures to help our hosts identify the members of the group. We recommend that future delegations distribute in advance enough copies of a long version of biodata that all scientists who meet with delegation members have the opportunity to familiarize themselves with the group's interests. Short versions of biodata may then be distributed at the time of the visit, as reminders of the interests and faces of the Americans.

As gifts to our hosts at various institutions, we brought with us copies of an audio tape and an accompanying script describing the history of superconductivity. This tape is part of a series called "Moments of Discovery," produced by the American Institute of Physics as an experiment in education at the high school and college levels. The series features interviews with scientists about important discoveries in which they took part. The tape we brought to China consists of an interview with Bob Schrieffer about the joint work of Bardeen, Cooper, and Schrieffer, and of an historical account by Charlie Slichter, setting the discovery in context. We are grateful to the American Institute of Physics, especially to Bill Koch and Joan Warnow, for providing us with copies of the tape for this trip.

During our travels we were accompanied by three very able Chinese, Mr. Lu Ching-t'ing (Figure 1) from our hosting organization, the Scientific and Technical Association, Mr. Wang Ju-ching (Figure 2) from the Planning Bureau of the Institute of Physics, and Ms. Wu Ling-an (Figures 2 and 3), a physicist from the Institute of Physics who served as interpreter. In no time at all, they learned to read our minds and were ever adjusting the program to suit our needs. Their energy, efficiency, and genuine friendliness were major factors

Figure 1 Lu Ching-t'ing, from our hosting organization, the Scientific and Technical Association, accompanied us throughout our trip. Here he is shown on the boat trip at Shanghai that was part of the October 1 celebration.

Figure 2 Wu Ling-an, physicist from the Institute of Physics, was our able interpreter, and Wang Ju-ching, of the Planning Bureau of the Institute of Physics, was untiring in making arrangements to fulfill our needs.

Figure 3 Anne FitzGerald and Wu Ling-an on the river trip at Shanghai, October 1.

in the success of our visit, and their interest in forthright communication helped to set the tone for a very satisfying and deep experience.

Our interactions with Chinese scientists were open and direct. A large amount of work and careful thought had obviously gone into the preparations for our visit at each university and institute. Both by their flexibility in adjusting the program and by their cooperation in answering our regular barrage of very specific questions, our Chinese colleagues revealed their desire to share information.

A typical visit began with a briefing on the institution, generally by a nonscientist, presenting the basic facts and developments since the Cultural Revolution. Following the briefing several of the host scientists would give talks on their current research, after which we would visit relevant laboratories. In order to cover more ground, the group usually divided into two, both for the talks and for laboratory visits. On occasion we had four groups simultaneously pursuing separate programs, and sometimes the delegation would separate to visit two institutions concurrently. On several occasions members of the delegation gave talks at an institution or at the hotel in the evening. We hosted several informal gatherings at the hotel for a few Chinese scientists to express our thanks. These sessions also provided valuable opportunities for further interchange.

Wherever we went, Chinese scientists asked us for our criticisms and suggestions. We interpreted "criticism" to mean "appraisal," not "faultfinding." However, it was clear that we had only limited qualifications to criticize, since there are so many features of the Chinese system that we understand only in part. We felt, however, that the continuing technical-scientific dialogue that took place during our visit provided a type of exchange that we were competent to undertake, and we urged our hosts to consider that dialogue as our response to their call for criticism. In preparing this report, however, we felt that it would be useful to all readers as well as responsive to our hosts' request for criticism if we attempted to make judgments, draw conclusions, and even make recommendations for the best ways to achieve the objectives of our hosts (as we understood them). In evaluating our comments readers must keep in mind the short duration of our visit, the small number of institutions that we visited, and the facts that most of us are not China specialists and that our judgments are inevitably influenced by our own experiences and backgrounds. We have tried to be careful to make it clear when we are reporting facts and when we are speculating or making judgments. We hope our work stands up under the scrutiny of those more knowledgeable than we.

In our report we make many statements that aim to present accurately solid state physics and technology in the People's Republic. Chinese scientists have made remarkable strides in a few short years. At times, however, we compare their work to research in the United States, making remarks such as "they are 5 years behind the United States." Such comments should not be considered pejorative but rather as efforts to assess truthfully their rate of progress. That they are behind in certain instances is no surprise, for their program started much later than ours; the United States itself had a similar experience with reference to Europe. At present China is striving to establish a broad scientific base through mass involvement and education. The progress that has been made in this short time-frame should be a source of great pride and encouragement to Chinese scientists.

The report consists of six chapters and five appendixes. The first chapter outlines the Chinese scientific tradition and describes aspects of scientific and political development since 1949 that bear relevance to the science of today. This chapter discusses the Cultural Revolution and its effects on science and education in order to set the context for our findings. The second chapter provides basic facts about the institutions we visited, serving, in addition, as a narrative of the trip. In Chapter Three we discuss research in solid state physics, topic by topic, and in Chapter Four, the education of solid state physicists. Chapter Five describes the communication and assimilation of scientific information among research institutes, universities, and factories in China. In Chapter Six we present some reflections on our visit.

The five appendixes include our original letter of requests sent to China, our day-by-day itinerary, the long version of the biographical information we distributed in China, the names of the Chinese scientists we met, listed by institution and by field of activity, where possible, and physics curricula at Chinese universities.

1

THE ROOTS OF SCIENCE IN CHINA TODAY

A. SCIENCE IN TRADITIONAL CHINA

To appreciate China's scientific achievements today, it is helpful to trace the history of scientific effort in China: the initial flourishing, then the hindered development, and finally the recognition of the social value of science. Since the early days of the People's Republic, scientific development has been affected in major ways by organizational changes and, perhaps more significantly, by changes in attitudes toward the role science should assume in a developing society. A discussion of these trends may help to explain the scientific work we observed in China in 1975.

Until late medieval times, China was in many ways ahead of Western Europe in technological inventiveness and systematic exploration of natural phenomena. Among China's early accomplishments were the development of paper, printing from movable type, the magnetic compass, the mechanical clock, the suspension bridge, gunpowder, the wheelbarrow, the stern post rudder, the draw loom, and deep drilling techniques. It was in China that the foundations of seismography, cartography, aspects of mathematics, astronomy, and pharmacology were laid. By about A.D. 1300, however, China's early scientific and technological advantage over the rest of the world had dissolved as a result of complex social and economic factors. Early achievements as important as those cited above were not formulated into a body of scientific principles that could be transmitted to and developed by future scientists. Why did science fail to develop further in China after the thirteenth century? European society responded vigorously to the surge of scientific discoveries, but China's traditional ways remained largely unchanged by the advent of science in the West. The reasons for these opposite responses have been analyzed in recent years by Joseph Needham, the foremost Western historian of Chinese science, and even more recently by Chinese scientists, historians, and the general populace. The issues encompass much more than would be possible to develop here. What follows must be seen only as a superficial and tentative sketch of some of the main theories about the dwindling of scientific activity in China after the thirteenth century.

The nondevelopment of science in China is attributed by many scholars to the nature of the Confucian system. The focus of learning in Confucian China was on social and personal relationships, not on the bridling of nature by man. In Joseph Needham's words, Confucians "always considered that the only proper study of mankind was man. They were thus, throughout Chinese history, in opposition to those elements which groped for a scientific approach to Nature, and for the scientific interpretation and extension of technology."[1] While recognizing the usefulness of China's early technological inventions, the Confucians refused to admit the necessity for detailed and tedious processes of scientific logic and investigation. Accordingly, little systematic thought or theoretical interpretation developed from the early discoveries.

Although the rationalism of Confucian thought might well have promoted scientific investigation, the Confucians' concomitant lack of interest in nature inhibited such developments. On the other hand, there were several other contemporary schools of thought, particularly Legalism and Taoism, that were immensely interested in exploring the mysteries of nature. The Legalists, especially, are regarded by present-day China as having been responsible for most of the scientific and technological achievements cited above.[2] Unfortunately, the overpowering political influence of the Confucian school virtually

[1]Needham, Joseph, *Science and Civilization in China*, Vol. II (Cambridge: Cambridge University Press, 1962), p. 9.
[2]Li Chun, "The Struggle Between the Confucian and Legalist Schools and Ancient China's Science and Technology." *Peking Review*, No. 47, Nov. 22, 1974, p. 8.

suppressed the growth of Legalism to the point of near-extinction around A.D. 1300.

One of the factors that inhibited scientific thought was the Confucian philosophy of education. The emphasis on humanistic studies was reinforced by the educational system, in which students spent years memorizing the large body of Chinese classics in order to pass the civil service examinations. As they learned by rote, students received little training in critical thinking. Moreover, the Chinese language, being pictorial and figurative, did not lend itself to the development of a system of logic. In short, the sheer investment in time to learn the written language and to master the classics allowed little room for other intellectual activities.

The limits set by the educational system had wider social implications which affected the development of science. Scholars comprised the highest social class while craftsmen and merchants comprised the lowest. Scholars confined themselves to mental activity, while manual labor was reserved for the working classes. As John Fairbank points out,

> This separation of hand and brain stands in marked contrast to the example of the early European pioneers of science from Leonardo on down, who often came from the tradition of craftsmanship and, although scholars, were not debarred by the mores of their society from setting up their own laboratories. In early modern Europe the heritage of learning and the manual skills of technology might be focused in one man of genius. This seldom if ever happened in China.[3]

Some practitioners of science, such as the court astronomers, established a niche for themselves in the social structure. But many scientists -- the Taoists, for instance -- remained outside the social system, tolerated but regarded as eccentrics and never appreciated as valuable members of the society. After the reign of Han Wu Ti (140-87 B.C.), when Confucianism gained the upper hand, the Legalists, too, were disfavored.

Economic circumstances also inhibited the development of science. Private enterprise was never completely free from competition with state monopolies, and businesses using new inventions or machinery were likely to be ignored or else exploited by the dominant official

[3]Fairbank, John K., *The United States and China* (Cambridge: Harvard University Press, 1971, 3rd edition), p. 70.

class. Individual enterprise and inventiveness were, therefore, discouraged. Moreover, due to the abundance of manpower, there was little incentive to invent labor-saving devices.

The Confucian state had followed established patterns for centuries; to alter the momentum of its cultural, social, political, and economic institutions was next to impossible. It was not until the Western incursion into China and the wars of the middle and late nineteenth century that the stability and self-sufficiency of the Confucian system were seriously threatened and that new forces, including science, were able to influence Chinese society.

B. THE BEGINNINGS OF WESTERN INFLUENCE IN CHINA

By the early twentieth century, China's deficiencies in technology could no longer be ignored. Embattled both militarily and economically with the West, the declining Ch'ing dynasty was forced to recognize Europe's technological superiority. Young Chinese intellectuals began to attribute their country's relative backwardness to its lack of modern science. Manchu leaders, in an eleventh hour effort to preserve their rule, reluctantly undertook a program of economic and social reform, making concessions to Westernizing trends. Dynastic politics continued to thwart these reforms. After the fall of the dynasty in 1911, the debate in China over social modernization centered around "democracy" and "science" as perhaps the only means for a national revival.

Although democracy did not take root, the pleas for scientific development brought forth results. In 1914, the Science Society of China was established and soon began publishing a monthly journal. The founding of the Academia Sinica in 1928 continued the trend of establishing modern scientific institutions in China. At the same time, research institutes were formed, and students began studying science and technology in the universities. In addition, thousands of young men and some young women went abroad to be educated in Japan, Europe, and the United States. Although science in China before the Second World War was still largely imitative of European and American research, an organizational framework was finally set up, and the general populace had come at last to believe in the social utility of science. When, in 1949, the People's Republic began restructuring scientific organizations, it was able to draw talent from an existing scientific community.

C. SCIENCE IN THE PEOPLE'S REPUBLIC OF CHINA: BEFORE THE CULTURAL REVOLUTION

The merging of the Academia Sinica and the Peiping Research Academy to form the Chinese Academy of Sciences occurred shortly after the establishment of the Chinese People's Republic in 1949. The new Academy was modeled after the Soviet All-Union Academy, becoming the center of research activities and the main recipient of state funds for science. For several years the scientists themselves drew up programs of research in the departments of the Academy, enjoying considerable independence, until in 1956 the Scientific Planning Commission was established as the organization responsible for science policymaking.

From 1949 to 1957, the Soviet Union was the primary influence in the formation of the Chinese research system. Thousands of Soviet experts helped set up programs in China, bringing with them blueprints and technology. China's main science policy objective at that time was to build up a capacity to perform its own research and development, with an emphasis on heavy industry, as in the Soviet Union.

Higher education, too, was reorganized along Soviet lines. As a result, engineering and vocational technical courses were excluded from the university curriculum and taught in separate institutions. While some scientists and engineers studied after graduation at research institutes of the Academy of Sciences and in university graduate programs, most young scientists went abroad for their training, especially to the Soviet Union, during this period.

In addition to establishing centralized institutions, the Chinese Communist Party began the process of remolding scientists ideologically. A great many Chinese scientists had been trained in capitalist countries, where they acquired attitudes considered "bourgeois" by the Party. Under the new system, scientists would have to give up their accustomed autonomy and their individualistic approach to their work.

An impression of this period may be gleaned from the *Biographical Memoirs* of Kathleen Lonsdale, who visited the People's Republic of China for 3 weeks in 1955. In her notebook she recorded the details of her visits to different laboratories and to a People's Court and of talks she gave. She also made brief notes of a conversation she had with Professor Huang Kun, who had worked with Max Born long before. These notes provide an interesting glimpse of scientific concerns in China at that time.

There was one story of China Kathleen Lonsdale liked to tell. Some of her colleagues in Manchuria asked her: "How far behind the West are we in our technology?" A little cautiously, trying to be as kind as she could, she said, "About twenty years." They laughed and said, "Splendid, we have caught up ten years in one year. Professor Bernal was here last year and he told us we were thirty years behind."[4]

As the 1950's wore on, differences between China and the Soviet Union emerged on many levels. In 1956 Khrushchev condemned the Stalinist era and set Soviet policy onto a new course emphasizing technological achievement rather than Communist ideology. The Chinese never accepted Khrushchev's repudiation of Stalin and viewed Khrushchev's policies as an abandonment of the goals of socialist revolution. (Today Stalin's portrait is prominently displayed in China alongside those of Marx, Engels, Lenin, and Chairman Mao.) Although Russian influence continued in China until the break in relations in 1960, the Chinese were already dissatisfied with their new Soviet-style system by the late 1950's.

A major change in policies occurred during the Great Leap Forward (1958-1960), a program which further strained relations with the Soviet Union. At this time, Chinese scientists were asked by their government to turn their attention to particular technological requirements stemming from new economic policies, which stressed agriculture and light industry. Scientific development was to be directed by social and economic needs, and the pursuit of pure science was discouraged. As the scientific system was decentralized, so was research to be linked with production, in accordance with the new policy of "walking on two legs" in economic and technological development.

The popularization of science became an important goal by 1958, with a proliferation of science committees at provincial and county levels and of "scientific research groups" in factories and villages. At the same time, a system of spare-time vocational training was inaugurated, run by universities, factories, local governments, and

[4]*Biographical Memoirs of Fellows of the Royal Society*, Vol. 21, 1975, pp. 470-71. Kathleen Lonsdale, by Dorothy M. C. Hodgkin, O.M.F.R.S.

trade unions. After the Soviet withdrawal from China in 1960 and with the end of the Great Leap Forward, scientific organizations underwent a considerable change. The predominance of ideology and politics during the Great Leap Forward was exchanged for a concern for providing a better professional research environment. The years 1961 to 1965 witnessed the reintroduction of academic and material awards for invention. Science focused on basic research and on military and industrial technology. During these years of Liu Shao-ch'i's ascendancy as Chairman of the People's Republic (1959-1966), it was argued that modern research, by its very nature, must be separate from ordinary production activities. The "Liu Shao-ch'i line" was to come under heavy fire during the Cultural Revolution.[5]

D. THE CULTURAL REVOLUTION

What was the Great Proletarian Cultural Revolution of 1966-1969? Observers do not have a single interpretation, for its character was extremely complex. One school of thought holds that it was primarily a power struggle between Mao Tse-tung and his arch-rival, Liu Shao-ch'i, while another school stresses the "Red" versus "expert" conflict (the conflict between those who believe that ideology is most important and those who opt for technological progress.) Those who seek an explanation in the cultural aspects of this upheaval argue that the rationale behind the Cultural Revolution was the necessity to thoroughly root out the many vestiges of the old China that still existed. Some point out that Chairman Mao initiated the Cultural Revolution in order to break down the increasing rigidity of creeping bureaucratism and to liberate the revolutionary spirit. To promote the development of this spirit, Chairman Mao wanted to give Chinese youths, too young to remember the Liberation personally, a direct taste of revolutionary experience. He hoped thereby to make his belief in "permanent revolution" live on even after his own death.

Since all these interpretations have been put forward by respectable China scholars, it is not our function to discuss them in detail.

[5]Sources from which the information in the section on science in traditional and pre-Cultural Revolution China have been drawn are Dean, Genevieve and Manfredo Macioti, "Scientific Institutions in China." *Minerva*, v. XI, No. 3, July 1973. Suttmeier, Richard P., "Science Policy Shifts, Organizational Change and China's Development." *China Quarterly*, June 1975.

Recognizing that the Cultural Revolution may indeed encompass all or nearly all of the elements mentioned above, let us focus on the magnitude and the impact of the Cultural Revolution.

For our purposes, the term Cultural Revolution must be construed in its largest sense: the sense of all components which make up a civilization. It penetrated every aspect of Chinese life in its attempt to uproot lingering traditions which ran counter to socialism. The Cultural Revolution aimed at a transformation of the relationship between the rulers and the ruled, the elimination of privileges and bureaucratism, the replacement of material incentives by moral incentives. The social cleavage between brain workers and manual workers came under attack, and the goals of education were thoroughly re-examined while universities and schools suspended normal operations.

Mao Tse-tung's struggle with Liu Shao-ch'i was not just a quarrel between two people, nor just a conflict of doctrines. It resulted from a complex of social and ideological contradictions, aggravated by growing material privileges, bureaucratic tendencies, and difficulties in keeping up with the rhythm of Mao's policies. Mao Tse-tung could not solve these problems simply by stripping his opponents of their jobs and influence. Rather, he had to try to undermine the ideological and social foundations of their policies. To this end he used the radical youth groups called the Red Guards to attack rightist elements in the society. In fact, the whole population was mobilized to criticize anything and everything in the society that had been subject to the influence of tradition. The call to criticize the workings of the state led to attacks on people in positions of authority -- a process which has continuing ramifications today for those in any kind of leadership position.

During the Cultural Revolution, many of the feelings underlying the Sino-Soviet split came into play. The Soviet Union's "backsliding into bourgeois habits and corruption" and its "abandonment of the revolution" under Khrushchev served as an alarm signal to the Chinese: China could also fall prey to the same phenomena. The "negative example" of the Soviet Union continues to spur Chinese leaders today to pursue policies which are true to the original goals of the Chinese revolution.

The Cultural Revolution is seen in China as the most important watershed since the founding of the People's Republic. Everywhere a visitor hears comparisons of "before" and "after" the Cultural

Revolution. These comparisons revolve around the difference between a bureaucratic-professional system involving central control, professional expertise, and material incentives, and a system based on ideological incentives, emphasizing the elimination of elitism, the integration of mental and manual work, and mass participation and decentralization. What does this mean, specifically, for the conduct of scientific and educational activities?[6]

E. THE EFFECT OF THE CULTURAL REVOLUTION ON SCIENCE, TECHNOLOGY, AND EDUCATION

The impact of the Cultural Revolution will be manifest throughout this report as we make specific observations on science, technology, and education in China. We shall leave the finer nuances to later chapters providing at this time only a general model drawn from information we were given in China modified by an occasional comment.

The Cultural Revolution has brought about a reorganization of relationships between scientific and academic institutions and the society at large. To lessen the isolation of academic institutions typical of pre-Cultural Revolution days, research institutions and universities have been restructured to relate actively to the society, combining research with production. Some of the measures taken were the establishment of production facilities within institutions and of links between universities and local factories or communes, the periodic dispatching of scientists and engineers to rural areas, and the system of sending all middle-school graduates to work in factories, communes, or army units. Research since the Cultural Revolution has become applications-oriented in order to fulfill immediate industrial, agricultural, military, economic, and social needs. As a result, basic research lacking identifiable immediate practical goals has been, on the whole, strongly discouraged. Some exceptions can be found in the fields of science that probe the large questions about the nature of the universe and of life, such as particle physics, astrophysics, cosmology, and microbiology.

The experience of operating a Soviet-style differentiated system, in which organizations were distinguished on the basis of specialized

[6]Source materials for this section are: Daubier, Jean, *A History of the Chinese Cultural Revolution* (New York: Vintage, 1974). Suttmeier, Richard P., *Research and Revolution* (Lexington, Massachusetts: Lexington Books, 1974).

functions, was said to lead to a stratification of society which should be avoided under the new system. The Chinese are now willing to sacrifice a certain efficiency or rationality in the hope of promoting wide popular involvement and mass initiative in applications of science. Their belief in the creativity of the masses has encouraged trial-by-error efforts by ordinary workers, particularly in agriculture and simple machinery. Scientists, in turn, are directly involved in social and economic realities. The Party goal is to greatly reduce previous inequalities between brain workers and manual workers, between industry and agriculture, and between the city and the countryside.

Decentralization has been a major trend since the Cultural Revolution. The Chinese Academy of Sciences, for example, has maintained direct control over only 17 of its former 120 research institutes; 19 institutes are now under the dual jurisdiction of the Academy and provinces or municipalities, with the latter as the main authority, according to the slogan "dual level of leadership, with the locality in charge." The remaining 70 percent have been placed directly under local authorities and industrial enterprises. Decentralization has been enhanced by the large-scale movement of urban personnel to the countryside, inaugurated during the Cultural Revolution. In the words of Richard Suttmeier, "the vision being institutionalized (is) that of a highly decentralized society, committed to regional development in which much of science and education are locally administered and closely related to local industry and a local resource base."[7]

Self-reliance and self sufficiency have assumed an important role in this new vision of Chinese society. Each locality is encouraged to become a self-sufficient unit, undertaking its own research and production. Given the poor communications system and the high cost of transport, the advantages of this policy are clear. China's historical predilection for local and regional economic independence continues to make sense today.

However, local self-sufficiency also implies duplication of effort. This duplication clearly slows the pace of progress in scientific research, as does China's policy of self-sufficiency in science and technology vis-à-vis the rest of the world. At the same time, the

[7]Suttmeier, Richard P., "Science Policy, Organizational Change and China's Development." *China Quarterly*, June 1975, p. 227.

"do-it-yourself" attitude does provide personal satisfaction for the individual and encourages widespread involvement in solving local and national problems. With regard to nations more advanced in science and technology, China now feels greater pride and self-respect because it works on its science and technology independently, rather than depending on direct help from abroad. While it appears that the Chinese are interested in learning of developments abroad and in looking for impartial guidance, it is also clear that they are bent on discovering their own solutions, appropriate for the unique conditions of China.

Perhaps the most independent and far-reaching reforms resulting from the Cultural Revolution occurred in the educational system. Chairman Mao specified in his directive of May 7, 1966, that students should learn industrial, agricultural, and military work in addition to their courses. Education should not consist of "bookish learning," but should be oriented toward practical objectives and problem solving.

The first step after the Cultural Revolution was to shorten the period of schooling: primary school to 5 years, middle school to 5 years, and university to 3 years. (Recently some university programs have been extended to 3½ or 4 years.) University students now spend one-third of their time doing practical work in factories, communes, or the army.

The selection of students for university has also changed radically, no longer catering to a small urban elite. All middle school graduates must engage in at least 2 years of practical work before becoming eligible for university, and the basis for selection no longer rests on academic credentials and examinations but rather on their performance during those years of work as judged by fellow workers, both in terms of ability and in terms of political consciousness and motivation. A student is typically sent by his or her local unit to be educated for a specific task, filling an identified need of the sending group. The student generally returns to this group upon graduation. Thus, students do not switch curricula in college and cannot be allowed to fail, since they are being trained to fulfill a recognized need.

Upon graduation, the students are assigned to positions by higher authorities, to go where they can best "serve the people." Although no examinations or grades are given, a report is written about each student describing his or her strengths and weaknesses. Because of small student-faculty ratios and close contacts between students and teachers, the students' abilities are probably well known without formal examinations.

The scientific training in universities, as in the technical colleges, emphasizes middle-level technical and engineering training, appropriate for the current levels of production technology. In tailoring the curricula to a 3-year program, universities have eliminated many courses in basic theory and other courses deemed nonessential to the student's special field of interest. The fields are selected to fill specific technological needs required by specific production operations. Political education is an important part of the curriculum. The trend since the Cultural Revolution, therefore, has been to produce engineers and technicians whose skills may be used for immediate production needs, rather than broadly based scientists. Through this new system of education, China is trying to avoid the development of an intellectual elite. Although our main concern was solid state physics, we tried to gain some feeling for the benefits and possible difficulties that may be encountered with the new system of education, which the Chinese themselves say is still in the "experimental stage" and subject to change.

2

VISITS TO RESEARCH INSTITUTES AND UNIVERSITIES

A. INTRODUCTION

THE SCIENTIFIC AND TECHNICAL ASSOCIATION

The Scientific and Technical Association of the People's Republic of China hosted our visit to China. It is an organization of professional societies and other technical groups, formed in 1958 by a merger of the All China Federation of Science Societies and the All China Association for the Dissemination of Technical Knowledge. The Association's membership consists of all specialized societies in China, such as the Physics Society, the Geological Society, and the Automation Society, as well as a national committee of 100 individuals. The present acting director is Chou P'ei-yuan.

There is considerable overlap in the leadership of the Scientific and Technical Association and the Chinese Academy of Sciences. In fact, these two organizations are housed in the same building in Peking. This close connection sometimes leads to confusion among foreigners about the roles and functions of the two bodies. The main distinction lies in the fact that the Academy is a government organization and the Scientific and Technical Association is a "mass" organization, and therefore considered nongovernmental. The Academy is under the leadership of the State Council, ranking on a par with

Figure 4 On our arrival in Peking, we were met by a group of our hosts, who made us welcome in the airport waiting room while the formalities of arrival were handled efficiently by others. From left, seated, are: Conyers Herring, Wang Shou-wu, Director of the Institute of Semiconductors, Anne FitzGerald, Lu Ching-t'ing of the Scientific and Technical Association, our interpreter Wu Ling-an, Miss Fu, Feng Yin-fu of the Scientific and Technical Association, Shih Ju-wei, Director of the Institute of Physics, Charlie Slichter, Bob Schrieffer, and Sam Chu. Standing are Wang Ju-ching of the Institute of Physics and Pat Wardlaw of the U.S. Liaison Office. Many members of the delegation had met Wang Shou-wu and Feng Yin-fu in the United States in April when they traveled as members of the Chinese Solid State Physics Delegation of which Wang Shou-wu was Chairman.

ministries, such as the Ministry of Agriculture and Forestry or the Ministry of Public Health, while the Association works under a broadly based scientific leadership. Mass organizations, like the Association, are gaining in importance in present-day China, and there is some speculation that the Scientific and Technical Association may eventually assume more and more of the Academy's responsibility. At this time, however, the Academy ranks highest among scientific organizations. It has a key coordinating role in scientific planning, being directly responsive to the State Council in determining science policy. Of course, the Academy is also responsible for supervising the work of the various research institutes under its mantle. In short, the Academy is a research organization and its members are research institutes, not individuals. (It is not an honorary society, and it has discontinued the system of electing scientists to become Fellows of the Academy.) The Scientific and Technical Association is charged with popularizing science and implementing the "mass line" in science; its activities have grown increasingly broad and varied in recent years.

The Association conducts work in five areas: domestic exchanges in science and technology, publication of scientific journals, dissemination of scientific and technical knowledge to the Chinese people, international exchanges in science and technology, and the study of Marxism-Leninism and Mao Tse-tung Thought. Through its international exchange program, the Association invites foreign scientific organizations to send groups to China and sponsors the travel of Chinese scientific and technical delegations abroad. The visit of the American Solid State Physics Delegation is one example of this program.

B. RESEARCH INSTITUTES AND UNIVERSITIES

This section describes the research institutes, universities, and factories we visited, city by city, and the next section briefly describes our sightseeing excursions, which balanced the professional visits. The five universities we visited are national universities under the Ministry of Higher Education; of the five institutes, the three in Peking belong to the Academy and the two in Shanghai to the local government.

PEKING

Our trip began in Peking. During our 10 days there, we visited the Institute of Physics, the Institute of Semiconductors, the Institute of Biophysics, Tsinghua University, and Peking University, as well as a semiconductor equipment factory. We were welcomed most graciously at a banquet hosted by Wu Yu-hsun, Vice Chairman of the Revolutionary Committee of the Scientific and Technical Association (Figure 5). In addition, we had several opportunities for informal evening discussions with Chinese scientists.

Figure 5 The welcoming banquet was hosted by Wu Yu-hsun, Vice Chairman of the Scientific and Technical Association and Vice President of the Chinese Academy of Sciences. Seated prior to a delicious dinner of Peking duck are Anne FitzGerald, Charlie Slichter, Wu Yu-hsun, John Bardeen, Pat Wardlaw, Bob Schrieffer, and Bob Silsbee. Shih Ju-wei is in the right foreground.

THE INSTITUTE OF PHYSICS We visited the Institute of Physics for three full days, September 5, 6 and 8, and observed activity in every department of the Institute. A small group also saw the library, and the three theorists in our delegation met with theorists from the Institute one afternoon, while the others were listening to talks. On the last afternoon five members of the delegation gave talks in two separate conference rooms (Figure 6). At all times we were divided into two groups in order to cover more ground and to gain a deeper understanding of the work being undertaken in each department.

Figure 6 Our hosts invited members of our delegation to give lectures at some of the institutions we visited. Here John Bardeen lectures on one-dimensional conductors at the Institute of Physics.

We were particularly grateful for this arrangement, as it enabled us to have excellent communications with a small group at a time.

The program organized by our hosts at the Institute was most satisfying and conducive to a rewarding interchange. We found our host scientists willing and eager to share their work and to answer our questions thoroughly. The director of the Institute, Shih Ju-wei, spent a considerable amount of time with us, and the many scientists we met gave us a very full impression of the Institute's work.

The Institute of Physics is one of the 17 institutes which have remained directly under the control of the Academy of Sciences since the reorganization that followed the Cultural Revolution. It was set up in 1950 and has been especially active since 1958. There are eight departments in the Institute: plasma physics, magnetism, lasers, crystallography, low temperature, high pressure, acoustics, and theoretical physics. The staff numbers 700, 90 percent of whom work in the laboratories.

The magnetism group was started in 1950 as one of the first activities after the Liberation. The current activities of this group concern magnetic bubbles, microwave ferrites, magnetic thin films, and theory.

The crystallography group has about 50 workers and has been involved in crystal growth since 1958. This group also studies crystal structure by means of x-ray diffraction and measures physical properties of the crystals being grown. Materials of current interest are yttrium aluminum garnet-neodymium, lithium iodate, and gadolinium gallium garnet.

In the low temperature department, we visited five laboratories where various aspects of research and equipment were discussed: an effort making a superconducting gravity meter for detecting earthquakes; niobium sputtered films, used to make Dayem bridges; a new effort concerned with tapes of niobium-Sn; a dilution refrigerator under construction, which will be the first such refrigerator in China; and the low temperature group's helium liquefier, which they have had since 1964 and have improved periodically. (It can now produce 20 liters/hr.)

The laser group was started in 1970. There are at present four subgroups: holography, optical processing, nonlinear optics (started in 1974), and semiconductor lasers.

Three activities of the high pressure group were described to us: static synthesis of diamond, shock synthesis, and apparatus for P-V studies to 45 kb.

The ultrasonics laboratory works in three areas, each described to us in a talk: ultrasonic holograms, high power transducers, and surface waves.

The plasma group was begun in 1973, after a study of the Western literature for one to two years. This preliminary study was carried out by five workers, two of whom had obtained advanced degrees in the USSR. None, however, had previous experience in plasma physics. The group now contains twenty workers, scientists, and technicians. We saw a small Tokamak machine, which was completed in July 1974. We also met with the laser-plasma interaction group. The preparation for this group started in 1972, experimental work was begun in 1973, and construction of the laser system was completed in 1974. The group now consists of ten people. Finally, we saw a plasma pinch experiment.

The theory group consists of about ten physicists, working in such areas as relativity and quantum field theory. In addition, each of the other seven departments of the Institute has a few theoretical workers. The magnetism group, for instance, has five theorists. Thus, the total theoretical staff of the Institute numbers several dozen. Some topics studied by the theory department are: superconducting tunnel junctions, especially those involving Nb; spin-wave modes in the range of conditions where magnetic dipolar interactions are important; relativistic moving-medium electrodynamics; the gauge theory of gravitation; optical information processing and analog-type optical simulation of computers; crystal growth; the not-yet-understood phenomenon of increase in neutron scattered intensity in a static electric field; and the scaling law for magnetic phase transitions.

<u>THE INSTITUTE OF SEMICONDUCTORS</u> On September 9 and 10 we visited the Institute of Semiconductors. Wang Shou-wu, the Deputy Director of the Institute, greeted us on the steps. For most of us his was a familiar face, as he had headed the delegation of Chinese solid state physicists who visited the United States in March and April of 1975. He had also met us on our arrival at Peking Airport.

The Institute of Semiconductors is housed in four buildings of traditional Peking architecture with a total area of 10,000 m^2, near the site of the original building established for research in physics

Figure 7 A portion of our group on their departure from the Institute of Semiconductors. Among others of our Chinese friends are: Row two, fifth from left, Wang Shou-wu, Vice Director of the Institute; second from right, Chen Ke-ming, our host at the Institute; far right, Sung Chen-hua, who works on integrated circuits; and left foreground, Miss Fu, who accompanied us on visits in Peking.

and chemistry under the Academia Sinica in 1911. The original building is no longer used for research. Because it is near the center of the city, dust is a major problem for semiconductor research, particularly for integrated circuits. Security was tight at the entrance to the complex and to the various buildings. This was the only institute where we were not allowed to take photographs.

At the initial reception for the U.S. delegation, Wang described the organization of the Institute and the major problems in which it is engaged. Semiconductor research in China started in 1956 in the Applied Research Section of the Institute of Physics. Semiconductor devices were made as early as 1958. The Institute of Semiconductors was established as a separate Institute of the Academia Sinica in 1960 with a staff of 100. Growth of silicon crystals and production of silicon devices began in 1963. The first integrated circuits were made in 1965. At present there is a staff of 900, of which 600 are involved in scientific research, including 400 university graduates. The Institute is divided into seven laboratories working in four major areas:

- Semiconductor materials--studies of Bridgman gallium arsenide for use as laser substrate, liquid and vapor phase epitaxial gallium arsenide for making microwave devices, and epitaxial silicon for integrated circuits.
- Integrated circuits technology--computer-operated mask making, MOS circuits stability and control, and passivation and reliability studies.
- Microwave devices--silicon impatt diodes as well as gallium arsenide Gunn devices and avalanche oscillators.
- Semiconductor Lasers--emphasis on gallium arsenide and gallium aluminum arsenide heterojunction lasers.

The dust problem is said to be too great to make integrated circuits, so that the emphasis in this area is on the development of the technology. Work on reliability and failure analysis is closely related to work in semiconductor factories.

According to Wang, two characteristics of the Institute are crowded working conditions, since the Institute is located in the center of the city with no room to expand, and an especially large number of younger scientists. A large percent of the technicians are trained by the Institute, including scientists and engineers, sometimes through classes but mostly through discussion with more experienced workers.

The program at the Institute consisted of visits to laboratories as well as talks by some of the scientists about their work. One talk concerned an extension of the work on avalanche oscillators that Wang talked about at the Denver American Physical Society meeting in March 1975.

THE INSTITUTE OF BIOPHYSICS While half the delegation remained at the Institute of Semiconductors on the afternoon of September 10, the others visited the Institute of Biophysics. Here Pei Shih-chang, the Director, met us on the steps and spent the whole afternoon with us (Figure 8). Mr. Pei visited the United States in November 1972 as head of the first multidisciplinary scientific delegation from China hosted by the Committee on Scholarly Communication with the People's Republic of China and the Federation of American Scientists.

The Institute of Biophysics was established in 1958 under the auspices of the Chinese Academy of Sciences (CAS). It was formerly part of the Institute of Experimental Biology and the Institute of

Figure 8 Pei Shih-chang, Director of the Institute of Biophysics, together with other members of the Institute, welcomed our group at the entrance to the Institute.

Physiology and Biochemistry of the CAS in Shanghai. The latter was divided in 1958 into three separate units: the Institute of Physiology, the Institute of Biochemistry, and the Institute of Biophysics. The first two remained in Shanghai, while the Institute of Biophysics was moved to Peking.

There are 350 research workers and 50 technical workers at the Institute, scattered in several buildings. The Institute consists of seven divisions and one small library. Radiobiology is the largest division. The other divisions are molecular biology, cell biology and fine structure of cells, technology, the physics of receptors, experimental technology, and crystal structure.

After listening to Mr. Pei's introduction, we visited a large number of laboratories, ending with a laboratory in which we saw a beautiful model of the crystal structure of insulin and two radiation labs. The last three laboratories were at the Institute of Physics, 5 minutes' drive away.

TSINGHUA UNIVERSITY Tsinghua University, sometimes called the MIT of China, was founded in 1911. Since 1952 it has been devoted exclusively to education in engineering and technology. We visited this university on September 11 and were greeted by Chang Wei, Vice Chairman of the Revolutionary Committee, and by other members of the university. There are 11 departments: Electrical Engineering, Mechanical Engineering, Automation Engineering, Radio Engineering, Precision Instruments, Electrical Power, Engineering Physics, Engineering Mechanics, Chemical Engineering, Architecture and Civil Engineering, and Hydraulic Engineering. The faculty numbers 3,000 and the students, 8,000. In the fall of 1975, 3,000 more students entered the university. The first batch of students since the Cultural Revolution, numbering 2,000, graduated in 1974. The length of the program has been reduced from 6 years to 3 1/2 years since the Cultural Revolution.

In accordance with the "open door" policy in education, students engage in productive labor in addition to their course work. The university has set up 25 factories and workshops that produce 60 different products. There are 80 major research projects. Through its production efforts, the university hopes to become financially self-sufficient.

Tsinghua also enrolls 40-50,000 students per year in short-term courses and correspondence courses. Many faculty members spend part of their time teaching in communes, and workers are invited to the university to lecture; hence, the "open door" method of operation.

We spent the morning visiting laboratories and workshops, and in the afternoon, those present divided into two groups for parallel discussions about the revolution in education. The atmosphere became increasingly open and informal, and we found this session to be

Figure 9 Chang Wei, Professor of Mechanics at Tsinghua University, and Anne FitzGerald exchange words of farewell after our visit. Next to Chang is Ma Wen-chung, Vice Head of the Administrative Office of the Revolutionary Committee. Bob Schrieffer (left) and Bob Silsbee (right) stand behind.

extremely valuable in developing our understanding of the goals and practices of education in China today.

PEKING NUMBER ONE SEMICONDUCTOR EQUIPMENT FACTORY While some members of the group remained at Tsinghua University in the afternoon to discuss education, the others visited Peking West District Number One Factory, which produces semiconductor equipment. After an initial briefing by the Vice Chairman of the Revolutionary Committee, we toured some of the facilities, including a product display room, circuit assembly and testing rooms, and shops for transformer assembly and heating coil winding. Throughout the afternoon, factory spokesmen emphasized the self-help, self-educated orientation of the design and production process.

The factory was started as a collective in 1958 by a group of seven housewives, who began manufacturing weights and measures of the simple string-and-beam variety used in the produce markets. In 1965 the collective responded to "an urgent need of the country for diffusion furnaces" and learned how to produce diffusion furnaces based on a 1965 Tsinghua University design. With great effort and perseverance, a group of eleven women studied at Tsinghua for 2 months, learning to read circuit diagrams and studying production methods such as soldering. No one in the group had more than a middle-school education. This study period was followed by practical experience in the Tsinghua production factories. After seven months' effort to set up a production line, the first furnace was completed in May 1966. They started with two lathes, a drill press and little capital. Since they were a self-owned collective, the state would not provide capital, so they continued making their old products (weights and measures) to generate capital. The collective was taken over by the state in 1970.

In the last 10 years, the factory's product line has been diversified to include such items as transistorized cardiographs, photoelectric radiometers for temperature measurements, and ultra-clean laboratory rooms. The total value of production had grown from 500,000 Y in 1965 to 11,000,000 Y in 1971 (1 yuan = $0.52).

About 350 employees are working in three small plants. There are now a few workers who have returned after some university training in such fields as integrated circuit design, but there is still a shortage of technically trained people. The factory still has no university graduates in electronics, although it does have some in machine building. The factory is considered a major producer of diffusion furnaces, supplying over 20 Chinese firms. Three models were displayed at the Canton Trade Fair in 1974.

PEKING UNIVERSITY On two mornings, September 12 and 13, we visited Peking University, which is renowned not only for its academic excellence but also for its revolutionary tradition. The university was founded in 1898. In 1918 and 1920 Chairman Mao came to the university to study Marxism-Leninism, and the famous May 4th Movement started at Peking University in 1919. It was here that the first "big character poster" went up, inaugurating the Cultural Revolution.

We were met by the Vice Chairman of the Revolutionary Committee, Chou P'ei-yuan, who was about to set off for the United States as head of a multidisciplinary delegation representing the Scientific and Technical Association. We were also delighted to see Huang Kun, a member of the Chinese Solid State Physics Delegation which visited the United States in the spring of 1975. We had already talked with him at two evening events, discussing what we were interested in seeing at Peking University. He quickly caught on to our interests, and, together with others at Peking University, arranged a program most satisfying to us.

The university has faculties of liberal arts, sciences, and foreign languages, with 20 departments and 75 specialties. There are 2,600

Figure 10 At the farewell ceremony at Peking University, Charlie Slichter presents the American Institute of Physics' tape on the history of superconductivity to Huang Kun as a memento of this visit and of the visit to the United States of the Chinese Solid State Physics Delegation, of which Huang was a member. On the far left is Chu Sheng-lin, Professor of Magnetism, and on the far right with his back to the camera is Chang Lung-hsiang, officer of the Revolutionary Committee.

members of the teaching staff and 5,300 students, with 2,700 additional students enrolled in the fall of 1975. The first class admitted since the Cultural Revolution, numbering 3,000, graduated in 1974. In addition to regular courses, refresher and short-term courses lasting from 1 month to a year are offered to students outside the university. Last year these students numbered 40,000.

The physics department has four specialties: theoretical physics, laser physics, low temperature physics, and magnetism. Theoretical students study for 4 years while the others study for 3½ years. There were 300 physics students at the time of our visit, growing to 500 later in the fall. The faculty numbered 200. Most scientific research projects are chosen in response to the needs of Peking Municipality, as well as various ministries of the government and the Academy of Sciences. Some projects, however, are developed for educational purposes. Although there are only four specialties in the physics department, related topics such as radio, electronics, and geophysics are taught in separate departments.

On the morning of September 12, half of the delegation concentrated on lasers, and the other half on low temperature physics and magnetism. The following morning consisted of visits to laboratories and a general discussion on science education, when we were again divided into two groups.

TSUNHUA COUNTY

We took a break from physics on September 15 and 16, visiting a commune and small-scale industries in Tsun Hua County, 3 hours by car from Peking. This excursion provided a great opportunity to see the flat, dry countryside east of Peking, giving us a feel for life on a commune. Having learned at the universities about the dispatching of students to the countryside, we were able to pursue the matter, this time from the commune members' point of view.

Upon returning to Peking we hosted a banquet for our Peking friends. We greatly enjoyed such opportunities to continue previous discussions and feel that these occasions furthered our mutual understanding and friendship.

On the afternoon of September 17, we flew to Sian, and were welcomed by a banquet hosted by the Shensi Provincial Revolutionary Committee. On the following day we visited Chiaotung University.

SIAN

CHIAOTUNG UNIVERSITY Chiaotung University, founded in 1896, was originally located in Shanghai and moved in 1956 to this new, completely planned campus in Sian. It is a technical university with 25 departments, including mechanical engineering, electrical engineering, power engineering, and radio engineering. There is no physics department as such; semiconductor work is carried out as part of the engineering program. The university maintains 40 laboratories. The university's factories produce lathes and radio components, and there are several small power plants located on campus. In addition, the university has links with more than 70 factories.

Chiaotung University reopened in 1972 after the Cultural Revolution, and there are now 3,800 students regularly enrolled. The staff numbers 3,000, including 1,000 active teachers. Seven thousand students are enrolled in 110 short-term courses.

During our 1-day visit we divided into two groups, one focusing on semiconductors and the other on strength of materials. In addition to hearing several talks, we visited laboratories, metal working shops, and the library. In the afternoon there were two separate discussion sessions.

NANKING

Since we arrived in Nanking on a Saturday night, the next day, Sunday, we spent sightseeing. That evening we were welcomed by a banquet hosted by the Kiangsu Provincial Revolutionary Committee. On Monday and Tuesday we visited Nanking University.

NANKING UNIVERSITY On the morning of September 22, we were met by about 19 physics professors and teachers, and were given an introduction to the university by Kao Chi-yu, Vice Chairman of the Revolutionary Committee. The university was founded in 1902 as South East University of China. It was later called Central University until it assumed its present name in 1949.

Nanking University has 12 departments: Chinese literature, history, politics, foreign languages, astronomy, mathematics, physics, chemistry, biology, geography, geology, and meteorology. The first class since the Cultural Revolution was recruited in 1972 and graduated in 1975. There are now 3,300 students, including the newly-arrived

Figure 11 The delegation says good-bye at Nanking University. Kao Chih-yu, Vice Chairman of the Revolutionary Committee and Professor of Chemistry receives the thanks of Chairman Charlie Slichter while all of our hosts look on. To the right in front is Ouyang Jung-pai, Responsible Person, Revolutionary Committee of the Department of Physics.

first-year students. The university also runs 600 correspondence courses and many short-term courses for several thousand students.

Four hundred and forty students are currently enrolled in the physics department, not including those participating in correspondence courses and other short courses. The teaching staff in physics numbers 270, with another 120 on the supporting staff. The seven specialties in physics are low temperature, crystallography, semiconductors, magnetism, radio physics, acoustics, and nuclear physics. The facilities of the physics department were rather crowded at the time of our visit, but we saw in the distance the new physics building, which should have been completed by the end of 1975.

On both days we divided into a low temperature group and a crystallography group. The first day involved talks and lab visits in the morning and parallel discussion sessions in the afternoon. On the second day members of our delegation gave talks, which were followed by discussions. There were also separate meetings of our theorists with theirs, a session with acoustics specialists, and a visit to the library.

WUHSI

Our 2-day stop in Wuhsi gave us a chance to relax, to enjoy scenic spots and boating on the lake, and to visit a silk filature factory and a commune. At the commune we had a very informative discussion with leaders and members of the commune after visiting the commune's fish ponds, pearl hatchery, hospital, and small-scale industries. Until evening fell, we discussed the economics of the commune and the selection of students for higher education as seen from the commune members' point of view. We were particularly grateful for the time and effort taken by our hosts to explain the system to us in detail. This visit provided much valuable information and helped us understand a number of areas which had been unclear in our minds.

SHANGHAI

In Shanghai we visited three institutions and one factory, as well as a workers' village, the Municipal Museum, the famous Industrial Exhibition, and other sightseeing spots. It was here that we participated in the National Day festivities, celebrating the founding of the People's Republic of China on October 1, 1949. We were glad to be present on this occasion. Our hosts in Shanghai were put to the test by our many requests for adjustments in the program, but they succeeded in giving us a rich and informative stay.

On September 27 the delegation divided into two groups for the whole day. One group visited Futan University while the others went to the Institute of Optics and Fine Mechanics.

Figure 12 Ivar Giaever and John Bardeen with Hsieh Hsi-te, Professor of Semiconductor Physics, and Lu Ho-fu, Professor of Theoretical Physics, with Futan University buildings in the background.

FUTAN UNIVERSITY Founded in 1905, Futan is a university of arts and sciences, with 13 departments. The college of arts has seven departments: Chinese literature, history, philosophy, political economics, journalism, foreign languages, and international politics and affairs. The college of sciences has six departments: mathematics, physics, chemistry, biology, optics, and atomic energy. In addition to these departments, there are research laboratories for linguistic research, historical geography, genetics, and mathematics.

There are presently 1,900 teachers, 2,000 workers and administrators, and 3,200 students at the university. In 1974 the university set up a postgraduate training program for 113 students. In addition, correspondence courses enrolling 17,000 students were set up in 1974 in four far-flung provinces: Kiangsi, Anhwei, Yunnan, and Heilungkiang. One hundred teachers take part in these correspondence courses. The university also conducts 90 short-term courses for 6,000 students.

The university has three factories. The first is a general electronics and instrument plant, which makes semiconductor components, including single crystals of Si and GaAs, Si integrated circuits, and electronics instruments. Next is an optical plant, producing electro-optic sources and gas lasers. The third is a petrochemical plant, producing intermediates (e.g., for use in grain fermentation) and high polymers. The university has a close relationship with 80 factories and communes outside the university. Teachers and students work at these factories and communes for short periods and may even carry out their research and development work there.

Our delegation divided into a semiconductor group and a laser group with separate activities, including discussion sessions in the afternoon. Three members of the delegation met with Futan theorists and two visited the library. As our trip was drawing to a close, we found ourselves asking a great many questions which we had neglected previously. Our Futan hosts tackled our questions in a very gracious and friendly spirit.

THE INSTITUTE OF OPTICS AND FINE MECHANICS Three members of the delegation visited the Institute of Optics on September 27. The Institute was founded in 1966, has about 1,000 workers, including 400 researchers, and is concerned with modern physical optics.

The Institute is housed in several large, well-equipped buildings and contains optical laboratories of high quality. Well-prepared expositions were presented to us, using fine line drawings of good legibility with English subtitles. These aided the animated technical discussions. Good projection facilities were available for the slides used in a talk given by a member of the U.S. delegation at the end of our visit. From the discussions it was apparent that the non-Chinese laser literature was followed rather closely in the Institute of Optics.

SHANGHAI NUMBER ONE MACHINE TOOLS FACTORY The delegation visited the Shanghai Number One Machine Tools Factory on the afternoon of Sunday, September 28 (Figure 13). Mr. Chou Ting-cheng described the plant, led us on a tour, and entertained questions at a discussion session. This factory is famous for founding the first July 21 school, which provides extra training *in situ* for selected factory workers. Chairman Mao first visited the factory on July 8, 1957, which suggests that the training of technicians from among the workers had begun even then. The name "July 21 school" originated from a report signed by Chairman Mao on July 21, 1968, in which he commented on the factory's program of training technicians and called upon other factories to "put proletarian politics in command and take the road of the Shanghai Machine Tools Plant in training technicians from among the workers." Inspired by this recognition, the factory instituted a college-level course for training machine tool design engineers in September 1968.

Figure 13 Ivar Giaever and three machine tool operators at the Shanghai Number One Machine Tools Plant.

The factory now employs about 6,000 workers and staff, producing over 70 types of machine lathes, some of which are exported to over 30 countries. In addition to its ten workshops, the factory runs four schools: the July 21 school, which trains machine tool designers; a technical school for training technicians; a spare-time school; and a primary school.

In the July 21 school, students (about 100 at a time) study full-time for 3 years. Their courses include political study, labor (students return to their regular jobs for two months of the year), military training and agricultural work, and technical courses. The technical courses consist of higher mathematics, engineering mechanics, electrical engineering, hydraulics, design and manufacture of machine tools, mechanical drawing, and English.

There are some 500 July 21 schools in the Shanghai area, but this one, with 109 students, is one of the largest run by a factory. Shanghai Municipality also runs July 21 schools, drawing students from the small factories that have no means with which to set up their own schools. The municipal July 21 schools are the largest, as they gather students from many factories. Municipal July 21 schools fulfill a particular need, each teaching a specialty; they are regarded, therefore, as supplementary educational institutions, not as replacements for regular university education.

The Shanghai Number One Machine Tools Factory uses three other methods for educating factory workers. The first is the "three-in-one" method, whereby workers, leading cadres, and technicians work together to increase the theoretical knowledge of the workers. The second is the spare-time school, in which the worker selects his own subject. The third method is to send workers to ordinary universities.

Like most large factories in China, this factory has a research institute. Examples of topics they pursue are the development of a digitally controlled machine for making curved surfaces and a laser distance measurer for their 5-meter planer. Two hundred eighty people are employed in the research institute, one-third of whom are researchers.

THE INSTITUTE OF CERAMICS On September 29 we visited the Institute of Ceramics, where Cheng Hsi-ch'üan, the Responsible Person of the Revolutionary Committee, gave us a brief introduction to the Institute.

The Institute of Ceramics (also known as the Institute of Silicates) was separated from the Institute for Metals and Ceramics in 1960. There are 900 workers in the Institute's six departments: crystal growth (diamond, quartz, niobates, tantalates), special glasses (chalcogenides, optical, high silica), special ceramics (transparent, ferroelectrics, high temperatures), new analytic methods, instrumental analysis, and a pilot plant and comprehensive workshop.

We heard several talks and visited three laboratories in the crystal growth division in the morning; in the afternoon we listened to lectures and visited laboratories in the areas of special glasses and special ceramics.

Our visit to the Institute of Ceramics was the last professional program on our trip. Thereafter, we enjoyed sightseeing in Shanghai and participated in the National Day celebrations, as will be described in the ensuing parts of this chapter.

C. NONSCIENTIFIC VISITS

Throughout our visit in China we were accorded the most thorough hospitality. Our hosts provided for every need, quietly and efficiently taking care of all the details which one is accustomed to struggling with oneself. A caravan of cars was always at our disposal. Delicious meals would appear on the table without prompting. Wherever we went, we were greeted by welcoming people, all of whom gave much time and thought to our visit.

PEKING, SEPTEMBER 4-17

In addition to the various research institutes and universities, our itinerary in Peking included visits to the Great Wall, the Ming Tombs, the Forbidden City, and the Summer Palace. Before we left Peking for Sian, we also spent the better part of 2 days in Tsun Hua County, visiting the well-known Sha-shih-yu production brigade.

<u>THE GREAT WALL</u> One of the mandatory stops on all China tours, the Great Wall still impresses one with its grandeur and longevity. Completed by the first unifier of China, Shih Huang-ti of the Ch'in dynasty, in 210 B.C., the Great Wall spans some 1,600 miles from the coast just

north of Peking westward to Yumen in the Kansu corridor region. The part of the Great Wall that we visited is near Nanko, some 75 miles by car north of Peking -- a section set aside for the constant stream of visitors (mostly Chinese). The special management of the Wall for tourists is evidenced by a sign, "Visitors please stop," that separates the well-restored section where visitors climb from the rest of the wall, which is crumbling. Huge crowds and an occasional sign cannot detract from the impact of walking on this historical wonder.

THE MING TOMBS Beginning with the reign of the third Ming dynasty emperor in 1403, Peking has been the capital of China, except during the Nationalist Period (1928-1949). Thirteen of the Ming emperors, therefore, are buried in elaborate tombs in a valley two-thirds of the way from Peking to the Great Wall. One of these tombs has been completely excavated, and it is visited daily by a large number of tourists. Of all the historical and archaeological sites we visited, the Ming Tombs carried the heaviest weight of political teaching. Well-designed placards and signs impress upon visitors the exploiting role of the Ming ruling class and the sacrifices of the common people who created the riches unearthed.

THE FORBIDDEN CITY Formerly closed to all but the imperial families of the Ming and succeeding Ch'ing dynasties, the inner quarters of the imperial court, set in the heart of Peking, are now a people's museum. Thronged with tourists on the Sunday of our visit, the palace recreated in our imaginations what the imperial government must have been like when the emperor and his court ruled the vast country. We visited the Palace Museum, which houses a fine collection of archaeological objects from northern China. The museum was formerly open to the public, but now it seems that only a few visiting groups are allowed entry. The entire Imperial Palace complex is presently undergoing a 7-year plan of restoration. We were able to see what it had been and what it will be when the renovation is completed.

THE SUMMER PALACE Set in a northwest suburb of Peking, the Summer Palace impresses the visitor more as an imperial garden than as a palace. In 1153 the Chin emperor Wanyen Liang built the first palace here and constructed an artificial lake. In Ming times the court in Peking came here to avoid the heat, and the residences became known as the

Summer Palace. Sacked in 1860 by European troops, the palace was rebuilt in 1888 by the controversial Empress Dowager Tz'u-hsi, with funds which had been intended for improving the navy. As a gesture toward the navy, a great marble boat was constructed on the lake. Today it is a people's park and a favorite Sunday haunt of Peking residents. In comparison with the Imperial Palace, the buildings of the Summer Palace appeared needlessly ornate, and its grounds, while beautiful, seemed to ramble without design, even in terms of a pleasure garden. Without prompting from our hosts, we found the Summer Palace a reminder of wasteful extravagance set in the sober, hardworking China of today.

<u>THE THIRD NATIONAL GAMES</u> This was one event on our itinerary that could not have been included had we not been in China in September of 1975. China had not held a national athletic meet for 10 years, since before the Cultural Revolution, which makes this meet even rarer than the Olympics. The opening ceremonies to which we were invited reminded us of the Olympics. Seated in the new, 60,000-capacity Workers Stadium (Figure 14), we saw the trooping of the colors and the procession of

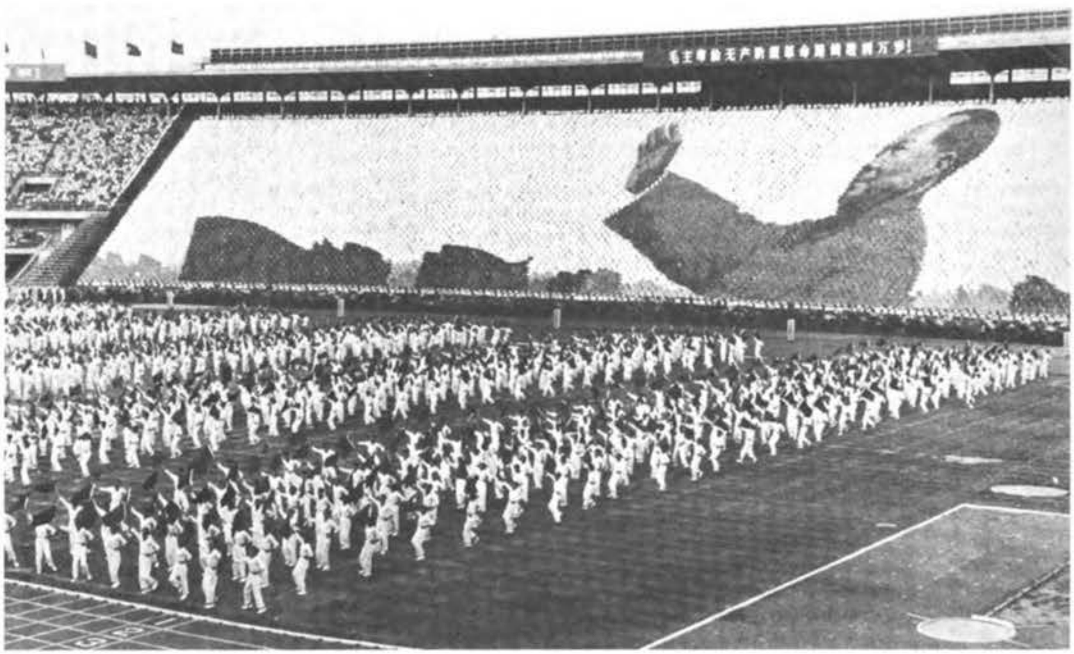

Figure 14 Our view from the grandstands at the opening of the Third National Games.

athletes, province by province, their determined steps set to rousing music. Each group of men and women wore different, brightly colored uniforms as they marched behind a banner proclaiming the name of their province. Then came the real spectacle: eight separate acts of mass display and drills, each involving several thousand performers, all perfectly trained to go through their paces on the field. But the greatest synchronization was demonstrated by the 12,000-person card section, which completely filled one side of the stadium. Through some 60 permutations they never missed a signal, the thousands of colored cards blending perfectly into breathtaking static and dynamic panoramas. We were told that months of rehearsal went into both the card display and the field spectacles, and the results fully justified this preparatory work. It was a truly impressive performance.

GENERAL COMMENTS ON PEKING Although we stayed in Peking for the unusually long period of ten days, most of our time was spent on the serious business of visiting institutes and universities. Our impressions of Peking, therefore, are necessarily sketchy. Today Peking is a vast,

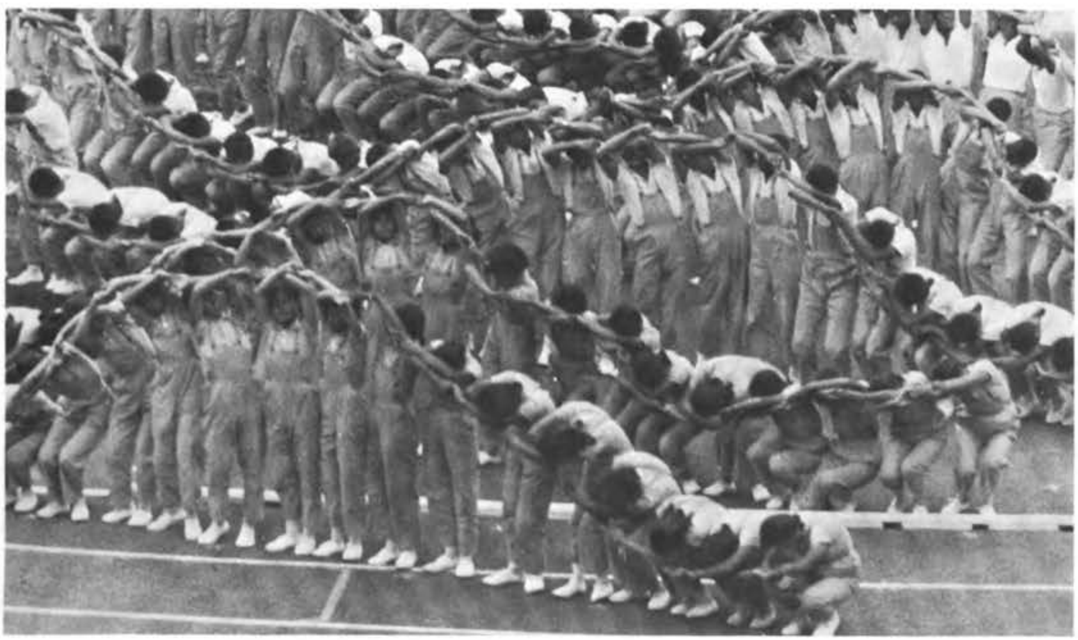

Figure 15 A close-up view, via telephoto lens, of children performing a demonstration of wave motion at the National Games.

orderly metropolis with some seven million inhabitants. The scale of the city is so large that one does not sense overcrowding. In the heart of Peking, where the very modern Peking Hotel is located, there is a changing tempo; the hordes of bicycles are slowly being supplemented with an increasing number of buses, trucks, and government-owned automobiles. One seldom sees an animal-drawn vehicle other than on the outskirts of the city (and, of course, in other parts of China). In the central part of Peking, the numerous government offices and headquarters, with their ever-alert sentries, give a businesslike atmosphere to the city. But the colors remain subdued, gray and taupe, punctuated with yellow sunflowers nodding over the gray outer walls of the houses. Peking at night is even more subdued, with the mist and sweet-smelling smoke from the chimneys lending a comfortable feeling. The city's vibrancy returns in the daylight. We were fortunate to be in Peking in September, when the weather is most pleasant, and the inhabitants of Peking seemed to revel in this special time of the year just before National Day.

TSUNHUA COUNTY (SHA-SHIH-YU BRIGADE), SEPTEMBER 15-16

Proceeding due east from Peking for 150-175 kilometers on generally adequate roads, we reached Ch'engkuan, a town in Tsunhua County, after a 3-hour automobile trip. There we were quartered in spartan but clean guesthouses. On the afternoon of September 15, we were driven 1 hour southeast of town to the celebrated Sha-shih-yu Brigade (which means, literally, "sandy-stony-gulch"). This arid spot at one end of a gentle valley used to be among the most barren land in the country. We were told that, inspired by Chairman Mao and the Communist Party, the people of Sha-shih-yu made the valley fertile by dint of their own determination and labor. It now produces apples, walnuts, and dates, in addition to the staple corn and sorghum crops. In 1966 the brigade finished making a reservoir out of a stone quarry, and for this occasion was honored by visits from Premier Chou En-lai and the President of Albania. Since then this brigade has become a national model. The latest accomplishment at Sha-shih-yu was the digging of a tunnel through a hill which forms the upper end of the valley. Soil from the fertile valley on the other side is now more easily transported through the tunnel. In the past this soil had to be hand-carried over the hill -- an immense job, considering that all of the brigade's crops are grown on "imported" soil. As impressive as the tunnel was, it appeared to us that its value was mostly symbolic, compared to the many other solid accomplishments of this brigade. The day we were there, a group of Frenchmen plus several groups of Chinese were also spending up to half a day at the brigade. That evening we saw movies documenting the history of this unit.

The following morning we were given a tour of the town Production Display Hall and of several small factories. The Display Hall, located on an old temple ground, is set up for visiting groups. The objects displayed were varied and well laid out, and the guides, mostly young women, went through well-rehearsed recitations. The display in the Science Hall was largely concerned with improvements in agriculture.

The factories we visited exhibited much vitality. At the towel and socks factory, Ms. Han, a stocky woman in her late fifties, spoke with great enthusiasm and animation. The machinery was adequate, the workers adept, and withal we sensed a real pride and accomplishment there. The hardware factory made nails, screws, and other small metal products. The managers proudly mentioned that some of their products were exported. At the third factory, one that produced such items as small electric motors, we noted that women workers did wear safety glasses, but as we found elsewhere, the general level of safety-consciousness was not high.

In general, we were impressed by the versatility and self-sufficiency evidenced in Tsunhua County. However, this county has been designated a model for some time (a local guidebook highlights only two model agricultural communes, Tachai and Sha-shih-yu), and therefore cannot be regarded as completely typical of the thousands of rural communes in China.

SIAN, SEPTEMBER 18-20

Aside from Chiaotung University, we visited Hua Ch'ing Ch'ih Villa and Hot Springs, Pan-p'o Neolithic Village, and the Shensi Provincial Museum, with a brief stopover at the mount of Ch'in Shih Huang-ti (the builder of the Great Wall) en route back from the hot springs.

HUA CH'ING CH'IH VILLA AND HOT SPRINGS These famous hot springs turned out to be one of the sightseeing high points of our entire trip.

Celebrated in ancient history as the place where the famous imperial concubine Yang Kuei-fei of the T'ang dynasty (ninth century) loved to bathe, Hua Ch'ing Ch'ih Villa gained further notoriety in the present century as the site where Chiang Kai-shek was kidnapped in the Sian Incident of 1936. Set among several charming ponds against a backdrop of craggy hills, the springs were visually delightful. The responsible cadre who greeted us gave an exceptionally fair account of the Chiang episode, and would have marched us up the hill to the spot where Chiang was actually caught. The day was damp, however, and the paths muddy, so amidst a chorus of apologies, we were treated to the warm baths instead, which we enjoyed thoroughly.

We then drove to the nearby mound of Ch'in Shih Huang-ti. Since it has not yet been excavated, we viewed it only from a distance. Archaeologists believe that buried under the mound are an "inner city" and an "outer city." If the recently excavated life-size figures from nearby mounds are any indication, this imperial mound may well become one of the major archaeological finds in China.

PAN-P'O NEOLITHIC VILLAGE About 6 miles from Sian is one of the largest and most remarkable neolithic sites in China, dating back to 6,000 B.C. Two large adjoining sheds have been constructed over the site to protect the village from the elements and to provide shelter for visitors. The various parts of the village, such as the houses, graveyard, and storage pits, are well marked by signs and serve an excellent educational function. In a separate building is the museum, which houses a variety of artifacts unearthed in similar neolithic settlements in this northwestern part of China. Discovered in 1953 when the foundation of a factory was being laid, Pan-p'o represents some of the substantial archaeological work done since the Liberation.

THE SHENSI PROVINCIAL MUSEUM AND THE FOREST OF STELES This museum has one of the finest archaeological collections in China. Most of the objects were excavated in Shensi Province, a repository of ancient treasures dating from the years when Sian was the political, cultural, and economic center of China (until the fall of the T'ang dynasty in A.D. 907). Recent finds, such as the life-size Han tomb figures, have greatly enriched the collection. The bronzes, pottery, and porcelains are exhibited with ample documentation of their historical and social significance. One of the annex halls contains an impressive collection of stone statues, including life-size animals from T'ang imperial tombs.

The Forest of Steles, begun in 1090, is the oldest and richest collection of steles in China. It is a curious form of archives: Under the T'ang dynasty, the twelve classics were engraved on stone and collected there. The "forest" grew larger as later steles were added in the Yuan, Ming, and Ch'ing dynasties.

GENERAL COMMENTS ON SIAN We were struck by the sharp contrast Sian presented to Peking. The streets were much freer of motor traffic and were sometimes dotted with wandering pigs and chickens. The buildings generally looked much older than those in Peking. The People's Hotel, where we stayed, was a massive gray complex of buildings, an architectural legacy from the period of Soviet influence, dating from the 1950s. Sian reminded us of the regional differences which remain in China. Sian was once a cross-roads between East and West, the biggest military, economic, and cultural center in Asia. It served as the capital of China for 12 centuries, until the center of gravity of Chinese life moved southward during the tenth century. Today, its atmosphere is that of a regional center which has developed much more slowly than some of China's other cities.

NANKING, SEPTEMBER 21-24

On our first day in Nanking, a Sunday, we were taken to see the mausoleum of Dr. Sun Yat-sen, the Yangtze River Bridge, Hsuan-wu Lake, and the Nanking zoo.

Figure 16 After a panoramic view from the top of a seven-story pagoda, we were delighted to rest and quench our thirst with a cool drink. Here Pao Chia-shan, Professor of Physics and Leading Member of the Department of Physics at Nanking University, talks with Bob Schrieffer.

SUN YAT-SEN MAUSOLEUM Sun Yat-sen was the founder of the Chinese Republic in 1911 and a figure revered by both Communists and Nationalists. He died in 1925, and in 1929 his ashes were transported from Peking to an impressive mausoleum constructed for him on the slopes of a beautiful hill just east of Nanking. Today this mausoleum, with its specially made blue tiles adorning the roofs, remains a major landmark. All of the pre-Liberation inscriptions have been preserved exactly as they were. This was one historical shrine we visited that made no reference to the eventful years since the Liberation. Dr. Sun's importance has guaranteed the preservation of the site unchanged.

YANGTZE RIVER BRIDGE In sharp contrast to the Sun Yat-sen mausoleum, this celebrated bridge stands as a giant symbol of China's own efforts under the Communist Party and Chairman Mao. A dream for many decades, the bridge was being built with Soviet technical assistance when the Russians pulled out in 1960. Left in the lurch, the Chinese had to start up again entirely on their own. After some years of delay, the bridge was opened to traffic in 1969. The day we were there, rail traffic was considerable, but there was not much auto traffic on the upper deck of the bridge nor much shipping below it. Nevertheless, we were impressed with the bridge, both as a practical accomplishment and as a symbol. Like the Great Wall, a structure of ancient China, this creation of New China was significant to us.

GENERAL IMPRESSIONS OF NANKING On the night of our arrival, we drove on miles of good roads from the airport to our hotel, beneath an unending arch of trees, delicately illuminated by elegant street lamps. Nanking is a city of trees, as we were told several times, and we were struck by its greenery and charm. The pace of life seemed consistent with the scene, being less provincial than Sian yet more leisurely than Peking. In the city of Nanking, however, foreigners are still relatively rare. That rarity was vividly illustrated when we visited the city zoo, located in Hsuan-wu Lake Park just outside the old city wall of Nanking. Our presence here created quite a stir, and the people turned from the animals to gaze at us, without animosity but with fascination at seeing such strange-looking people among them.

WUHSI, SEPTEMBER 25-26

Our short stay in Wuhsi served as a rest stop, since there was no physics institution to visit. For our hosts, however, it was equally important that we see the communes, silk filature factory, and sanitorium there. In spite of the continuing pace of activities, our view of Lake Tai from the hotel windows and our boat ride in the warm, humid air made this visit truly restful.

Shortly after arriving from Nanking by train, we were treated to an excursion on Lake Tai in a clean, fast, and spacious motor vessel. Our first stop was at the workers' sanitorium, located on an island in the lake. Here workers with respiratory and other noninfectious diseases may spend several weeks, undergoing both Chinese and Western medical therapy. We saw acupuncture, moxibustion, and other heat treatments being administered. The rest of this pleasant afternoon was spent skimming over the lake and making brief stops at scenic spots. The Wuhsi authorities seemed anxious to create a good impression, since the Chinese government is attempting to build up Wuhsi as an alternative to the better-known scenic spots nearby, Soochow and Hangchow. We thoroughly enjoyed the outing.

The next day we visited a silk factory. Amidst mountains of silk cocoons in bags, machines of sturdy (though old) design spun silk into strands. The aged look of the building bespoke years of silk manufacturing.

In the afternoon we visited a roadside commune, which provided an interesting comparison with the northern commune we had seen. Since Wuhsi is in the heart of the silk and fishery industrial areas, the commune grew mulberry trees to feed the silkworms and had some 120 man-made ponds for hatching many kinds of edible fishes. Members of the commune gave us a fish "harvesting" demonstration, after which we visited one of the cultured pearl ponds and a building where voracious silkworms ate through stacks of mulberry leaves, as they have done for centuries. We also visited the commune's hospital and primary school. Our full afternoon ended with a very informative discussion session, from which even our able timekeeper, Mr. Wang, could not tear us away. Our questions kept pouring out!

Figure 17 Jack Gilman, John Bardeen, Pat Wardlaw, and Lu Ching-t'ing inspect a rice-planting machine made by a small commune factory at Wuhsi. The design of this machine is typical of a project involving visiting faculty, students, and factory workers required in the students' senior year in college.

SHANGHAI, SEPTEMBER 27-OCTOBER 2

The last leg of our journey in China was again by train, from Wuhsi to Shanghai. There, aside from research and educational institutions and a factory, we visited the Shanghai Industrial Exhibit, and some of us went to the Shanghai Historical Museum and a workers' village. On the evening of September 30 we were invited to a special National Day Eve program. The next day we participated in the October 1 festivities, watching performances at Sun Yat-sen Park in the morning and cruising down the Whampoo River in the afternoon (Figure 18).

SHANGHAI INDUSTRIAL EXHIBIT This exhibit is a source of great pride to Shanghai residents because it displays what Shanghai alone has produced. Everything from a 15-ton dump truck and other heavy industrial equipment to a wide variety of consumer goods, including traditional handicraft artwork, was exhibited in a large complex of buildings which used to be the Sino-Soviet Friendship Palace. The display gave ample evidence that Shanghai, long the industrial center of the country, continues to hold that distinction in spite of rapid

Figure 18 Hsieh Hsi-te, Bob Schrieffer, and Lin Tsun-chi, laser researcher at the Institute of Optics and Fine Mechanics, on the boat ride at Shanghai on October 1. Lin visited the United States as a member of the Laser Delegation in 1974.

industrialization throughout the country. For our personal shopping we were taken to the Number One Department Store, which was very well stocked but did lack a number of the consumer items shown at the Exhibit, perhaps because they are not yet generally produced. The Exhibit was genuinely impressive, and we understood why this is a mandatory stop for all visitors to Shanghai.

SHANGHAI HISTORICAL MUSEUM Not all of us chose to visit this museum, since some went to visit workers' housing that same morning. The six of us who chose this visit saw a well-run museum consisting of two separate sections, bronzes and ceramics. Drawn from all parts of China, the superb collection is very well exhibited and documented. Having an experienced curator as our guide made our visit even more enjoyable and informative. The museum is open to the general public only 3 days a week, part-time even on those days.

P'EN P'O WORKERS' VILLAGE A second group chose to visit a workers' housing community in the outskirts of Shanghai, a planned community of 4,200 households and 20,000 people, which has been built up in the period since 1959. Related in concept to a number of "planned communities" in the United States, this district was organized to provide not only housing but also stores, schools, nurseries, a health clinic, and recreational facilities for the community. The inhabitants typically work at one of the 15 nearby factories, the stores or other facilities of the district, or a small shoe factory in the district that was set up explicitly to provide the housewives of the community with the chance to participate in productive activity.

After hearing a most informative introduction, we visited the kindergarten, where we were warmly welcomed and then treated to a performance of dances and singing by the class. A brief tour of the shoe factory was followed by a visit to several of the individual apartments in the complex. Though feeling somewhat as if we were intruding, we particularly enjoyed this opportunity to meet some Chinese people in their own homes and to talk with them briefly about their families. The visit was completed as we explored several of the stores available to the workers. We were very appreciative of the warm welcome we received from our guides and particularly from those who opened their homes to us.

NATIONAL DAY EVE CELEBRATION On the eve of National Day, the city suddenly became ablaze with lights. We were taken in our usual motorcade through the holiday throngs, dressed in their cleanest and neatest. The special program took place at the brand-new, air-conditioned Shanghai Sports Palace, which opened in May 1975. There were a dozen acts, ranging from a symphonic piece to acrobats and jugglers to animal acts. (Although there are no longer circuses in China, we realized that special programs like this one in fact contained many of the same acts.) Leaders of the Shanghai municipal government were seated in a prominent section of the stadium. After the program, along with all the other foreign visitors, we were driven in a slow procession through streets lined with cheering crowds and reverberating with the sounds of loudspeakers announcing, among other exhortations, that we were in China to witness the vast advancement of the country. From the top of the Cathay Mansions, overlooking Soochow Creek and the Whampoo River, we viewed the city dressed in lights before retiring for the evening.

NATIONAL DAY CELEBRATIONS We felt very lucky to be in China on October 1, National Day. Festivities started early in the morning, with crowds of people dressed in their most colorful clothing. Every park in Shanghai had multiple programs of singing, dancing, acrobatics, and

Figure 19 Bob Schrieffer, with a "laser gun," has just scored a hit on a toy enemy tank. The crowd around makes us welcome, as is evident, but also enjoys a chance to inspect foreigners at close range. In the spirit of the Shanghai Industrial Exhibition, the display of a toy gun using a laser is a way of showing the people the accomplishments of their fellow countrymen.

skits going on simultaneously. We were taken to Sun Yat-sen Park, one of the largest parks, and there attended a variety of performances. Well-rehearsed and brightly costumed schoolgirls welcomed us (and sent us off later) with cheers and dancing. Wherever we made an appearance, the people made way and clapped. Everyone was in a holiday mood, and we enjoyed being part of the show.

After lunch at the hotel, we drove to the waterfront where, together with other foreign groups, we boarded the special motorship *Friendship* for a boat ride down the Whampoo River to its junction with the Yangtze River. The 2-hour ride in mild weather was most pleasant. Factories lined the Whampoo banks virtually all the way, and more than two dozen Chinese-made cargo ships of up to 25,000 tons were anchored in the river, among scores of ships from other nations. Shanghai, long the main port of the country, continues to be a bustling shipping center.

3

RESEARCH IN SOLID STATE PHYSICS

A. INTRODUCTION

The visit to the People's Republic of China was exciting for us all. We saw substantial amounts of scientific work that had progressed a long way, from which the citizens of the People's Republic were clearly already deriving important economic and social benefits. Other work was rather recently initiated, for our Chinese colleagues have entered a number of research areas in which they had not previously worked. That they have done so is a measure of their seriousness of purpose.

Every member of the delegation has had the experience of venturing into a new field, one in which other scientists had already developed the state of knowledge and were moving rapidly. We know from personal experience how difficult and discouraging it is to obtain one's first results while others appear to race ahead. Seeing our Chinese colleagues embarking on new paths, cut off from personal visits with other scientists, gave us a strong sense of fellowship with them. It made us realize how much alike we all are, how similar are the hurdles each scientist must overcome. The story of the progress of the Chinese scientists is an exciting one to tell. While past accomplishments are important, equally important are the skill, energy, and determination with which they are working to develop the technology their country needs. We wish them every success in their work, knowing that our sentiments are shared by all scientists around the world.

Chinese scientists are vigorously pursuing research in a number of areas. We visited a large number of scientists in groups small enough that there were genuine scientist-to-scientist discussions of each other's work. In addition, we were fortunate enough to see apparatus firsthand and frequently were shown demonstrations of the phenomena under study. We are deeply grateful to have had such intimate contact. It gave us a real sense of the abilities of the Chinese solid state physicists. They proved to be an extremely talented group, quite competitive in quality with scientists one finds in the good laboratories of other countries of the world. In many instances they were relative beginners in their particular area of research and were thus at a stage of learning through duplication of experiments which were known to work. This is the tried and true method of entry into a new field that is used around the world.

As a result of our close contacts with Chinese physicists, we felt we could form quite accurate impressions of the work they showed us -- probably as accurate an impression as we could have formed on such a visit in other countries. Perhaps the principal difference in our ability to gain accurate impressions in China, as opposed to other countries, was the lack of reprints or preprints. In most countries, one is so showered with written accounts of native research that one worries about one's luggage being overweight at the airport. In fact, to almost every question that a visitor may ask, most hosts will provide a document containing a partial answer. Not only reprints and preprints of scientific work, but tables of organization, lists of personnel, and vital statistics about the organization are all readily available. In China, such printed material is almost never offered. Visitors would be greatly benefited if more material were available. Despite this lack in China, we are fairly confident that our comments on the research we actually saw are trustworthy.

We are less confident, however, that the generalizations we attempt are valid, because we do not know how well we sampled research in solid state physics in the People's Republic of China. One member of the delegation aptly characterized China today as being operated on a "need-to-know" basis. We were given the impression that the People's Republic does not distribute information except to people who need it, and then often only at the actual time they need it. Therefore, the visitor usually finds that even the most helpful person often knows little beyond what applies to his own job.

We asked to visit those institutions which, to the best of our knowledge, were in the forefront of solid state research. We were unable to visit two that we requested. One of them, the Institute of Metallurgy in Shanghai, has been visited by other Westerners and is highly regarded. We had been told by one of them that we should give high priority to going there. Among research we had hoped to see at this Institute was work on the mechanical properties of solids, a topic missing from the research programs of almost all the other places we visited. Moreover, we expected to see work on properties of materials at high temperatures as well as on such topics as composites, materials of significance to applications, for example, in jet aircraft and rockets. We do not know why we were unable to visit this Institute, which other foreigners had seen.

We were also unable to visit the Fukien Institute of Matter Structure. This Institute, to our knowledge, had not been visited by Western scientists, but we felt it must do important work in solid state physics since two members of its staff were members of the Chinese Delegation in Solid State Physics that visited the United States in spring 1975. We were told, however, that at this time Fukien province is off limits to foreigners.

We saw only a small fraction of the research institutes and institutions of higher education active in China today. We suspect, however, that many of those we did not visit carry on work properly called testing and engineering development, since there is a strong emphasis in the People's Republic on research and teaching organizations taking part in the solution of practical problems.

In most countries there are important research activities which are not shown to visitors. In some cases, a company may have a proprietary interest and not wish to reveal its methods to possible competition. In other instances, work is concerned with national defense. Experience with atomic energy shows that the Chinese carry on some major projects requiring a mantle of secrecy. Thus, it is possible that major areas of advanced solid state physics research take place entirely in laboratories not open to foreign visitors.

Perhaps it is logical to conclude that the total absence of work on a technology known to have important military applications outside of the People's Republic of China, and likely to be important to China as well, is good evidence that the work exists in China in a classified arena. Were it not for a policy decision to put such research work under wraps, one would expect to see some nonclassified work in that technology at some of the leading research centers.

Not only did our visit give us a great deal of information, but it also stimulated our thoughts and raised many questions. One area about which we know very little is the process of selection of research topics, such as who initiates ideas and who must approve proposals. What considerations and analyses lead to decisions is another question.

In the United States, there are many separate decision-making systems concerned with selecting topics for scientific research. Each company that carries on research has its own mechanisms and criteria for deciding what research to undertake, and when to drop an unpromising topic. Universities also have their own systems, typically with decisions depending partly on the university faculty and administration, and partly on officials of various government agencies, foundations, or industries from which the university may seek funding. Government laboratories have still other criteria and decision-making organizations. In short, we have a highly pluralistic system in terms of organization and criteria for making decisions.

We have much to learn about these matters in the People's Republic. They are discussed further in the chapter "Reflections on Our Visit." We were surprised to find some topics stressed as much as they were, while other topics were omitted. Generally, we anticipated that at its present stage of development, the People's Republic would be focusing on those areas of science and technology that have proven themselves to be of economic value in the West. We did not expect emphasis on technology which had yet to come into its own economically in the West.

In this chapter we will review the work we saw by fields: semiconductors, lasers, low temperature physics, crystal growth, other fields of solid state physics, and theoretical physics.

B. SEMICONDUCTORS

INTRODUCTION

The Cultural Revolution has reshaped science policy in China. The much-professed objective of relevance has a two-fold impact on semiconductor research: The field of semiconductors had received top emphasis in the general area of solid state physics, and the main goal of research is to build up semiconductor technology, not to advance science per se. China today is still a country severely limited in resources. In its effort to become a modern, industrialized country, it is attempting to build its electronics industry rapidly by accelerating the development of semiconductor technology. As a result, research efforts are applicational in orientation, developmental in nature, and phenomenological in approach. This is the context in which we view and assess semiconductor research in China.

Among the various institutions that we visited, four of the five research institutes have semiconductor activities, the Institute of Biophysics being the obvious exception; there are no exceptions for the five universities. The activities, in order of importance as judged from the amount of effort, generally can be classified into four areas: integrated circuits, injection lasers, microwave devices, and amorphous semiconductors. The Institute of Semiconductors, appropriately, covers all four areas. Work in injection lasers is also carried out at Peking University, the Institute of Physics, and the Institute of Optics and Fine Mechanics. Activities at the Institute of Ceramics deal with amorphous semiconductors. All five universities not only engage in work in integrated circuits but actually have factories on campus for their production.

INTEGRATED CIRCUITS

The emphasis on Si integrated circuits is easy to understand, for they are the base upon which the modern electronics industry is built. Because we were a solid state physics group, however, we did not visit any full-fledged factories -- the Peking Number One Semiconductor Equipment Factory, which makes diffusion furnaces, is more a showplace to illustrate what can be done by determination than it is a typical factory. The most complete production lines for integrated circuits that we saw are at the university factories of Tsinghua and Futan, the former in MOS circuits and the latter in bipolar circuits. The lines include substrate preparation, photolithography, oxidation, diffusion, epitaxy, metallization, and bonding. Conventional techniques are employed at all places. The choices of processes, generally speaking, are as follows: $SiCl_4$ for epitaxy, $POCl_4$ and $B(OCH_3)_3$ for P and B diffusions, Al for metallization, and both ultrasonic and thermal-compression techniques for bonding. The chemicals and materials used are of good quality and highly pure, including the starting single crystals of Si. They are all produced in China and are "commercially" available. The Si-wafer size, however, is typically 1½ in. in diameter as compared to the standard 2¼-3 in. in the U.S. industry. The economy involved in large wafer size is obvious. This fact, then, while it may be merely a matter of standardization, may also reflect to some degree the level of technology and the scale of production.

The equipment we saw in the area of integrated circuits is also manufactured in China, including the diffusion, oxidation, and epitaxy furnaces with automatic control features, the photolithographic apparatuses, and bonders. Of interest is the laser-guided step-and-repeat equipment for mask-making developed at the universities. Cr masks with a life of better than 40 uses are common. Masks with simple patterns can be made at most places (some are better equipped than others), but complicated ones are supplied from outside (for example, the Institute of Semiconductors, where facilities for computer-aided design and operation are available). The alignment equipment is said to be able to register about 1μ under optimum conditions. The production area is air-conditioned and strict rules of cleanliness are maintained: The density of particles larger than 0.5μ in diameter is kept below $100/m^3$ in the diffusion room and below $5/m^3$ in the photoengraving area. Generally, these university factories, being production units, are larger in scale and more complete in operation than any university laboratories for teaching in the United States. However, because they are part of a university, they are dwarf in size and are far behind in sophistication even compared with the small-to-medium U.S. industrial plant.

The university factories are a product of the Cultural Revolution inasmuch as they combine teaching, research, and production (the well-known "three-in-one" principle). Production is probably the main objective. We were told at the technical universities that in-house factory production in various fields would eventually make them self-sufficient. They produce a wide range of products. In addition to the main-line Si-chips, there are, for example, devices such as Si-control-rectifiers, instruments such as dual-trace oscilloscopes, and equipment such as step-and-repeat cameras. It appears that the scale of production determines if a certain product line is to be kept at the universities or transferred to industrial factories. We saw examples of such transfers when large-scale production was warranted.

While one can dispute the wisdom of operating a factory within an educational institution, the university factory does provide an effective means for students to gain practical knowledge and experience, as well as an effective channel for the transfer of technology.

Work related to Si-integrated circuits is carried out at various places. Talks in this area were given at the Institute of Semiconductors and at Chiaotung University. At the former we were told about research on building a library of blocks for mask generation, which paralleled original Japanese work in 1972. We were given an example of the method for making masks for a moderately complex LSI circuit, which has a metallization linewidth and spacing of 4μ and a total of 1 k MOS-memory elements. The yield at present is still relatively poor. Also described was work on Na-contamination in SiO_2 that uses HCl and P_2O_5 for processing and on capacitance measurements and neutron activation analyses for testing, similar to the work pursued in the United States in the late 1960s. The equivalent surface charge density is reduced to the low 10^{10} cm^{-2} region and the stability of the oxide has been brought under control. At Chiaotung University, we heard a lecture and visited laboratories researching the use of amorphous Al_2O_3 in place of SiN_4 in the MNOS memory device. This study is preliminary and can be traced to similar work in Japan in 1972. It is clear from these talks that, although original concepts and ideas are rare, the Chinese workers are rapidly learning techniques developed in other countries. We also saw an ion-implanter at Tsinghua University, a 100 keV machine for P and B implantation. It appears, however, that it has just gone through the stages of installation and testing, and is not yet incorporated into the established production processes.

Overall, we were very much impressed with what we saw in the Si activities. The Chinese scientists deserve enormous credit for their achievement in building up the basic Si technology in a relatively short time with only indirect outside communication and with no outside support. To assess the level of achievement in this area in terms of the state of the art is obviously difficult, considering the complexity and diversity of the technology and the short duration of our visit. It appears that the product capability in China is comparable to that which existed in the United States in the late 1960s. There is little that is produced in an industrial country that the Chinese are not capable of doing, from a television set to a complex computing system. Where China lags is in the degree of sophistication and in the scale of mass production.

In the immediate future, we expect that China will seek to utilize technology achievements to the maximum extent in order to advance economically, broadening the scale of activity to bring about the stated goal of social transformation. In the meantime, the technology level will advance, no doubt in the direction of large-scale integration. No LSI work of any sophistication exists, from what we saw during our visit, but efforts directed toward that goal are clearly visible. The Si-chip produced is aimed at an increasing circuit density, currently 800 ckts/chip of the p-channel MOS shift-register type at the Tsinghua University factory. The mask-making project at the Semiconductor Institute, as mentioned earlier, is said to be able to produce LSI circuits. At Chiaotung University, study in integrated-injection logic has been under way. The recent announcement of a series of sophisticated computers with a capability of 10^6 instructions/sec indicates a vigorous effort in this area. They far exceed in performance the earlier third-generation computers made in China in 1970-1972, including the one we saw at Futan University.

INJECTION LASERS

Next to the integrated circuits, lasers received the most attention and emphasis in the semiconductor area. The emphasis probably stems from the prediction that microelectronics and lasers represent the two areas in which technology will advance rapidly and with great impact. The effort is almost exclusively concentrated on the GaAs-GaAlAs injection laser, particularly the double-heterojunction type. We observed activities using this specific device at all three places mentioned earlier. The growth process used is the conventional liquid-phase-epitaxy. Standard four-layer structures are grown on a GaAs substrate in a graphite boat at different stages, each having its controlled temperature, Al-composition and suitable dopant. The active lasing region is typically p-type, Si-doped GaAs with a concentration of 10^{17} cm^{-3} and a width $\leq 0.5\mu$. The final device geometry is fabricated using both photoetching and proton bombardment, as is used elsewhere. Measurements include time-resolved emission spectroscopy, far and near field emission patterns, temperature rise, threshold current density, and lifetime testing. Good devices operate cw at room temperature with a threshold density of ~1 kA/cm^2 and a lifetime longer than 1,000 hours. It was admitted that the work was relatively new, and no meaningful statistics could be given for reproducibility and lifetime. Work has been started to study the problem of degradation, the same problem that has plagued the injection lasers at a number of laboratories in the United States.

A total of seven talks were given at the Institute of Semiconductors, the Institute of Physics, and Peking University, dealing with either specific aspects of or work related to the injection laser. The effect of heating and thermal resistance on the emission characteristics was investigated. The phase diagram of the Ga-Al-As system in the dilute Al region was studied, and lasing action was achieved in the visible range by replacing the GaAs with a dilute GaAlAs in the injection region. In the case of Zn and Si, the effect of impurity compensation on emission behavior was pursued. The last talk dealt with optimizing the laser characteristics in terms of the parameters affecting growth by use of an orthogonal matrix method. This method, which is not commonly used in the United States, is apparently quite popular in China in investigations where a large number of controlling parameters are involved.

All the talks given in this area were well organized and clearly presented. The work itself was carried out in a competent and professional fashion, although few novel features were in evidence. The approaches and interpretations were still basically empirical in nature, but the speakers did show concern for the underlying physics in their work -- a departure from many talks we have heard in other, perhaps more engineering-oriented, areas.

Other efforts that we have encountered in the injection-laser area involve the preparation of materials. One deals with the detailed purification and processing of GaAs infrared emitting diodes for application as a range finder, and the other with producing heavily-doped and low-dislocation GaAs to be used as substrates on which the laser junctions are grown. In the latter case, GaAs with a dislocation density less than 100/cm^2 and a Te-concentration of 10^{18} /cm^3 is made by the horizontal Bridgman technique. In general, the Chinese have put a large effort into materials preparation and crystal growth, not only in semiconductors but also in other areas, and they have achieved considerable success. Such low-dislocation GaAs, for example, is not readily available commercially in the United States, mainly because of a lack of market.

The relatively large efforts on the GaAs injection laser, conducted in parallel at many institutions, is puzzling. It is not clear what specific application the Chinese have in mind. Injection lasers are usually associated with application in integrated optics and communication, but supporting techniques required in the field, such as fiber optics, are not pursued at present. In any case, the Chinese achievement in this particular device probably represents the smallest time lag behind U.S. and Japanese achievements, about 2-3 years. This is a good example of what one can do by entering an area where the basic technology has already been developed. The double heterojunction laser was invented in 1971, when the Chinese had already started work in the homojunction laser, which was discovered much earlier. The lack of research and development of associated techniques in China may create a problem in the long run. Advancement in integrated optics in the United States progresses at a rapid pace, and before long a large gap may develop if the Chinese stand still in this area. This perhaps serves to illustrate the problem that a developing country with limited resources faces: an uneven development in different areas of technology. The technology gap is usually larger and more profound when viewed over all industries.

Figure 20 Jack Gilman and Leroy Chang are shown the double-heterojunction laser laboratory at the Institute of Physics in Peking.

MICROWAVE DEVICES

Microwave devices in the semiconductor area can be made with a large variety of structures: p-n junctions, Schottky barriers, tunnel diodes, impatt diodes, and bulk negative-resistance devices. At the Institute of Semiconductors, there is a major effort on these devices. It appears that the current work is mainly on Si-impatt diodes and planar GaAs Gunn diodes. Presentations were given on each of these. The objective of working on semiconductor microwave devices was not stated, but it is known that such devices are already capable of operating microwave receivers and low-power transmitters, and, because of the size advantage, are particularly suitable for airborne and space applications.

The two talks given in this area provide an interesting contrast. The work on Si-impatt diodes is mainly an engineering project, aimed at generating microwaves in the 4 mm wave region. The structure is the simple p^+nn^+ type made by epitaxy followed by diffusion. The performance is relatively poor, with low power and efficiency and high noise level, and problems exist in both control and stability. In the planning stage for improvement is the use of ion-implantation techniques for fabrication. The work is newly begun and is comparable to that in the mid-1960s in the United States. The gap between the Chinese and the U.S. technologies is expected to narrow, but a great deal of effort is needed in China to catch up with the U.S. state of the art in both device sophistication and performance. If the work appears to be excessively concerned with engineering aspects rather than physics, as it did to us, perhaps it merely reflects the infant stage of the project.

The work on avalanche relaxation oscillation in planar Gunn diodes, on the other hand, is similar to a research effort as we know it, pursuing a phenomenon perhaps accidentally discovered while raising the threshold field of Gunn oscillation to that of avalanche. Although avalanche oscillation has been predicted and analyzed in general, this work appears to be clear observation in a bulk structure. Studies have progressed to observation and analysis of the associated recombination radiation. While this oscillation may eventually find its application, the interest at this stage is probably mainly academic. It is dangerous, of course, to attempt to draw any conclusion based on a single isolated case. But this example may bear on the often raised question: How much academic research is encouraged or tolerated in China? Part of this work was presented by Wang Shou-wu, Deputy Director of the Institute of Semiconductors, when he headed the Chinese Solid State Physics Delegation's visit to the United States. His presentation was in response to the invitation of the President of the American Physical Society to speak at the Society's March 1975 meeting in Denver.

AMORPHOUS SEMICONDUCTORS

The amorphous semiconductor work at the Institute of Ceramics deals with the switching and memory properties in chalcogenides, specifically, the GeTeSSb compound with the Sb substituted by various elements. The scientists at this institute realize that the effect is mainly thermal in nature, involving perhaps only the Ge and Te, but they are unwilling to admit that heating is the only cause. Such properties of memory and switching in amorphous semiconductors attracted a great deal of attention almost everywhere a few years ago, but efforts in the field have since diminished to the point of near-extinction, at least at most major laboratories in the United States, as far as applications are concerned. Activities in this area also exist at the Institute of Semiconductors, although they were not shown to us. It is, of course, unfair to blame the Chinese for venturing into this field, since others have done the same. What is difficult to understand is that they seem to be pursuing the subject in such a vigorous fashion.

OMITTED RESEARCH AREAS

It is clear that the semiconductor effort is intensively concentrated on integrated circuits or on Si-technology in general, at the sacrifice of other research activities. It is equally clear that this situation arises by design, a matter of assignment of national priority. As mentioned at the beginning of this section, semiconductor research should be assessed in this context; and it is perhaps in the same context that the areas of omission should be identified.

The most notable area of neglect appears to be that of semiconductor applications to optoelectronics, with the exception of the injection laser. No work on far infrared photodetectors or on window materials was apparent. Not much attention has been paid thus far to

II-VI, IV-VI, or even III-V compounds other than GaAs. We were told that studies of GaP and GaAsP materials are about to begin, which might eventually lead to the development of light-emitting diodes (LEDs). Work on solar cells and other photovoltaic devices in general also appears to be absent. Other devices that have been neglected include charge-coupled devices of different schemes and a variety of electron-emission devices.

The lack of effort in these areas could be caused by a variety of circumstances. The application of light-emitting diodes is usually associated with display for instrumentation or consumer products, in which the Chinese may not be interested. The development of electron emission devices requires high vacuum technology, which seems to be lacking in China. Solar cells find application in space exploration and potentially in energy generation, areas that the Chinese may not want to show to visitors. However, the omission of work in the case of charge-coupled devices remains unexplained, considering such devices' technological importance and applications in memory and imaging and their close relationship to MOS technology.

It should be kept in mind that the areas of omission noted above may be actively pursued in other institutes which we did not visit. Furthermore, omission does not necessarily imply total absence, but rather a lack of emphasis. We saw a GaAlAs laser that emits visible light, and a range finder that uses GaAs omnidirectional emitting diode and a Si-photodetector. However, we do not consider these items to represent a serious research effort in the LED and solar cell areas.

CONCLUDING REMARKS

To summarize our observations on the overall activities in Chinese semiconductor research, we are immensely impressed by the achievements in the Si-technology but disturbed by the limited scope in other areas. The narrow coverage is probably unavoidable, considering China's limited resources of capital and scientific manpower. In order to become an industrialized country without initially having much technological base, China must start somewhere. The emphasis and concentration on Si-technology is, no doubt, the correct choice. China's limited resources may also explain the fact that work in this area mainly duplicates what has been achieved in industrialized countries, while innovative ideas are lacking; initially, this is the only way for a country so far behind to catch up in a rapidly advancing field. The impressive achievements that the Chinese have attained must be ascribed to their high motivation, strong determination, and hard work. As important as the achievements themselves is the confidence gained by the Chinese workers that will enable them to face future challenges. It is evident that the present gap of 5 to 6 years between Chinese and Western technology is narrowing rapidly.

As the technology base is built up in the People's Republic, we expect that the scope of research will broaden, that a more exploratory type of work will be pursued, and that the approach will necessarily become more physics-oriented than engineering-oriented. There is ample evidence for these expectations in the trend visible in the work already in progress. Most of the other research areas, such as lasers and microwave devices, which were not in existence before the Cultural Revolution, were initiated in the early 1970s after the semiconductor foundation had been laid. The concern for physics increases as the work moves closer to the forefront of the state of the art, as illustrated by the talks given in the various areas. In addition, plans seem to be under way, at least at some universities, to organize special research courses to strengthen the education of solid state physicists whose contributions to materials and device development will be increasingly needed and appreciated as Chinese technology grows gradually more advanced.

The Chinese achievement so far is largely a result of the contributions of two groups: the older generation of people, trained outside China, who provide leadership, planning, and supervision, and people in their thirties, graduated before the Cultural Revolution, who comprise most of the work force. Those who graduated after the Cultural Revolution have yet to play a major role. The complexity and diversity of LSI technology, for example, which is a horizontal integration itself of various scientific disciplines, calls for the combined knowledge and talent of material scientists, semiconductor physicists and chemists, and electronics engineers. (An example is the development of microprocessors on a single chip of silicon, which, together with associated microcircuits, can be programmed to perform desired functions.) It seems unrealistic to expect that the narrowly trained recent graduates alone could cope adequately with the situation and carry the technology level to surpass advanced countries.

C. LASERS

INTRODUCTION

The Chinese solid state physicists place considerable emphasis on lasers and electro-optic materials and devices. These efforts obviously cannot match the work on semiconductor devices in importance, but a separate section on this subject appears warranted, even though our solid state delegation was not shown much work on gas lasers. The three categories of institutions (universities, institutes of the Academy of Sciences, and institutes of local government) all have significant programs in this area. Some of the fruits of this work are already being demonstrated publicly at the Shanghai Industrial Exhibition. There the general public can view a Nd-YAG laser range finder. When this laser is trained on a distant tower or cloud, the distance is recorded on a digital read-out meter. There is an argon-ion laser coagulator for ophthalmic applications, which was not demonstrated at the time of our visit; but a 100-W CO_2 laser scriber with the focus at the end of an optical movable arm was in operation. In this section, the Chinese state of the art in solid state lasers, electro-optic devices, and optics research will be briefly reviewed.

ND-GLASS AND ND-YAG LASERS

Work at the Institute of Optics and Fine Mechanics near Shanghai concentrates on modern technology. One of the group leaders in this Institute, Lin Tsun-chi, was a member of the Chinese laser delegation which visited the United States in 1974. He has built a Nd-glass laser system with eight glass rod amplifiers and two Faraday isolators. A disk laser system, consisting of three slabs with a 10-cm aperture of the light beam, is under development. Although this particular device was not shown to us, we did see a well-engineered electro-optically Q-switched Nd-glass laser system, which was used for damage and self-focusing studies. A systematic study of thermal and photo-elastic effects of self-focusing for glasses with different values of the absorption coefficient, the temperature coefficient of the optic index, and the photo-elastic coefficient had been made by time-resolved Mach-Zehnder interferometry. The problem of Pt inclusions had been eliminated by fabricating the glass in ceramic crucibles. Clearly there was close coupling with the glass-manufacturing facility, and a good-quality laser glass was available. The laboratories had modern optical tables and adjustable mounts. Altogether, the facilities at the Institute of Optics were the most advanced of those shown to us anywhere in China. It is estimated that Western technology is followed here with a time lag of about 3 to 5 years.

In contrast, the glass laser system shown to us by the plasma physics group at the Institute of Physics in Peking had a more old-fashioned and improvised appearance. The technology there appeared to be about 8 years behind the Western state of the art. Nevertheless, a small plasma laser group of about ten people, which started from scratch in 1972, had within a few years (with no previous optical experience) put together a system that could deliver 36 Joules of light in a 6-nanosecond pulse. The storage bank capacity was 10^6 Joules. The system used six glass rod amplifiers and two Faraday isolators with Pb flint glass and a pile of glass plates at Brewster angle for polarizers. The beam diameter at the final amplifier stages of 60-cm length was 5 cm. All optical polishing was done by technicians in-house. There was no attempt at spatial or temporal mode control. The output was focused on LiD or CH_2 targets of 1-mm diameter. The production of x rays from the plasma with a temperature of about 300 ev was observed. Safety precautions were minimal. It was a typical example of self-reliance, with a relatively small degree of sophistication.

Nd-YAG crystals of high quality are grown at the Institute of Optics and Fine Mechanics. In order to eliminate dislocations and coring simultaneously, Institute physicists initiate growth with a convex interface to move the dislocations to the sides and then flatten the interface to minimize coring. The thermal and elasto-optic coefficients are measured. Thermal distortion in [0, 0, 1] and [1, 1, 1] cut crystals is analyzed. The crystals are used in a 20-MW Nd-YAG oscillator-amplifier system, which is used for nonlinear optical investigations.

SEMICONDUCTOR LASERS

A considerable amount of effort is devoted to the fabrication of double hetero-structure GaAs injection lasers. Parallel efforts are going on at the Semiconductor Institute and at the Physics Institute of the Academy of Sciences in Peking, and at Peking University as well. Technical details of these programs were discussed earlier in this chapter. With such a relatively large effort on these semiconductor laser devices, the nearly complete absence of related optical semiconductor devices was remarkable. We did not see any work on thin film optical guides, integrated optics, electro-optic coupling and switching of semiconductor layers, infrared windows and far-infrared detectors, solar cells or visible light-emitting diodes. Work on GaP and AsGaP was said to have just begun. At Peking University, hemispherical infrared emitting GaAs diodes are being manufactured for use in a range finder, while Si-photodiodes are used as detectors.

Presumably, the effort on semiconductor lasers is a first step toward an integrated optics and optical communications technology. It is not clear why it is being pursued in at least three laboratories while other problems in semiconductor optics receive scant attention.

ELECTRO-OPTIC MATERIALS AND DEVICES

A considerable fraction of the effort in crystal growing and materials research shown to us is now oriented toward optical materials. At Nanking University, the emphasis was switched in 1972 (after the Cultural Revolution) from the study of grain boundaries and dislocations in metal crystals of Mo and W to the study of the growth habits of $LiNbO_3$ and YAG crystals. The curriculum in laser crystal physics at this university includes measurements of electro-optic and acousto-optical coefficients and the evaluation of the influence of strains, dislocations, inclusions, and ferroelectric domain walls on the optical properties of these crystals.

High-quality $LiNbO_3$ is grown at the Institute of Optics and at the Institute of Ceramics, both in Shanghai. In the latter institute, Fe-doping of $LiNbO_3$, with concentrations ranging from 0.001 to 0.05% for holographic recording purposes, is actively pursued. At this institute barium sodium niobate is also grown for nonlinear optics applications. Both lithium tantalate and bariumstrontium niobate are grown and evaluated for use as pyroelectric detectors.

Lithium iodate crystals are produced by the crystallography group of the Institute of Physics. The application is for harmonic generation in nonlinear optics. This material has a high nonlinear index of refraction, although its resistance to damage is, of course, much

Figure 21 Nico Bloembergen observes a Faraday rotation demonstration at the Institute of Physics.

lower than that of KDP and ADP. Apparently, crystals of good optical quality of these latter materials are available in China, but they need good temperature and humidity control. This was given as a reason for the active programs to find alternate nonlinear crystals. Q-switching of solid state lasers is commonly accomplished in China by electro-optic crystals, rather than by passive saturable absorber techniques. This appears to be related to the difficulty in obtaining satisfactory dyes.

Yttrium aluminate, doped with Nd, has been grown in optical quality, and diffraction-limited laser action with these crystals has been obtained at the Institute of Optics and Fine Mechanics. Various electro-optic switching devices using different crystal and electrode geometrics are built and studied in the institutes and at several universities. It is clear that a broad optical materials program exists.

DYE LASERS

Futan University in Shanghai was the only place where a dye laser was shown to us. It had been constructed during the past year,

Figure 22 Ted Geballe and Bob Schrieffer with our hosts of the chemical laser group at Futan University.

and the principal investigator had never seen a dye laser in operation before. He had studied the Western literature on the subject and through self-reliance had constructed a nitrogen-pumped dye laser. The pump power was 500 kW in a pulse of about 8 nsec. The conversion efficiency in Rhodamine 6G was about 10-20%. The emitted spectrum was about 2 Å wide. There was no telescope to use a large portion of the grating, nor interferometer plates to narrow the spectral width. The pulse repetition rate was 100 pps. With a few other dyes, supplied by the Shanghai Dye Institute, the frequency ranges of 400-450 nm and 500-670 nm could be covered. Future efforts will be devoted to improving the characteristic of the device, including spectral narrowing and stability. Little consideration had been given to possible application and uses of the device. The availability of dyes for laser action and saturable absorbers is apparently limited, but no imports from Japan or other countries had been made.

GAS LASERS

Although our solid state group had no direct access to gas laser research laboratories, the laser programs at the universities, as well as investigations of holography and nonlinear optics at research institutes, included the use of gas lasers. Thus, we did obtain some impressions about the state of the art.

At both Tsinghua University and Peking University, the training of students in physical optics includes a workshop experience in the fabrication of He-Ne lasers. Vacuum and gas handling techniques are taught, as well as the fabrication of reflective and antireflective coatings with multiple layers. Optical alignment and interferometric quality control are also part of this training. At Tsinghua University, which is the foremost technological school in the country, a production of several hundred He-Ne lasers per year is achieved. Some of these have an output of 30 mW. Smaller types have diffraction-limited operation with a frequency stability of one part in ten million.

While He-Ne lasers are generally available and are used for such purposes as alignment and holography, argon-ion lasers are not readily obtainable in China. The Shanghai Industrial Exhibition displays an argon-ion laser coagulator, and we saw a Chinese-built commercial 1-W argon laser in operation for holographic recording at the Institute of Optics and Fine Mechanics, but there still appear to be problems with the lifetime of the discharge tube. At Peking University we saw a prototype argon laser, which had an appearance very similar to the early 1964-1965 home-built models in the United States, before commercial models became available. The Peking model had the same bulky type of solenoid around the discharge tube, and the total light output was 100 mW. Peking University also had a Cd-ion laser with an output at 441.6 nm, which was used to detect NO_2 in the atmosphere by observing the fluorescence at 650 nm from dissociation products.

A cw CO_2 laser was under construction at Peking University, designed for an output between 10 and 50 W. A 200-W model was said to exist at the Institute of Optics and Fine Mechanics. No pulsed CO_2 laser, or gasdynamic, chemical or electron-beam pumped lasers were shown or discussed. They may very well exist in other laboratories that were not accessible to our delegation.

HOLOGRAPHY

The laser group of the Institute of Physics in Peking has an active program in holography and optical processing. A commercial He-Ne laser with an output of 10 mW in a single spatial mode (costing about 4,000 Y [$2,000]) is used. Character recognition by the method of spatial filtering was demonstrated, wherein a Chinese character is recognized among a sample of 20 different characters. Automated typesetting is a possible application of this method. Holographic recording techniques included off-axis holography, wide-angle holography, and holography for reconstruction by white light.

At the Institute of Ceramics in Shanghai, holographic recordings were made in Fe-doped $LiNbO_3$ with an argon-ion laser. By changing the angle of the reference beam, three-dimensional storage of optical information could be obtained. In the same institute, holographic recording in glassy As_2S_3 was pursued. The effect is probably based on a temperature grating produced by the holographic interference pattern, which in turn produces local phase changes in the glassy semiconductor, which are thereby recorded.

NONLINEAR OPTICS

In addition to the work on self-focusing and electro-optic devices, we were shown some research on harmonic generation and parametric down conversion. The nonlinear optics group at the Physics Institute was started in 1974. After the group surveyed the literature, they decided to practice by doubling and quadrupling the frequency of a Nd-glass laser. For the doubling, a lithium iodate crystal ($2\times5\times5$ cm^3), grown by the crystallography department of the same institute, was used. A conversion efficiency of 10-20% to green light at 530 nm was achieved. The rather primitive Nd-glass laser was Q-switched by a rotating mirror without temporal or spatial mode control. An output pulse of 1 or 2 Joules and 20 nsec duration entered the iodate crystal with a flux density of 10 MW/cm^2. The relatively low damage threshold for the iodate is near 100 MW/cm^2. In spite of the modest power level, good conversion efficiency was achieved because of the large nonlinear coefficient. The green radiation was passed into an ADP crystal, which was 90°-phase-matched at a temperature of 45.5 ± 0.1 °C. About 1% conversion efficiency from the green to the ultraviolet at 265 nm was achieved. This rather unsophisticated equipment was reminiscent of the nonlinear optic experiments in the early 1960s in the United States. This Chinese pioneering effort, in accordance with the principle of self-reliance, began in almost complete isolation, except for the important advantage of the availability of an extensive Western and Soviet literature on the subject. It is clear that more rapid progress could be made with the utilization of better equipment.

Even without imports of Western commercial products, much better equipment was available and demonstrated in the Institute of Optics and Fine Mechanics in Shanghai. There a Nd-YAG oscillator-amplifier system was Q-switched electro-optically. A 1060-nm diffraction-limited pulse of 2×10^7 W was doubled in a KDP crystal with 25% efficiency.

The second doubling in an ADP crystal was claimed to have an efficiency of about 10%. The resulting radiation at 265 nm was powerful enough to produce spontaneous parametric down conversion in another ADP crystal. A striking demonstration of bright blue and red pulses, at the signal and idler frequencies respectively, was performed. Extensive data on the tuning characteristics of spontaneously emitted radiation as a function of orientation and temperature had been obtained, in good agreement with the theory. The spontaneously emitted radiation was amplified considerably in the focal spot of the 265-nm radiation, so that the down conversion process without resonator feedback had 10% efficiency.

CONCLUDING REMARKS

Like most other aspects of the Chinese scientific enterprise, the efforts in lasers and quantum electronics have been shaped to a large extent by the Cultural Revolution. The universities were most affected by this political development and were at a virtual academic standstill from 1966 until 1971. A gradual resumption of activities took place, but most laser-related programs were started in 1973 or later. In accordance with the principle of self-reliance, they were started with little outside help and were instituted to provide technically-trained manpower for the emerging optical technology. Therefore, the universities are not leading in research in the laser area, but seem to be following the needs of research laboratories and industrial plants.

Even during the height of the Cultural Revolution, some scientific laboratories were shielded from its turmoil. The atomic energy and rocket propulsion laboratories probably belong to this group. The Institute of Optics and Fine Mechanics, begun in 1966, at the beginning of the Cultural Revolution, also appears to be one of these. Its mission is to develop modern optical technology. It had the most advanced laser instrumentation shown to us in China. The technology gap in this case appears to be reduced to 3-5 years. This is probably the minimum gap that can be achieved under the present system, which does not emphasize original contributions to increase knowledge.

The present goal is to achieve independent competence in building devices by copying advanced technology developed outside China. A delay of 1½-2 years is involved between the time this work is done in non-Chinese laboratories and its publication in the non-Chinese literature. An equal, additional time lag is involved for the Chinese decision-making process to follow up on a particular foreign development and to begin a Chinese effort in this area. The results of this policy of "catching-up" have been quite remarkable. Obviously, China is establishing a rapidly expanding technological and trained manpower base in the area of lasers and electro-optics.

There is a laser device institute known as the "experimental laser station" in Shanghai with the mandate to develop laser applications and to provide a link between the research laboratories, where a prototype is developed, and the industrial production of a device. Presumably, the laser devices shown at the Shanghai Exhibition were so produced. The factories, in turn, send workers back to the universities, or to an extension course conducted by the university, or to their own July 21 industrial schools for training.

The position of the institutes of the Chinese Academy of Sciences in Peking appears to be intermediate to that of the universities and of some of the more independent laboratories. The work in these institutes slowed down, although it did not cease, during the Cultural Revolution. Most programs involving lasers were started recently -- after 1970. Although the laser field apparently enjoys some preference in funding over several subfields of physics pursued in the institutes of the Academy, the instrumentation at other institutes cannot match that of the Institute of Optics and Fine Mechanics in Shanghai. The technology lag in the Peking institutes was correspondingly larger (8 years or more). The mission of the Academy institutes, as several spokesmen emphasized, is supposedly not restricted by considerations of relevance to practical applications. Nevertheless, most of the research undertaken was rather device-oriented and was not aimed at a deeper understanding of the physical phenomena. This is characteristic of all present Chinese laser research. There is, for example, virtually no high-resolution laser spectroscopy or nonlinear spectroscopy of any kind. In several instances, our Chinese spokesmen in the laboratory did not seem to grasp fully the fundamental physical principles on which their devices were based.

Chinese coverage of the laser field is uneven and appears to be determined by somewhat arbitrary initial choices. This is unavoidable, as the means and manpower to cover the entire field do not yet exist. The virtual absence of work on infrared windows, parametric generation, and detection of far-infrared radiation, as well as on other fiber and thin-film techniques in integrated optics, is especially notable. There are also examples in the materials field where the Chinese continue to concentrate on substances which have been virtually abandoned by Western technology as noncompetitive. Occasionally, they have picked up a topic in the Western literature and are not aware of the fact that this work has been discredited or de-emphasized subsequently. In the majority of cases, however, the Western literature is followed closely and with understanding. Questions asked during our visit, especially after some of our lectures, indicated an eagerness to hear about the latest developments in the field outside China.

China clearly has the capability to copy existing laser technology in any area in which it chooses to do so. It will, however, need a much larger reservoir of highly trained manpower if it is to catch up with and surpass foreign technology. It is remarkable that even now the existing academic facilities and faculty are not fully utilized, and many more students could be trained. It is entirely possible, even likely, that the situation 5 or 10 years from now will be very different, as the rate of change in China is high. Progress during the short life span of most of the laser projects has been remarkable and shows the results of the innate capabilities and hard work of the Chinese scientists. Laser technology in China will undoubtedly be ready for rapid expansion, if and when the political timetable for China's economic development deems this desirable. The groundwork for this technology has already been laid.

D. LOW TEMPERATURES

Solid state physics, as a field, has made extensive use of a low temperature environment. We need only think of the variety of subjects covered at the International Conference on Low Temperature Physics held every other year, which includes topics such as properties of liquid and solid He, specific heats of alloys, various properties of magnetic materials, the Kondo effect, Fermi surface work, electrical and thermal conductivity, and superconductivity. In comparison, the low temperature work we saw at Peking University, Nanking University, and the Institute of Physics was very narrow, although it comprises a sizeable fraction of the total effort at these institutions. The research efforts were largely restricted to superconductivity, much of it dealing with magnet wire (Nb_3Sn and NbTi) and the Josephson effect (Pb-PbO-Pb junctions) with a great deal of overlap among the institutions.

The experimental work on the Pb-PbO-Pb junctions at the two universities was aimed at using the Josephson effect to establish the voltage standard. At the time, it was also used as a laboratory exercise for the students in low temperature physics who would have to make and test the junctions. Microwaves were directed at the junctions to develop the voltage steps, which presently became barely visible. As yet, no screened rooms and sophisticated amplifiers were available, nor was the earth's magnetic field screened out. It was surprising that the work was strictly limited to Pb at both universities and that no attention was paid, for example, to work at a temperature lower than 4.2 °K or to study of the phonon structure in the superconductors.

The work on the magnet wire at the three institutions was also limited in scope. At Nanking University, there was only a testing facility to check various critical parameters of superconducting wire, received from outside factories, which were both NbTi and Nb_3Sn (singlestranded and multistranded). At the Institute of Physics scientists were fabricating short lengths of Nb_3Sn tape by passing Nb tape containing 1.4% Zr through a bath of Sn containing various amounts of Cu. The purpose was not to manufacture Nb_3Sn tapes, but to study flux pinning in these materials. The work was farthest along at Peking University, where they had just made a small 100-k Gauss magnet with an inner bore of 1.4 cm. In comparison, Nb_3Sn magnets with fields of 160-k Gauss and an inner bore of 4 cm are available in the United States.

Most of the research we observed was an effort to catch up with similar work in the West -- for example, the superconducting magnets and the tunnel junction work -- but three other efforts deserve to be mentioned. At the Institute of Physics, a dilution refrigerator was under construction, which they hoped would be finished by October 1, 1975. We were told it would be the first such facility in China. At the same institute, a superconducting gravity meter to support earthquake studies is under development. At present, a capacitive measurement is made of the displacement of a superconducting ball floating on a magnetic field, but they plan to use the Josephson effect utilizing a NB Dayem bridge. Finally, at Nanking University a broad band detector based on a Nb-Nb contact is being developed. The goal is to achieve $\sim 10^{-14}$ W/cm^2 in the mm region; present capabilities are 10^{-14} W/cm^2 at a wavelength of 2-3 cm. The planned use of the detector is in astronomy.

All the laboratories we visited were reasonably well equipped with the necessary tools, such as glass dewars, evaporators, x-y recorders, and oscilloscopes. While the various equipment is adequate for research purposes, it resembles a laboratory in the United States in the early 1960s. Of course, one can have nothing but admiration for the Chinese, who, with simple means and within a relatively short time, have mastered the basic technique of liquefying gases and of dealing with a low temperature environment. It is not surprising that present efforts are technically motivated, and though they are lagging behind the United States by about 10 years, the young students and research workers are becoming familiar with the various techniques.

In summary, the Chinese are training students in low temperature techniques, but as yet their actual research efforts are only applied, short-term, and restricted in scope. Everybody we talked to was interested in high transition temperature superconductors, but we saw no actual programs in this area. They have made good progress in a short time, but it is somewhat puzzling that they have chosen to work in areas with very limited and esoteric applications. We can only speculate on the reasons for this. It is, of course, necessary to liquefy gases in order to obtain oxygen for steelmaking or liquid hydrogen for rocket fuel, and this could be an important motivation. Superconducting magnets are important for certain aspects of experimental high-energy physics. In addition, superconductivity has, for some time, appeared to be a promising technology for the electrical industry (for both power and signal applications), but, of course, it is still only a promise, and the technology will be highly sophisticated. Since China is rather decoupled from the rest of the world, Chinese scientists may have misinterpreted many optimistic statements made in the West about the imminent application of superconductivity. Many European low-temperature research workers have visited China, and their enthusiasm for their chosen field of research could have played a part in such misinterpretation. In our judgment, the present effort in superconductivity is too large, relative to other neglected areas

TABLE 1 Crystals Grown for Research at Some Chinese Universities, Institutes, and Factories

	Organization with Identified Work[a]									
	Universities					Institutes				Factories
Crystals	Chiaotung	Futan	Nanking	Peking	Tsinghua	Ceramics	Physics	Optics	Semi-conductors	
Alkali halides	--	--	--	--	--	--	--	--	--	X
Aluminum oxide	--	--	--	--	--	--	--	--	--	X
Ammonium dihydrogen phosphate	--	--	--	--	--	--	--	--	--	X
Barium strontium niobate	--	--	--	--	--	X	--	--	--	--
Barium sodium niobate	--	--	--	--	--	X	--	--	--	--
Bismuth germanate, silicate	--	--	--	--	--	--	X	--	--	--
Diamond	--	--	--	--	--	X	X	--	--	?
Gadolinium gallium garnet	--	--	--	X	--	--	X	--	--	--
Gallium (aluminum) arsenide	--	--	--	--	--	--	X	X	X	--
Gallium phosphide	--	--	--	--	--	--	--	--	*	--
Lithium iodate	--	--	--	--	--	--	X	--	--	--
Lithium niobate	--	--	X	--	--	X	--	X	--	--
Lithium tantalate	--	--	--	--	--	X	--	--	--	--
Quartz	--	--	--	--	--	X	--	--	--	X
Silicon	--	--	--	--	X	--	--	--	--	X
Yttrium aluminum garnet:Nd	--	--	X	--	--	X	X	X	X	X
Yttrium aluminum perovskite:Nd	--	--	--	--	--	--	--	--	X	--

[a] X - observed or explicitly mentioned; * - reported to be starting; ? - inferred.

of physics, but the low-temperature effort is justified if a better coupling with research in the general field of solid state physics can be achieved.

E. CRYSTAL GROWTH

A broad range of crystals is being grown in China for research in universities and institutes. Several kinds of crystals are also being produced by factories. Table 1 summarizes the activities that were either actually observed by us or referred to explicitly by Chinese researchers in response to our questions. This list of approximately 20 different crystals is extensive, but probably not complete.

Table 1 indicates that more than one organization often works on the same crystal type. The case of YAG:Nd is noteworthy in this regard. In part, this duplication reflects the practice of the principle of "self-reliance" at various organizations; it may also reflect the fact that it is very difficult to grow high-quality specimens of YAG:Nd, so multiple efforts have been encouraged.

Table 1 indicates rather broad coverage of the electro-optic crystals that are grown in other countries. It also indicates little that is unique to China. This does not mean that unique efforts do not exist. However, we did not see them either because they are proprietary, or because they are not considered ready for exposure.

None of the laboratories that we visited exhibited crystal-growing technology that equals or exceeds the state of the art in foreign countries. In all cases the work is competent and done in a professional style, with clean laboratories and well-built equipment. Therefore, Chinese industry is capable of providing any and all of the necessary components of the technology, including rare metals, rare earth oxides, power supplies, control equipment, and so on. Once the motivation exists for doing a task, increasingly intense efforts are applied until it is accomplished.

The motivation for growing a specific crystal comes from the "national need." This has been particularly true since the Cultural Revolution. We saw no evidence of general work on mechanisms or theory. It is not clear whether the leadership always proceeds from a central scientific planning bureau down through various levels of responsibility to the research workers (with some flexibility along the way), or whether the needs are "advertised" and then various research groups respond with their local proposals. Perhaps both methods of assigning work are used.

In some cases, the coupling between the users and growers of crystals is good. It is evident that frequent contacts are made and that information flows between the two. In other cases, the growers appeared to be emphasizing their own interests somewhat independently of whether the crystals have useful or optimized properties. Thus, the details of the operating modes do not appear to be imposed by Chinese authorities except in highly mission-oriented laboratories.

All the work that we saw is based on foreign literature and therefore lags behind current foreign technology. The lag includes the publication delay, of course, plus delays for decision making and constructing equipment. The lag ranges from 5 to 10 years except where a project has been in existence for several years and can be modified quickly, reducing the gap to 2 to 3 years. In the future, it may be expected that Chinese patience, perseverance, and ingenuity will produce superior crystal-growing capabilities in selected areas. Whether truly novel materials will emerge remains to be seen.

F. OTHER RESEARCH AREAS

INTRODUCTION

As indicated by the grouping of these research summaries, the specialties of semiconductors, lasers, low temperature (superconductivity), and crystal growth represented by far the majority of the research efforts that we were shown. This section summarizes briefly other areas of research to which we were introduced on a much more limited scale.

MAGNETISM

Only at Peking University and at the Institute of Physics in Peking did we see work in magnetism, although there was a group in magnetism at Nanking University, and perhaps at some of the other institutions which we did not have the opportunity to visit.

Most of the work in magnetism was either directly applied in nature or at least in areas with possible or likely technical applications.

In the former category was work on ferrite-core memory elements and on calculations of coupled-eddy current-domain rotation losses in ferromagnetic materials, microwave ferrites, and magnetic thin films. The work on garnet films for bubbles, like much of the work we saw, was heavily oriented to the development of high-quality material with apparently little emphasis on the physics of bubble formation or transport. In the area of microwave ferrites, the original motivation seems, again, to have been the development of materials, specifically low-anisotropy materials, for microwave applications; the present effort seems a more academically oriented study of the effects of a variety of ion substitutions upon the anisotropy. The magnetic film work included the development of sputtering techniques to produce well-controlled films of the amorphous ferromagnetic CoGd, again with possible application as a bubble material in mind.

In contrast to this work was one project involving the study of the creep of domain walls in permalloy films, in which the principal interest seemed to be the development and testing of a model in terms of the dynamics of Bloch lines whose motion was driven, in the experiment, by a high-frequency ac magnetic field. This type of project, involving the description or explanation of phenomena in terms of a microscopic model, seemed the exception rather than the rule among the various research projects we discussed. There were also optical studies, not very far developed, on Faraday rotation of magnetic films.

Absent in the laboratories we visited were experiments concerned with magnetism on an atomistic scale. Even theoretical work from an atomistic approach seemed little pursued, although one innovative piece of work on critical exponents in phase transitions was described to us at the Institute of Physics. Also lacking was the development of technically important hard and soft alloy magnets and small particle magnetic materials.

The work we observed seemed to be of high caliber. Although some of the equipment (such as magnets and microwave gear) was of ancient vintage, it was probably adequate, and where necessary, routine modern equipment such as x-y recorders, oscilloscopes (Chinese), and microscopes (East German) seemed to be readily available. More sophisticated equipment is now or will soon be available. For example, an ion microprobe is on order from France and will be used for more detailed study of magnetic films (and presumably for other types of analysis as well).

ULTRASONICS AND ACOUSTICS

The work in ultrasonics and acoustics that we found most interesting was in progress at the Institute of Physics in Peking, in the areas of acoustic holography and surface acoustic wave generators and detectors. The work in both areas was in an exploratory stage, reproducing or extending ideas or experiments found in the Western literature. Institute scientists have established the ability to obtain satisfactory acoustic holograms of two-dimensional masks, with a field of about 1×2 cm in a water medium. The distortion of an air-liquid interface produced by the acoustic radiation pressure serves as a phase hologram, which is read by diffraction of an optical laser beam. Plans for this project include attempts to obtain holograms of small three-dimensional objects. This is a technique which is the basis of a commercially available instrument in the United States with a 3-in.-diam. field.

Scientists at the Institute of Physics are also exploring the capabilities of interdigital electrode transducers for the launching and detection of surface acoustic waves on ferroelectric materials. In doing so, they are using both the electrical response of the transducers and laser scattering from surface and bulk waves generated by the tranducers as probes of the behavior of these systems. The detailed presentations of these projects indicated an excellent grasp of the relevant physics and apparently a high degree of experimental skill, although we did not visit the laboratory. The techniques are similar to those used in the United States, and the current exploratory efforts at the Institute of Physics are similar to work done in the United States about 4 years ago.

In more classical areas of acoustics, we heard a discussion of a straightforward problem in acoustic impedance matching in the improvement of ultrasonic cleaning baths. At Nanking University we were shown a recently constructed reverberation chamber and an anechoic chamber which are to be used for problems in architectural acoustics and noise pollution. It was interesting that this second group had been diverted to their current efforts from pre-Cultural Revolution work in acoustic study of Fermi surfaces.

STRENGTH OF MATERIALS

At Chiaotung University we heard about a productive but pedestrian study of fatigue and failure under repetitive impact. The approach, purely empirical, was to vary composition and heat treatment and to measure the number of impacts needed to cause failure. There seemed to have been little consideration of possible atomic processes as a guide in choosing the variables to be studied. During subsequent questioning it appeared that, to the knowledge of the Chiaotung group, there was no work anywhere in China that focused on such subjects as atomic defect structure, motion, or dislocations in metals.

We were disappointed that we were not afforded the opportunity to visit the Institute of Metallurgy in Shanghai. Reports of other visiting groups suggest that the work there is of high caliber, and this opinion was confirmed in informal conversation with physicists from Futan University who spoke highly of the Institute's work and who were surprised that we were not to make such a visit.

HIGH PRESSURE

The principal effort of the high-pressure group at the Institute of Physics has been devoted to the development of techniques, both static and using shocks, of producing artificial diamonds for industrial use. Artificially produced diamonds are currently being made industrially in China, and this group is now concerned with determining the influence on yield of the various controllable parameters in the productions process. A more recent project involves the development of apparatus and techniques for studies of physical properties of materials at pressures up to 45 kb. Inquiries about specific scientific objectives of this high-pressure work, used in the West to elucidate a variety of physical properties, brought rather vague answers about the determination of elastic constants and phase transformation. The motivation seems to have been more the development of techniques than specific scientific objectives. Again we were struck by the ability of Chinese scientists to solve tough development problems using limited resources.

OTHER TOPICS

Individual projects in the area of solid state physics not mentioned elsewhere include a new program to use the 3MeV electrostatic generator at Futan University for a variety of applications to solid state problems. A few of us visited the Biophysics Institute in Peking (Figures 23 and 24) and were very much impressed with the variety and apparent quality of the work, although the tour was too rapid for us

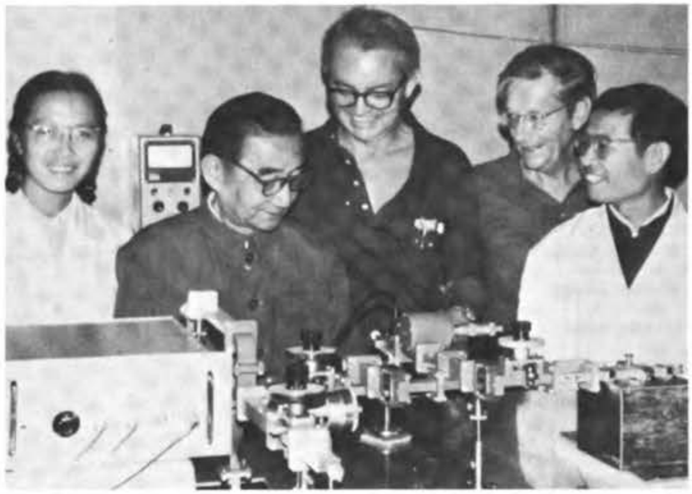

Figure 23 At the Biophysics Institute, Charlie Slichter beams at the electron spin resonance apparatus displayed with pride and pleasure by two workers and by Pei Shih-chang, while Nico Bloembergen (now a laser lover but once a resonator like Charlie) enjoys the scene. This apparatus, newly completed, was the only electron spin resonance equipment we saw on our trip.

to obtain more than an impression of any individual project. The laboratories seemed better equipped and the research problems less directly connected with immediate applications than at the Physics Institute. At Futan University, one department was devoted to the development and testing of a large variety of high-intensity discharge

Figure 24 The famous model of insulin is shown Nico Bloembergen and Ivar Giaever on the afternoon of our visit to the Institute of Biophysics. The model is actually housed in the Institute of Physics.

lamps, many designed to achieve suitable color adjustment for photographic use and to stimulate solar radiation. This was clearly a very successful and intensive engineering program which had made important contributions to industrial products and production techniques.

G. THEORETICAL PHYSICS

INTRODUCTION

During our visit we had the good fortune to meet with groups of theorists at the Institute of Physics (Peking), Nanking University, and Futan University (Shanghai). In all these meetings we were given a very open and warm reception by the theorists, who were anxious to exchange information about research and teaching activities. In other institutions that we visited, we often learned something about theoretical work being performed, or else we learned that there was none. The following summary of what we learned will be divided into three parts: first, some remarks about patterns of organization and communication; second, some observations on general patterns of research activity, with illustrative examples from a number of fields; and third, some observations about the role of theorists in such areas as education and planning.

ORGANIZATION AND COMMUNICATION

At the Institute of Physics, one of the eight departments is devoted to theoretical physics; in addition, each of the remaining seven departments has a few theoretical workers attached to it. Thus, the total theoretical staff numbers several dozen, a quantity that would not be considered unreasonable for an American or European institution of this size. The theoretical department, whose membership numbers about 10, does work in quantum field theory, relativity, and so on, and seems likely to interact with theorists of similar interests in other institutions in the Peking area. Work in solid-state theory is done by theorists attached to the other departments and is usually closely correlated with experimental work or practical needs. A significant fraction -- perhaps 1/5 to 1/4 -- of the theorists now working in the institute have previously done experimental work.

Similar patterns of organization were present in many of the other institutions we visited. The theorists were largely associated with experimental groups, although theoretical groups sometimes also existed. Our impression is that there are a number of gifted theorists in solid state physics at present, although with a few notable exceptions they are largely confined to working on relatively simple, calculative problems. Communication among theorists at a given institution seems to be comparable to that in the West. Periodic theoretical physics seminars are a common feature of the stronger institutions we visited. On the other hand, nationwide communication among theorists appears to be limited to narrow subdisciplines, and nothing like the regional conferences in theoretical physics common in the United States exists.

The present maximum of 3½-4 years of education for theorists limits training, in essence, to the undergraduate level. We found, however, that plans are under way for special research courses to further the education of theorists beyond the standard degree courses. Such courses were discussed with the group at Nanking University, where notes for many advanced courses have already been prepared. It appears that some advanced training will be under way for solid state theorists within a few years.

RESEARCH WORK: GENERAL COMMENTS AND EXAMPLES

One general observation is that virtually no microscopic theoretical work on the electronic structure of solids is now being carried on. While we heard that this was not the case prior to the Cultural Revolution, this activity was stopped as a result of the Cultural Revolution. Part of the rationale for this decision is no doubt the idea that theory should serve the immediate needs of experiment, which in turn must serve the present needs of production. As a result, theory is tied to phenomenological and macroscopic description of solids. We were surprised to learn that there is not a single theorist in the Institute of Semiconductors in Peking, since it appears that great contributions to device design could be made by theorists familiar with the electronic structure of semiconductors.

The general flavor of theoretical research in some of the institutions we visited can be gauged from the following examples of work in various major fields of physics:

MAGNETISM At the Institute of Physics we were told about work on the dynamics of domain wall motions in ferromagnetic films, which was done in collaboration with experimental studies of such motions. There was also work on long-wavelength spin-wave modes in the range of conditions where magnetic dipolar interactions are important. Effects of specimen geometry on such modes were being investigated, although to achieve mathematical tractability, cylindrical shapes were being studied rather than the spheres used by the associated experimentalists.

PHASE TRANSITIONS Some theorists attached to the magnetism group of the Institute of Physics described to us some rather sophisticated and imaginative work on critical exponents near continuous-phase transition points. This study used renormalization-group theory and diagrammatic analysis, methods similar to those used in the most advanced contemporary work in the West and in the Soviet Union. We were told of some related work at Futan University. These studies were the most conspicuous exception we found to the general pattern of the Chinese solid state theorists' preoccupation with classical or semiclassical phenomenology.

SUPERCONDUCTIVITY We were told of some theoretical work at the Institute of Physics on tunneling in superconducting contacts, and of work at Futan University on the $2\Delta/n$ steps in the characteristics of Josephson junctions.

CRYSTAL GROWTH AND STRUCTURE ANALYSIS At the Institute of Physics, we were told of work on the theory of crystal growth, in particular of efforts to understand a surprising increase in the intensity of neutron scattering that occurs in $\alpha LiIO_3$ when a static electric field is applied.

OPTICS We were told of work at the Institute of Physics on optical information processing, and an analog-type simulation of computers.

NON-SOLID-STATE AREAS Although our contacts were naturally focused on solid state physics, we could not help but note that in the Institute of Physics and in many of the universities there was significant work going on in such areas as quantum field theory, general relativity, relativistic electrodynamics, theoretical astrophysics, and theoretical nuclear physics. Although these areas (with the possible exception of theoretical nuclear physics) are much more remote from technology than the quantum-mechanical behavior of electrons in solids, there seems to be much more activity in them than in the latter field. It was interesting to learn that, in some cases, such work has partially supplanted research in pure mathematics in mathematics departments.

OTHER ROLES OF THE THEORISTS AND CONCLUDING REFLECTIONS

The necessity of giving experimental physicists highly sophisticated training in their specialty very rapidly has forced the education of most physicists after the Cultural Revolution to be highly specialized. Because of the nature of theoretical work, one would expect the education of theorists to provide a somewhat broader base. This expectation seems to be confirmed by the fact that, where it exists, the university curriculum for theorists lasts from ½ to 1 year longer than for other students, and by remarks that were made to us at some of the universities we visited. Thus, it is to be expected that theorists play a particularly important role in the planning of curricula and of new research projects, as well as in teaching itself. It might well be desirable to encourage some of the theorists specifically to act as "gatekeepers" to keep their colleagues informed of a broad range of significant developments in the foreign literature. In addition, we were told that the theorists play an important role in presenting lectures to factory workers on the conceptual aspects of physics, and in consulting on factory-generated problems.

The future of solid state theory in China is difficult to judge. If Chinese technology develops a deeper appreciation for the important role fundamental theory can play in materials and device development, and if increased flexibility in problem choice is allowed for these activities, significant strides will no doubt be made, since many talented theorists and potential theorists are involved in solid state physics in China today. Theorists may well turn out to have a particularly important role in innovation, since they are more often able to work as individuals than are experimentalists who are usually organized into tight cooperative groups whose decisions on research directions are always made collectively. Experience in the West has shown that many of the most productive ideas in science and technology have been championed at the start by a single individual.

H. RESEARCH DECISION MAKING

Despite obvious variations in quality, the laboratories we visited demonstrate that the Chinese have considerable ability to move into a research area, such as ultrasonics, and develop in a few years, from essentially zero background, a high level of technical competence in that field. Although decisions to move into specific areas are based on a review of the Western literature, and some of the more sophisticated research equipment comes from outside China, these thrusts into new areas are for the most part self-generated, bootstrap operations.

The initiation of new research projects has often grown out of the demands of the national plan; accordingly, the Chinese Academy of Sciences has assigned priority items to particular institutes. At the same time, however, each institute under the Academy has its own Planning Bureau, responsible for approving new research areas within that institute. The research projects approved by the Planning Bureau generally do not require negotiation with the Academy. In fact, most decisions on research directions are made within the institute, without the consent or prompting of the Academy. However, the degree of autonomy varies from year to year.

At the Institute of Physics, most of the six or seven members of the Planning Bureau have had formal training in physics; one or two are self-taught. Their main job is to coordinate the research proposals of the institute's scientists. In making decisions, they draw upon the expertise of others, both within and outside the organization. The financing of new projects is the responsibility of a separate financial section, which raises money from the Academy of Sciences. The Planning Bureau coordinates informally with the financial section.

In universities, proposals for new areas of research come from "above" and "below" (i.e., from higher governmental or university authorities and from working-level scientists and researchers). Suggestions by university scientists and research workers must go first to the university authorities, or Revolutionary Committee. If the authorities support the idea, they, in turn, negotiate with other authorities. In the case of a national university, such as those we visited, those higher authorities are officials from the Ministry of Higher Education in Peking, who call upon specialists for advice. Scientists from other parts of the country may be consulted by such officials regarding a proposal from a particular university.

There may be a considerable amount of duplication among universities and research institutes because of wide interest in a certain topic. Duplication is not considered a drawback. As one scientist pointed out, China is a big country and it is important for several organizations to try their hand at a problem. Some institutions will become more excited about a problem than others and will do better work. After all, Western Europe is a smaller geographical area than China, yet England, the Netherlands, and France may all be working on the same topic.

What happens, we once asked, if a professor or researcher is unable to sell his new idea to the others in his small research group? The response was that if he or she is advocating an experiment, the prospects for carrying it out are slim, because experiments require equipment. Equipment is not readily available in China; a scientist cannot simply look it up in a brochure. There is a set plan for the production of equipment and, as a result, there are no extras in storage. Either parts would have to be bought from various places or the apparatus would have to be made-to-order. However, if the professor or researcher proposes a new theoretical idea, unsupported by his colleagues, he may well go ahead on his own.

Above is reported what little knowledge we obtained about the network of individuals who take part in initiating or approving research and development plans. Another important aspect of decision making is the basis on which choices are made among the various possible plans. What are the roles of intuition derived from experience, of rational economic principles, and of basic philosophical or ideological principles? These questions are discussed in the chapter entitled "Reflections on Our Visit."

4

THE NEW APPROACH TO SCIENCE EDUCATION

A. INTRODUCTION

The People's Republic of China has many institutions of higher education, catering to a wide variety of needs. We visited several institutions known as national universities, all of which are quite well known both within and outside of China. National universities draw their students from many provinces in China, and receive their funds from national rather than provincial or regional authorities. We expected they would be one of the major sources of graduates preparing to work in high-level science and engineering, thus representing what the Chinese would consider the best thinking in educational matters.

The fact that the Cultural Revolution produced major changes in education in the People's Republic of China is well known to everyone who reads about China today. That major changes in engineering education took place in the United States in recent years is perhaps not as well known to non-engineers. The contrast in the directions of these two reforms is striking, leading one to examine the underlying causes.

The reform of American engineering education stemmed from two causes. The first was the spectacular technical accomplishments of scientists and engineers during World War II. The harnessing of nuclear fission and the development of radar with its concomitant opening of the microwave region of the electromagnetic spectrum are but two examples which dramatically demonstrate the revolutionary technical achievements which could be made by people deeply grounded in basic science when they devoted themselves to practical objectives. Even an understanding of those achievements was beyond the scientific capability of many able and proven engineers educated in the prewar years. Then came the discovery of the transistor in 1947. Within a few years, semiconductor devices had largely replaced vacuum tubes in a host of applications. Electrical engineers educated just a few years earlier found themselves unable to do electronic designs using state-of-the-art technology. Almost overnight their education had become obsolete in important aspects. They were not even equipped to understand an explanation of the principles underlying the operation of the new devices.

The engineering community responded with strong introspection and major reform of the curricula, greatly increasing the content of basic science and advanced mathematics, adding courses in subjects such as solid state physics, and largely doing away with courses or work experience aimed at teaching current practice. The changes were not uniform among the engineering fields. Those branches of engineering in which substantial numbers of graduates went into large firms working in fields with rapidly changing technology, such as electronics, left the learning of most current practice to on-the-job education. Employers were able -- in fact they preferred -- to educate new engineers in their company's own techniques. Curricula for students going to small firms or to government offices employing few engineers placed more emphasis on current practice. In those cases the student could not count on receiving on-the-job education; such employers expected the student to be fully prepared to do the job from the start. Even so, the need for flexibility and preparation for self-study were felt.

One of us recalls an old-school engineering professor grumbling about how ill-advised it was to add the requirement that civil engineering students learn differential equations: "The student must learn to think like a bridge," he said. Of course, the reformers' view was that mathematics helps one to think.

Prewar engineering faculties in the United States had a relatively small number of Ph.D.s. Frequently a master's degree and several years of industrial experience were not only more usual, but indeed were judged to be preferable to a Ph.D. Today engineering faculties have a much higher proportion of Ph.D.s than in those prewar years.

As is discussed in Chapter One, educational reform in the People's Republic of China has many stated objectives. One is to create a non-elitist educational system, in contrast with earlier times. Another is to assure that education prepares students to do tasks which are needed. A third is to assure that students selected for higher education will indeed succeed in the educational task for which they have been selected and not be threatened with failure, as they had been under the earlier, more formal, "bookish" system. The fact that these changes were accompanied by a substantial shortening of the time spent on education both before and during college, and by a focus on preparing students specifically for certain jobs, has led many Westerners to wonder whether or not China is still offering college-level education. Some surmise that Chinese universities have become vocational schools. It is certainly true that their educational reforms have carried them in the direction opposite from the changes which took place in the United States. In fact, we remarked several times that the new Chinese curricula bore a strong resemblance to the pre-World War II engineering curricula of the United States.

We were naturally very interested in learning what our Chinese colleagues were doing. As fellow educators, we had hoped for and did have quite substantive discussions with them. Unfortunately, we were not able to obtain copies of written material prepared for the students, but in several instances we were able to thumb through class notes currently in use. We feel that we did obtain a concrete picture of the nature of current university education in solid state physics. We did not have any satisfactory means of measuring the success of the reforms, and so must rely on what we were told, tempered by our

Figure 25 Ivar Giaever admires a lead tunnel junction shown him by the student who made it as part of her work in the low temperature curriculum at Peking University.

own experience. This situation is not too different from what we have experienced in the United States in trying to evaluate educational reform.

In this chapter we begin with a discussion of the curricula in solid state physics. Though the experimental nature of all programs was continually emphasized, we sensed that the broad outline and essential character that we saw will persist, although the details may change somewhat as Chinese educators further perfect their programs.

One of the major constraints within which educational reforms must take place in the United States is a budget limit. Most universities are financially squeezed; therefore, the economic aspects of the Chinese program are taken up in this chapter.

A salient feature of the new Chinese education is the close coupling of universities with factories. We discuss, then, various aspects of this fascinating relationship, turning next to the selection of students, another area of reform in China that aims to achieve various social goals. In the United States about half of the 18-year-olds enter either a 2- or 4-year college, so the problems of elitism and isolation of intellectuals, which worry the Chinese, are diminished significantly by the sheer number of enrollments.

Last we discuss the process whereby students are placed in jobs, a critical area since high-level technical work requires a careful allocation of talent if it is to progress well. The extent to which job allocations can be done successfully by a bureaucratic system such as China's was a matter of great interest to us.

B. EDUCATIONAL PROGRAMS IN SOLID STATE PHYSICS AND ENGINEERING

BACKGROUND

The U.S. Solid State Physics Delegation visited the physics departments of Peking University, Nanking University, and Futan University (in Shanghai), and the engineering schools, Tsinghua (in Peking) and Chiaotung (in Sian). On all visits the enormous changes produced by the Cultural Revolution were evident. We were constantly reminded of the experimental nature and transient state of the educational structure which we saw. Perhaps it was for this reason that our hosts were reluctant to give us copies of class notes and usually qualified their statements concerning course content. Nevertheless, we were given sufficient information to obtain an impression of the way solid state physics was being taught in fall 1975. It is important to remember that the universities were completely shut down from 1966 to 1971 and have started up again only gradually. The lack of a complete range of coverage of solid state physics is understandable when viewed in this context. Similarly, the striking degree of specialization introduced in the first year of college becomes understandable when viewed in terms of the boundary conditions laid down by Chairman Mao during the Cultural Revolution. One of the most notable is Chairman Mao's "Brilliant Directive issued on July 21, 1968," which gave rise to the factory-run July 21 schools. It stated:

> It is still necessary to have universities; here I refer mainly to colleges of science and engineering. However, it is essential to shorten the length of schooling, revolutionize education, put proletarian politics in command and take the road of the Shanghai Machine Tools Plant in training technicians from among the workers. Students should be selected from among workers and peasants with practical experience, and they should turn to production after a few years' study.

Thus, the Cultural Revolution has imposed strict boundary conditions upon the curriculum, roughly as follows:

- Undergraduate education must be shortened from the 5-year, pre-Cultural Revolution, "bookish" education. In practice, this has resulted in a 3-year engineering program and a 3½-year program in undergraduate physics (although it is being stretched to 4 years for theorists).

- The curriculum must be closely tied to practical objectives, and the student must devote one-third of his time to practical work.

- The preparation of the student for university study consists, in most cases, of altogether 10 years of primary and secondary school plus at least 2 years of work in the countryside, in a factory, or in the armed forces (giving rise to the frequently used term "worker-peasant-soldier students").

- During the undergraduate years, the students must serve 1 month in the army. Each year they must work 2 weeks in agricultural production. They have six weeks' vacation.

PHYSICS CURRICULA

Because of the second boundary condition, there is no general study of physics. The field is distributed into subspecialties with a heavily applied, device-oriented nature. A student must select, and be admitted to, a particular subfield. It is virtually impossible to switch from one subfield to another.*

The subfields offered by the physics department at Peking University are magnetism, low temperature physics, laser physics, and theoretical physics. In addition, radiophysics and geophysics are offered in other departments.

The subfields offered at Nanking University are magnetism, semiconductor physics, radiophysics, low temperature physics, laser crystal physics, acoustics, and nuclear physics.

The subfields offered at Futan University (as separate departments) are optics (laser and light sources), microelectronics (integrated circuits), microwave semiconductor devices, and nuclear physics (the Institute-built accelerator is being employed in interdisciplinary research involving ion implantation).

Some examples of detailed curricula are given in Appendix E, which

Figure 26 Conyers Herring and Jack Gilman are shown the holography laboratory at Nanking University.

*A cited case of a change that was allowed, albeit in a different field: "A student with flat feet was transferred out of geology."

Figure 27 Conyers Herring is shown apparatus from the laser optical demonstration teaching laboratory at Futan University.

describes the subject matter given in the laser crystal physics course at Nanking University, the low temperature course at Nanking University, the magnetism course at Peking University, and the semiconductor physics course at Futan University.

Most students participate in an electronics workshop, where oscilloscopes or other instruments are manufactured. Short training periods in production workshops total one-third of the time spent in practice.

Typical practice courses include:

- Various stages in the fabrication of integrated circuits (for the semiconductor curriculum)
- Various stages in crystal growing and epitaxial layers for heterostructure semiconductor lasers (for the semiconductor and laser programs)
- Various stages in production of He-Ne lasers (in the laser physics program)
- Crystal growth and measurement of electro-optic and acousto-optic properties of crystals (in the laser program)
- Cryogenic liquefaction techniques (in the low temperature program)
- Fabrication of superconducting solenoids and Josephson junctions (in the low temperature program)

The student devotes the final semester to a graduation practice project. This involves work on a problem occurring in the "production units" set up at the university, in an actual factory, or at a research institute. In the first two cases, the student is closely tutored by a member of the teaching staff, while in the last case, supervision is primarily by the Institute staff.

ENGINEERING CURRICULA

Tsinghua University has 11 departments: electrical engineering, mechanical engineering, automation engineering, radio engineering, civil engineering (including architecture), electric power engineering, chemical engineering, hydraulic engineering, engineering physics, engineering mechanics, and precision instrumentation. The programs last for 3 years and have the same boundary conditions as the physics program. The training can probably best be compared with that of standard engineering colleges before World War II in the United States, if allowances are made for the programs' shorter duration and for the different preparation of the students. Chinese students have less formal high school training but more practical technical experience when they enter. No detailed course syllabus was made available to us. Four-year college programs in the United States include longer vacations, so the actual time spent on formal training in China may not be much shorter. It is also true that many U.S. students get the equivalent of "on-the-job" training during part-time or summer employment.

Chiaotung University has programs in mechanical engineering, electrical engineering, power engineering, and radio engineering. The resumption of courses after the Cultural Revolution was slower than in

Figure 28 Ch'ien Wei-ch'ang, Professor of Mechanics, shows Sam Chu, Bob Schrieffer, Jack Gilman, Conyers Herring, and Miss Wu the semiconductor factory at Tsinghua University.

the other institutions visited. As at Tsinghua, the radio-engineering course emphasizes semiconductor technology. Strength of metals and aerodynamics are the more advanced specialties for graduation practice work in mechanical engineering.

COMMENTS ON THE PHYSICS AND ENGINEERING CURRICULA

GENERAL COMMENTS The mathematics course in the first three semesters appears to be rather uniform, although separate courses are given for each of the physics subfields. The classes are small, with the students organized on the basis of ability and background. The basic topics are listed in Appendix E. There is a refresher course in high school mathematics available to entering students.

There is considerable differentiation in the subject matter of the physics topics for the various subfields. The students receive rather narrow training, and no overall physics insight is developed. Some special mathematical skills, as needed in each physics subfield, may also be developed in the physics course. The choice of material used to introduce concepts and ideas is greatly influenced by the specialty being pursued. The omission of a course in introductory chemistry is remarkable in the materials-oriented programs.

A separate set of course notes is developed for each course. The students are encouraged to read additional texts. The effort to teach one foreign language (usually English) is noteworthy; it is hoped that students will be able to read technical articles published in that language in their subfields.

The subfields were not all started at the same time, and there are also differences in the resumption of classes at different schools since the Cultural Revolution. The earliest post-Cultural Revolution programs graduated the first class last year. Therefore, the results of this new curriculum are still untested, and new subfields may be added. There is some evidence that the strict adherence to narrow specialization may be breaking down. In magnetism, the theorists at Nanking are given an added semester, which includes atomic physics, quantum mechanics, nuclear physics, and high energy physics (making a total of 4 years). There is already some flexibility in the system, and the "experimental" nature of the current programs was repeatedly mentioned. This means that the programs are subject to change in the future, as more experience with graduated classes of students becomes available and as the perceived needs of the Chinese nation are reassessed.

The present courses in physics are device-oriented and pay scant attention to basic understanding of physical phenomena on a microscopic basis. The physics courses are, in this sense, hardly distinguishable from engineering courses.

The emphasis in the magnetism course is on magnetic materials for computer, radio, and microwave applications. The emphasis in semiconductor courses is on integrated circuits and semiconductor devices. These items are obviously being emphasized in the current plans for technological development. The laser and electro-optic fields also enjoy some priority. The official rationale for low temperature studies may be related to the promotion of cryogenic technology and to the development of superconducting wires and Josephson junctions. No other solid state physics investigations at liquid helium temperature were shown to us at any of the low temperature laboratories that we visited. Such a rather uniform focus in each subfield may be indicative of a centralized policy, as the stamp of approval by the Ministry of Education is undoubtedly required, in practice, for each curriculum.

QUALITY OF EDUCATION The physics curricula appear to be applied physics training programs in selected, narrowly-defined subfields. This probably meets China's most pressing immediate needs. In a "catch-up" society, a broad education may be seen as a luxury that is of low priority, or even deemed undesirable. The responsibility for China's "catching-up" will largely fall to trained specialists, who are graduating under the current programs.

Under the present system, the best result that can be expected is a minimum time lag in the dual tasks of educating the technologists and producing the technology that presumably will be developing continually in the scientifically advanced nations. "Surpassing" the advanced nations, or even keeping completely abreast of them will certainly require a much broader and deeper education in physics of many worker-peasant-soldier students than is presently occurring. Some developments in this direction are emerging -- for example, a new "physics specialty," which began in the fall of 1975, provides a more general physics major curriculum at Futan University. The prevailing method of education, however, concentrates on "catching-up," which really means reducing the technology gap rather than creating new technology and increasing knowledge in general. The undergraduate curricula in all specialties are oriented toward phenomenology rather than atomistic theory. The level of sophistication reached is no greater than in undergraduate physics courses in major universities in the United States, but the given specialty and its applications are covered in much greater detail. Thus, the Chinese graduate has a more practical and wider knowledge of his given specialty than his American counterpart and much less knowledge of the broad fundamentals of physics.

QUANTITY OF EDUCATION Chairman Mao's statement of July 21, 1968, quoted above makes it clear that the bulk of higher education required by China will not be undertaken at the national universities of the type that we visited. The numbers in Table 2 bear this out.

TABLE 2 Number of Students and Faculty at Five Universities

University	No. of Undergraduates (3-3½ yr)	Teachers	Physics Students*	Physics Staff	Short term Courses†	Correspondence Courses
Peking	8,000*	2,000 or 2,600	500	200	40,000	
Tsinghua‡	11,000*	3,000				40,000 to 50,000
Chiaotung‡	3,800	1,300			7,000	
Nanking	3,300	N.A.§	440 +600 correspondence	270	3,200	
Futan	3,200	1,900	500	200	6,000	17,000

*Adjusted to include incoming students accepted for Fall 1975.
†Short-term courses can last from 1 month to 1 year. They combine theory and development research. In Futan, three such courses are concerned with a new light source for photographic printing, a new type of catalyst, and computer hardware and software.
‡There is no physics department at this university.
§Not available.

The low (vis-à-vis the United States) student:teacher ratio is due to the small number of students compared with the larger number of teachers employed. We were told that the opportunity to attend one of the national universities is no longer the prerogative of an elite class. Nevertheless, it is restricted to a low percentage of Chinese youth.

If significant numbers of scientists and engineers are to be educated, either the national universities will grow and/or proliferate much more rapidly than we were led to believe, or the bulk of technical education will be accomplished mainly by institutes other than the national universities, such as the July 21st schools, of which there are more than 500 in Shanghai. These schools aim at improving the technical capability of the factory workers by holding classes right in or near the factory. The Shanghai Machine Tools Plant offers a 3-year mechanical engineering-type curriculum (see Appendix E).

Finally, we comment upon the role of self-study. Time and again self-study was cited by students and staff as the method to be relied upon to cover future needs. In factories or communes well away from educational centers, students can obtain help from workers trained in other specialties, through correspondence courses and exchange visits. At present, it appears that a substantial self-study program is contemplated to avoid the vast amount of technological obsolescence that could take place in a rapidly changing technology carried out by the narrowly trained specialists currently being graduated.

GRADUATE EDUCATION Graduate education, as the term is used in the United States, is virtually nonexistent in China at this time. The term "graduate student" is used in the engineering schools (Tsinghua and Chiaotung) to refer to graduates in factories who return to school because they are trying to solve particular factory-related problems and need more background. They receive more education and also direct help, if necessary, with the problems. At Futan, 113 students from the Shanghai area have started a 2-year program, entering school from factories and institutes, with the aim of going deeper into their specialties. Each program is tailored to fill precise individual needs. For example, one student was receiving special training in vacuum deposition work. Five students were enhancing their skills in the area of lasers; two of these were older workers who had never attended a university before.

New members are being added to the teaching staff from the graduating class and elsewhere. Such persons (who are counted as teachers in China and thus swell the student:teacher ratio vis-à-vis the United States) bear the closest relation to what is termed "graduate student" in the United States. The new faculty members have the opportunity both to attend classes and to obtain help from more senior staff members in studying advanced subjects. At Futan last year, 80% of the graduating class went back to the provinces whence they came for reassignment, 10% stayed at Futan, and 10% were assigned to other institutions.

A great deal of preparation for "research classes" for junior faculty members (i.e., graduate courses) has been under way at Nanking. Future courses may start formally in a year or two. Lecture notes in many-body physics and quantum statistical mechanics have been prepared along with a text in theoretical solid state physics and the use of Green's functions.

ECONOMIC ASPECTS OF HIGHER EDUCATION The main costs in U.S. higher education are faculty manpower, the operation of real estate (such as classroom buildings, dormitories, laboratories, and libraries), and advanced research in graduate education. The last cost is borne mainly by the federal government and private foundations, but it need not be discussed in this report because there is no Chinese equivalent at present.

In the United States, to a great extent, the possibilities for innovation in education are limited by a hard confrontation over the alternative uses of educational funds. The methods of allocation of funds to universities (tuition, endowments, grants from foundations or industry, state funds for public institutions) involve academic administrations in a continual process of trading-off competing uses within rather fixed funding levels, and of appealing, in competition with others, to various possible funding agencies. It was thus a strange experience to find that at no time did our Chinese hosts discuss budgetary considerations in relation to any of the innovations they showed us. The high teacher:student ratio, the university-based production facilities, the modern equipment supplied to the universities, the extended trips to factories (with their consequent use of the time and facilities of the factories) all involve an economic impact that the People's Republic has accepted. One naturally wonders, when these budgetary matters are never mentioned, whether the Chinese are concerned with such economic trade-offs as occur in the United States.

In China the budgetary cost of manpower (salary or faculty labor) is not high. The wages are uniform, low, and noncompetitive. However, educational manpower with advanced scientific and technical training is a scarce commodity and is likely to become scarcer as the senior faculty members, who received a broad training in the West or in the Soviet Union, grow older; no broad-based graduate programs exist in China today to replace them. In spite of this scarcity of faculty manpower, the student:faculty ratio is still very low. The number of students is small indeed, relative to the size of the population and to the anticipated national needs. Thus, a rather curious situation exists: a scarce commodity is under-utilized. In addition, the current programs do not utilize the full scientific capabilities of the faculty, many of whom have Ph.D.s or the equivalent. They are capable of teaching graduate courses, of directing advanced-level theses, and of taking part in research at the frontier of science. Their efforts now are devoted to undergraduate-level teaching and research and to the teaching of correspondence and short-term courses. However important these missions may be, the high level of technical knowledge of the faculty does not seem to be effectively used.

A similar situation appears to exist with respect to educational real estate in the leading national universities, such as those we visited. There are large, well-constructed buildings, well-stocked libraries, and extensive laboratory space; but the degree of utilization of these facilities in the educational process is spotty. From the point of view of cost-effectiveness, it appears wasteful to devote high-grade laboratory space to conducting an assembly-line training and production program, which might better be left to the factories.

The increase in enrollment during the fall of 1975 was substantial, and it may well be that within a couple of years the foremost facilities for higher education in China will be bursting at the seams. At the time of this writing, however, it must be noted that the recovery from the Cultural Revolution is still incomplete, and that in an economic sense valuable resources and scarce commodities are under-utilized. Apparently, the Chinese government is still willing to pay this economic price. The question is, How long will this continue? If China is to catch up to the West in technology, it must use its leading national universities and their faculties more efficiently.

Much of the production activity carried on in universities would be judged inefficient if evaluated narrowly in terms of the ratio of output to the input of labor and resources. The efficiency of the university factories, in this sense, is probably lower than could be feasible in the United States, if for no other reason than that the students are inexperienced and that to learn the operations takes the time of the non-student workers. There is likewise a component of negative economic impact when students and faculty go to a factory outside the university. In the United States it would probably not be possible, in general, to persuade university faculty and administrators to fund the subsidy needed for a university-based factory that would have to compete in the marketplace with highly efficient commercial enterprises, despite the strengthening of the educational program that might result. Of course, many students in the United States do have part-time jobs, as well as summer employment, and some universities have work-study programs in which the student alternates between terms in college and terms working. However, in these programs it is the employer who makes the decision on how to balance long-term societal benefits against immediate productivity. Perhaps we go too far in exacting such economic discipline in the United States, because our procedure certainly does not guarantee the students the educational value of such employment, nor does it completely factor society's needs into the economic trade-offs.

We were told that numerous new universities have been set up in most provinces, and the large number of July 21 schools, correspondence courses, and so on, are probably a cost-effective way to train large numbers of skilled engineers and technicians. These programs make good use of existing engineering manpower and of existing industrial buildings. It should be noted that in the United States much technical training proceeds in a similar way, for example, in electrical power engineering. The Chinese system is based on a low student: faculty ratio and on intensive contacts between student and teacher. This is a worthy goal in U.S. education also, but it is severely hampered by our wage structure and by the fact that such a large part of our population receives higher education.

C. UNIVERSITY-FACTORY RELATIONS

INTRODUCTION

Since the Cultural Revolution, there has been a dramatic change in the nature and extent of relations between universities and factories. A basic dictate of post-Cultural Revolution educational philosophy is that "education must serve proletarian politics and serve production."

To implement this policy, the universities have (to varying degrees) tightly arranged their teaching, research, and university-based production units to serve the practical needs of factories. The specific form of these interactions varies widely, ranging from student participation in actual factory production to faculty members teaching workers in short-term courses and consulting with workers on specific production problems. While these modes of coupling between universities and factories are still evolving, it appears that considerable success has been achieved in attaining the stated goals in the short run. However, we have serious reservations about the long-term prognosis unless significant changes in education are carried out for at least a fraction of the students.

STUDENT-FACTORY INTERACTIONS

A fundamental requirement of post-Cultural Revolution education is that students must spend one-third of their time in productive labor (largely factory work, for those in physics). The stated reasons for this requirement are many: (a) by being exposed to actual production practice, the student better comprehends the formal course work in his field of study and is better motivated to carry on these studies; (b) the student has an opportunity to learn from experienced workers the practical problems of factory production; (c) the student is integrated socially with the workers, suppressing the "elitist tendency" of the pre-Cultural Revolution student; and (d) the student is able to contribute to the solution of practical production problems, particularly through his graduation project work.

Typically, a student during his first year of university study will work in the university-based factories, such as those manufacturing

Figure 29 Ted Geballe and Anne FitzGerald with members of the luminosity laboratory at Futan University.

Figure 30 At Futan University, an important curriculum involves the manufacture of lamps. Here Bob Schrieffer and two students watch as two others gather data in the lamp spectral distribution and color measuring laboratory.

ferrite memory cores, integrated circuits, oscilloscopes, lasers, and high-intensity lamps. These "internal" factories generally have close ties with "external" factories and/or institutes.

During the second year, the student spends a significant fraction of his time in a factory, accompanied by one of several professors who continue to hold formal classes for these students in the factory. For example, at Tsinghua University one third-year student of automation worked in a factory on pulsed circuit electronics, while a student of electronics helped in making an automatic transistor tester and a zero bias compensated dc amplifier while at the factory during her second year. At Chiaotung University, a student of welding went to the factory in his first year and joined in a project designed to improve the quality of welding rods being fabricated from a substandard batch of material. On returning to the university, he continued to work on this project. We learned at Tsinghua University that as many as 30 students may take part in a given factory visit (lasting up to several months) if a large project is involved. Another example of motivating students through involvement in factory experience comes from Tsinghua University, where students worked 2 months in a factory with machinists who illustrated how drawings were used in the manufacture of parts. Also, some students at Futan University go to the factory for their first-year course in electronic circuits, where they study specific devices under fabrication. In addition these students helped set up temperature controllers for factory furnaces.

The above examples have been drawn from curricula at the technical universities which are closely connected with well-developed industries. At universities of arts and sciences (e.g., Peking, Nanking, and Futan), many departments are involved in advanced technology that is yet to be heavily industrialized. Hence, as we learned at Nanking University, the students in low-temperature physics, for example, work in factories producing liquefiers, dewar vessels, or superconducting wire and tapes, or in a large-scale liquefaction plant. Finally, if the situation warrants it, the students work at an institute developing a new technology. All of these modes of "external work" count toward satisfying the "one-third" requirement.

Clearly, the most important part of the student's involvement with the factory is through his graduation project. Problems from which such projects are chosen come from the state, from factories, or are internally generated. The magnitude of the problem varies widely, with large problems often being divided among several departments in the university (this typically occurs for the technical universities where complex machine-system design is often involved). For example, the third-year class in automation at Tsinghua made a small process-control computer for a larger system, part of which is being designed by the precision instrument class. When finished, the system could go into manufacture "if up to state standards." A second example is a graduation project of designing and constructing a digital control system, a project inherited from an earlier class that had been unable to complete the task. At Chiaotung, we learned of a compact ellipsometer being designed and built to measure the thickness of an Al_2O_3 film on Si. At Futan, the 1974 class took part in designing a laser for surveying and alignment and made lasers for cutting drinking glasses 2 mm thick and for drilling. Another group from Futan University, visiting at a semiconductor factory, was able to diagnose and solve a problem of excess leakage currents in transistors being manufactured there.

Corresponding graduation projects in the advanced technology areas were discussed at Peking University and Nanking University, such as one on the preparation of 37-strand wire or tape of Nb_3Sn composite superconducting wire, and another on the mechanism of ac loss in soft magnetic materials. Both projects are somewhat removed from current factory production.

While in principle the students return after graduation to the brigade, commune, or factory from which they came, special requests by factories for certain students are possible if deemed beneficial to the national welfare. We learned that this is often arranged for students doing their graduation work in a given institute, so that they may continue their work as an institute member.

FACULTY-FACTORY INTERACTIONS

As mentioned above, when the students go to a factory, they are accompanied by some of their professors. In addition to continuing formal lectures to the students, the faculty often present lectures to the workers and consult with them on practical production problems. It is hoped that, like the students, the faculty benefit from becoming acquainted with practical problems in regard to improving the relevance of their formal lectures to factory-type problems.

Consultation is widespread -- for example, we were told that Futan University receives 100 requests for help per week. The faculty also give informal lectures and short courses to workers in the factories, and some faculty members teach in the factory-based July 21 schools.

Finally, the faculty may initiate new factories or convert old factories to making a new product when the new product that they have designed gains government approval (for example, the ex-door-knob factory in Shanghai now produces computers as the result of design work by the faculty of Futan University). (See Chapter Five, Section C.)

WORKER-UNIVERSITY INTERACTIONS

In addition to taking courses in the factory, workers come to the university to take short courses on new techniques, instruments, and machines. These courses typically last 1 to 2 months. We were told specifically of several cases: (a) a team of 11 women studied at Tsinghua University for 2 months learning to read circuit diagrams and learning "production methods," such as soldering, in order to begin production of diffusion furnaces; (b) workers came from a factory to Futan University to learn of a new light source for photographic printing; (c) a group of workers formed a class to study computer software; and (d) a group studied a new efficient catalyst developed by the chemistry department at Futan University.

The universities also teach refresher courses, typically lasting a year. In a sense, this is graduate work, but more realistically it appears that if an ex-student runs into difficulty solving a problem, having been in a factory for a year or two, he can return for help on this problem, as well as enrolling in specialized courses to help him in the future. At Tsinghua University 100 students were involved in such refresher courses last year.

Finally, the faculty devotes a very large effort to running correspondence courses for factory workers (and others). At Peking University more than 40,000 students were involved in short, refresher, and correspondence courses last year, while at Tsinghua University 40,000-50,000 are involved in correspondence courses alone. This is clearly an important component in upgrading the education level of workers who cannot attend the university.

COMMENTS

Accepting the constraints of a 3-3½-year university education following 10 years of elementary and secondary education, that education must serve proletarian politics and serve production, and that China is trying to leap-frog from a pre-modern agrarian society to a modern technological society in two generations, the present scheme of education and the relations of universities and factories seem to be reasonable first steps. The extensive contact students have with actual technology and research in factories and in institutes is admirable. Many engineering students in the United States and abroad have traditionally had the advantage of cooperative work-study programs arranged between a university and a number of factories. Less common is the participation of undergraduates in research programs in universities and in industrial and governmental laboratories. Yet summer work programs at such laboratories have been in existence for a long time, and a new thrust toward early involvement of undergraduates in university-based research is taking place (for example, the Massachusetts Institute of Technology strongly emphasizes this).

Having faculty directly involved in production problems is also desirable to a degree, so long as they are not so tied to short-term problems that long-range creativity is suppressed -- a common conflict facing research laboratory directors. At this time, the various benefits of faculty in the factories look positive on the whole.

Short courses are not uncommon in the United States and Europe, and they appear to work well in China, too, playing the role of high-quality technical school courses. Refresher courses appear to have multiple purposes, from bailing out a student in trouble on a difficult problem to serving as a kind of graduate training. The correspondence course program is clearly more extensive and is possibly on a higher level than it is in the West.

On the whole, the interactions between universities and factories seem quite effective and imaginative in structure. One serious concern, however, is that the universities are not being utilized now in a manner which exploits their great potential for truly creative work. The university research efforts are at the level appropriate to the undergraduate program and do not reflect the full ability of the faculty. Also, we did not see evidence of the training of researchers and teachers at the high level required to renew institute staffs and the leading faculty positions. These practices represent living off one's capital. No doubt China is well aware of the potential difficulties lying ahead if it intends to compete with (and even surpass) the rapidly evolving technological nations. At present, the emphasis is on disseminating and reproducing known technology. Soon China must begin to produce truly new technology if its ultimate goals are to be achieved. The close relation between universities, factories, and institutes developed during this period could be an important asset in the future.

D. SELECTION OF STUDENTS

INTRODUCTION

A fundamental theme in current Chinese educational philosophy is that the university educational program must "serve the people," (in the collective, of course, not the individual sense). Youths are sent from the production units (perhaps factories, perhaps agricultural communes) to the universities to receive training, with the expectation that the student will return to the production unit and, with his new knowledge, increase the productivity of that unit. The university is to help the production units and the student is part of the mechanism by which the universities provide this aid. A natural corollary of this philosophy is that the selection of students to attend the university should be determined by the needs of the factory or commune. We shall see that indeed these units do play a critical role in determining who will attend the universities. The students who are selected represent only a small percentage of their age group, and they are very conscious of the responsibility placed upon them by this selection; they are "sent by the masses to study for the masses." This philosophy and selection procedure are designed to break down the elitism which, we were told, has been so long associated with higher education in China.

RECRUITMENT

The first step in selection is the definition of yearly student quotas by the State Planning Council in Peking. Each university receives a quota, based upon discussions between the Planning Council and the university, but with the final decision in the hands of the central government. These quotas are then divided among the various specialties within the university, and the available openings in each specialty are announced.

For the provincial universities, which draw most of their students from a single province, the process is fairly straightforward. For the national universities, which draw perhaps only one-third of their students from the home province, the procedure is more complicated. In such a case, the available openings in a particular specialty are announced only in certain provinces, according to the needs of those provinces, as discussed with the Planning Council in Peking. These announcements are then distributed on the local level so that youths who are eligible may apply and so that the revolutionary committees of communes or factories, who may wish to suggest application to youths in their organization, are made aware of what opportunities exist.

QUALIFICATIONS AND APPLICATION

To be eligible to apply to a university, a youth must have completed at least junior middle school (8 years of education) and would normally have finished senior middle school (10 years). In addition he must have worked for 2 years after leaving school in an agricultural commune, a factory, or the army as an "educated youth" (middle school graduate) who is "learning from the masses." This 2-year work period entitles him to call himself a peasant, worker, or soldier, as appropriate, which assures that he can meet one of the entrance requirements: that he be of good class background.

Satisfying this criterion, a youth may apply for any one or several of the programs which have been announced as available in his province. He applies to specific programs at specific universities and may list several choices in order of preference. A student now at Futan, for instance, had applied to the laser program at Futan as first choice, and to the Peking Number One Foreign Language Institute as second choice. The available specialties are very narrowly defined (as pointed out earlier in this chapter) and once accepted to a specialty, it is effectively impossible for the student to change his mind and switch to a different program.

A choice of specialty may also be made by the factory or commune on the basis of expertise they wish to develop, and they may well do some research on what program in which university would best suit their specific needs. This idea may be carried to the point that a factory with a specific problem may wish to send a worker to a university with the ultimate aim of solving that particular problem, either through his general training or by his taking that problem as a "graduation project," or senior thesis.

SELECTION

The initial, and perhaps most important, stage of the selection process is the recommendation by the masses (i.e., by fellow workers in the factory, commune, or army). Apparently, there is open discussion among those who know and have worked with the prospective student. This peer recommendation plays a very important part in the selection process.

The oft-quoted criteria for selection are good class background, good health and physical condition, good class consciousness, and at least 2 years' practical work in a factory, the countryside, or the army. Presumably other criteria also play a role. Among factory workers manual dexterity is highly respected and undoubtedly is an important factor in consideration of prospective students. One student who gave a presentation of his work had served as an announcer and technician for a commune radio station after finishing middle school, and presumably a recognition of his technical abilities was a factor in his selection as a student.

After a student is selected by "the masses," this recommendation is evaluated against others at various levels -- commune, city or county, and province -- to provide a limited pool of applications for final consideration by university committees which include administrators, cadres, and teachers. This candidate pool may be twice the provincial quota for the program in question (we received varying numbers at different universities for the ratio of candidate pool to quota, ranging from 1:1 to 3:1). The final selection is made by the university committees. These committees may consult with provincial, city, or county authorities, interview the students as time permits, and review middle school records, although there is some feeling that this information may be too old to be relevant. There are no entrance qualification examinations used in this selection process. We did not determine whether the prerogative of the university to select from a candidate pool was available only to the national universities, such as the ones we visited, or whether it was the procedure used by the provincial universities as well.

Among the applicants may be many youths who have been employed as "workers" in research institutes and university workshops as well as factories, or who have taken correspondence courses, attended July 21 schools, or attended night courses, or who have served as teachers in commune schools. It is apparent that the university committees may be able to assess rather well the academic abilities of such applicants. This additional information may boost these students in the selection process over the academically untested worker or peasant.

An example of the constitution of the student body obtained by this selection process over the past 3 years was given to us at Nanking University: 40% peasants (including youths from the cities who have been assigned to rural areas after completing middle school), 30% factory workers (probably including "workers" at university factories and research institutes), 10% soldiers from the People's Liberation Army, and 20% cadres. The average age of 19 for entering students at Nanking University is somewhat higher than the typical age of 18 because of the presence of some older students who have worked for a number of years after completing middle school.

SUCCESS OF THE ENROLLMENT SYSTEM

The Chinese report that this selection procedure has been very successful, and that there have been few mistaken selections. In particular they say that the students now are more mature, better motivated, and more critical in their thinking than the students before the Cultural Revolution. Certainly we were impressed with the poise and accomplishments of those few students with whom we had contact. We were told that the failure rate of students since the Cultural Revolution has been zero, a result said to be due in part to the selection of students who are strongly motivated, but in larger part to the extensive help given to the weaker students both by teachers and by other students, and to the emphasis placed on group rather than individual work.

We have reported what we were told about how the new system works. It was, of course, impossible for us, in the limited time we were in China, to gather evidence of our own. Much of what we were told sounded reasonable and was described with conviction. But as teachers we have also had the experience of working on programs which seemed superb in principle, as do many of those that we heard described in China, but were disappointing in practice. We realize that there is debate among Chinese educators on the extent to which, in any given instance, the reforms are fully achieving the desired effect. Some of the points which might be the subject of discussion in attempting to perfect the system are the following:

- In the admissions procedure, do the local selection committees, in their effort to find strongly motivated candidates, choose applicants with strong academic ability?

- Does the more relaxed relationship between faculty and students provide a situation in which, inadvertently, the standards gradually deteriorate?

- Is student activity in the factories carried out with sufficient effectiveness to merit the student's spending one-third of his total education there?

- Are the student's abilities in problem solving and self-study developed with sufficient strength to enable his future growth to provide adequate flexibility and breadth, starting from the rather narrow specialties?

In view of the selection for strong motivation and good class consciousness, the final screening by university committees, and the small number of students who finally achieve admission, we feel it is likely that the student body of the universities represents "the cream" of China's "well-rounded" youth, being both politically sound and academically strong. It is difficult to see how the brilliant but socially maladjusted or nonconforming youth can have much opportunity in such a selection procedure, but the importance of this shortcoming depends critically upon the cultural and political viewpoint from which the problem is judged.

Finally, we might mention a few questions which come to mind concerning the ways in which the people with a stake in the outcome of the selection procedures -- the prospective students and the commune or factory leadership -- might attempt to influence that outcome. In view of the small number of positions available, one would expect there to be keen competition for acceptance as a student, even though in principle it is the interests of the people, not the individual, that are of importance. If there is such a sense of competition, what strategies might a student adopt in order to improve his chances? Would he select specialties on the basis of his own interests and abilities, on the basis of the needs of his own production unit, or on the basis of what offers him the best chance of acceptance? Would he attempt to be assigned to specific jobs in his production unit that seem most likely to lead to a university assignment? Would the choice of school or specialty by the local leaders be influenced by their estimate of the probability that a particular promising student would be returned to them rather than be assigned elsewhere, or that a troublesome student might not be returned? Might there be social reasons, such as the fact that a prospective student has come to a commune from the city rather than having grown up in the commune, in addition to official criteria, that could influence the recommendations of the local leadership? Or are these questions simply a reflection of our own point of view, from a society in which competition plays such an important role?

E. STUDENT PLACEMENT AND INSTITUTE RECRUITMENT

JOB OPPORTUNITY

In accordance with the concept that students are sent to the universities by production units in order to return to that unit with technical skills, the majority of students, upon graduation, return to the commune or factory from which they were sent, or in certain cases to fulfill special needs within the province from which they came, if that would better satisfy the needs of the society. We were told that such "returnees" represent 80% of the finishing students at Futan University. The remaining 20% were divided equally between assignment to research institutes and retention as teachers by the university. Similarly, at Peking University the percentages were: 40% to factories, 40% to research institutes, and 20% retained at the university. (These are rough estimates for only a single year and are probably confined to physics specialties only, not the whole university.)

The decisions concerning placement of the students involve negotiations at a variety of levels. University authorities discuss matters with the state concerning the return of students to the provinces, their retention as teachers at the university, and their assignment to research institutes. The state or provincial authorities have their own views on the needs to be filled and must then match these needs with the available graduates. The students, too, discuss among themselves their desires and the various needs which may have to be satisfied, and they report their opinions and recommendations to the university authorities.

RETURNEES

A student sent to a university by a factory or commune normally expects to return upon completion of his education, but there are clearly many variations from this concept. A commune may well recognize technical talent in a youth and support his desire to serve the state better through university training in a specialty with no relevance to the activities of the commune. In such a case, the student, upon returning to the province from the university, would routinely be assigned to a factory, to a research institute, or as a teacher to a provincial university where his new skills could best be used. In instances where there is a conflict between the provincial authorities and the unit of origin of the student, there is a "consultation" about the relative needs for the student's talents, but the final decision rests with the provincial authorities, whose needs are usually considered more important.

We saw examples of both processes. A student at Tsinghua had completed a specialty in electronics and was about to return to her factory in Northwest China to develop automatic process control systems there. A student at Peking University who was sent from a commune will probably return to teach in the provincial university in the province from which he came, since his expertise would be of little benefit to the commune.

UNIVERSITY STAFF

It is common for the universities to keep some of their graduating students to continue as teachers at the same universities. Futan University, for example, with a teaching staff of 1,900, had kept 200 students as new teachers over the last 2 years. The danger of "inbreeding" is evident, especially in view of the narrow training which the students receive. We were surprised that this is the dominant source of new teaching staff, the appointment of a graduating student at one university to a teaching position at another being relatively rare. A few "worker" teachers, 30 in this 2-year period, were obtained from factories or communes.

Each specialty within the university is responsible for maintaining its own teaching staff. It negotiates, via university authorities, with the state for the desired new positions, recognition being made of the teaching needs of the specialty as well as of the needs elsewhere in the society for graduates in that specialty. The specialty is also responsible for further training of these teachers after they have joined the teaching staff.

RESEARCH INSTITUTES

The requests of research institutes for new staff members are referred to a job assignment bureau (*fen p'ei pu*), a temporary organization of scientists and administrators that matches requests with available talent. This procedure is carried out on an anonymous basis, matching student qualifications with job specifications. For many highly skilled jobs this is a most unsatisfactory procedure, in our opinion, since one really must have intimate knowledge of a person to be able to judge his capability to perform a particular task. In fact, we were told that in China it is often possible to write a sufficiently specific job description to narrow the selection to a particular student who is known for his special abilities.

There are a variety of opportunities for contact between students and institute staff that allow the institute staff to identify promising students. Some institutes have "open house" sessions, in which interested students may acquaint themselves with research projects and make contact with institute staff. Visits of institute scientists at the universities, on a short- or long-term basis, provide a means of contact with students, and continuing contacts between these scientists and teachers at meetings and through common research interests provides a further means of exchange of information concerning students. In certain instances the most important contact may be provided by the student's "factory experience," which, in some instances, consists of work at a research institute. It is our impression that when such contacts have been made and a research institute has identified a student it would like on the staff, hiring can be arranged as long as it is not in conflict with needs of higher priority.

As in the case of a student remaining at a university as a teacher, when he joins an institute staff he will typically continue his training, with help from his co-workers and in self-study programs. At least for the moment, this seems to be an "on-the-job" substitute for a graduate training program. Neither in the formal graduate training which is just now beginning nor in this substitute "on-the-job" training did we see evidence that this additional work adds to the breadth of the students' training. These advanced studies are related specifically to the worker's specialty.

This narrowness was apparent in the attendance and questions at the seminars that we gave. In the same light, we understand that in China there is no parallel to our general interest seminars; there are only special topics seminars, attended by workers with specific interests in those topics.

CONCLUSIONS

Because there have been only one or two graduating classes since the Cultural Revolution, it is impossible to develop a sense of the success either of the procedures for placement or of the new educational program in providing the desired technical base in factories and communes, the new teaching staff required by the universities, and the scientific staff for the research institutes. Our principal concern is with the educational implications of replenishing teaching staff principally by keeping on some of the graduates of each university. This practice has led to problems of stagnation in U.S. universities. In the Chinese system, the problem seems considerably worse in view of the very narrow and specialized training received by the students. The stimulation of new ideas brought into a program, either educational or research, by personnel trained in different environments, by different methods, and perhaps in a somewhat different field can be crucial in maintaining vigor and vitality in an institution. The practice of keeping students on as new faculty seems destined to lead to a stagnation that seems very contrary to the spirit of the Cultural Revolution.

In contrast, the procedure for filling positions at the research institutes seems well adapted to making the best use of their limited resources, and an important aspect is the apparent ability to identify and obtain particularly well-qualified students to fill specific positions.

Finally, we are concerned about the implications both for the universities and for the research institutes of the narrow training to which we keep alluding. It is important that teachers be able not only to transfer a certain body of knowledge or skills to a student but also to put that body of knowledge in proper perspective and to judge the merits of possible changes in emphasis in the teaching program. Interchange between different but related fields of research is often important to progress in those fields. Wise choices in research administration and in changing directions of research programs require broad training and understanding in many fields of research. Currently China has a large body of scientists trained in the West or in the Soviet Union, and the training they have received has had the breadth to allow them to fulfill the needs noted above. By whom will these scientists be replaced? The training programs we have seen cannot do this job.

We must note, however, that the education system in China is evolving continually; some of the scientists with whom we talked were concerned about this problem, and there were occasional signs of the development of some programs of broader scope designed to meet these needs.

5

COMMUNICATING THE FRUITS OF RESEARCH

A. INTRODUCTION

As was explained at the outset, our goal in China was to observe and try to understand Chinese research and education in solid state physics, and their relations to technology and the other sciences. In all of these activities communication of information is central -- the progress of research depends upon enlightened awareness of the state of knowledge throughout the world and on the critical reactions of scientists to each other's work. Education not only involves transfer of information, but also the training of students to be aware of and to use the available channels for obtaining information; technological innovations involve the passage of information from the world of science to that of the inventor, and from the latter to that of the manufacturer.

In our brief solid-state-oriented visit it was, of course, not possible to glimpse more than a fragment of the total pattern of scientific and technical communication in China. However, we did observe some interesting characteristics of Chinese communication channels, as well as differences (sometimes favorable and sometimes unfavorable) between these channels and those typically available in the United States and Europe. The account of our observations and reactions given in this chapter is divided into two major sections: communication and assimilation in the scientific community, and "technology transfer" (the coupling of scientific advances with the practical needs of the economy). We shall begin with the first of these, discussing in turn the communication among research workers within China and contact with developments in other parts of the world.

B. COMMUNICATION IN THE SCIENTIFIC COMMUNITY

The characteristics and relative roles of the various channels for oral and written communication of scientific information have been extensively analyzed in the West, especially in the physics community. Studies have been made both by scientists who use the channels being studied and by specialists in information science, who bring a somewhat different point of view to the field. We spoke with members of both these communities in China (i.e., with physicists and with librarians), but did not come into contact with any person who had done research on the communication process, nor did we learn of any such studies.

A number of different modes of communication, oral and written, formal and informal, are of comparable importance in supplying the information that American and European scientists need in their work, and these are connected together in a network of series and parallel relationships. Many of the channels are almost uninfluenced by international boundaries. As we shall now see, the roles and characteristics of many of these channels are quite different in China because of differing goals, conditions, and historical background.

COMMUNICATION WITHIN CHINA

Following are the various oral and written channels of communication about which we inquired.

EXCHANGE OF PERSONNEL We were told several times that transfers of people between institutions, and visits of several months or a year, are common and important mechanisms for diffusing awareness and know-how in the scientific community. For example, some people from Futan University are visiting the Institute of Metallurgy in Shanghai, in preparation for experiments using the Futan Van de Graaf accelerator for the study of solid-state problems; also, some Institute of

Metallurgy people will come to Futan. However, we did not have occasion to talk with any scientific workers currently taking part in such exchanges.

SEMINARS Both in universities and in research institutes we were told that intra-specialty seminars are frequent -- they are held every week or two. Often, such seminars are attended by workers in the same specialty in neighboring institutions; for example, seminars in such fields as relativity and quantum field theory often bring together people from various Peking institutions, such as the Institute of Physics, the Institute of High-Energy Physics, Peking University, and Peking Observatory. On the other hand, we did not hear much about seminars bringing together workers in the different physics specialties. Most of the meeting rooms that we saw, as well as the blackboard, paper-pad, and projection facilities in them, did not seem to have been planned for use with large audiences.

CONFERENCES We were told there has been no general national physics meeting (comparable to the American Physical Society meeting in the United States) in China since the Cultural Revolution. However, there seem to be a fair number of national conferences devoted to very specialized topics, to which any large institution doing work in those specialties is likely to send one or more representatives. We did not, however, hear of such meetings inclusive enough to be attended by a majority of the participants in a research project. A typical subject might be "Surface Passivation"; typical attendance might be 150 people.

RESEARCH JOURNALS As has been noted elsewhere in this report, the efforts of Chinese physicists, and of solid-state physicists in particular, have in recent years been strongly channeled toward the support of specific areas of technology. It is not surprising, therefore, that the proportion of their work which eventuates in scientific journal publication is considerably smaller than it is for the basic-research-oriented physicist population of some of the Western countries; in this respect, Chinese physicists are more like Western engineers. There seem to be only two Chinese journals devoted to physics to the exclusion of other sciences: *Wuli* (Physics), and *Wuli*

Xuebao (Acta Physica Sinica, which was formerly translated by the American Institute of Physics [AIP] under the title "Chinese Journal of Physics.")* The latter is the most important journal for publication of new research, the former containing a sizable proportion of non-research articles (such as quasi-popular and political articles). Publication of both journals is under the auspices of the Chinese Institute of Physics.

Besides the two physics journals just mentioned, there exist a number of journals that span a number of scientific fields and that publish physics papers as well as others. The best known of these, at least in the West, is *Scientia Sinica,* which is published in China in an English version as well as in Chinese. Mention was made in one of the discussions at the Institute of Physics of a letter journal serving all the sciences, but we have not learned more about it. Finally, many of the nation's universities and institutes publish their own journals, some covering all natural sciences, some dealing only with physical sciences and engineering. The library at the Institute of Physics had about a dozen such journals on its shelves.

Most of the physicists we queried on the subject of publication indicated that *Wuli Xuebao* was the most favored journal for publication of significant new research results. This impression is roughly confirmed by a study of references in samples of papers in *Wuli Xuebao*: 5 of 14 references to Chinese work published since the start of 1970 were to papers in *Wuli Xuebao.* Unfortunately, the numbers are small, and one must allow for the well-known tendency of articles in a given journal to cite the same journal. About all we can conclude is that *Wuli Xuebao* probably publishes a sizable fraction of the new physics research results that are formally published in China. But this fraction is rather small, only a couple of score articles per year, in all areas of physics. One is tempted to infer that it is limited not only by the fact that the overall scale of research work is as yet rather small, but also by the fact that formal publication is a much less important channel for communicating the results of physicists' work in China than it is in the United States and Europe.

Despite these differences in communication patterns, *Wuli Xuebao* is, in many ways, similar to the physics journals of the rest of the world.

*The AIP was unable to continue this translation, as of January 1976, in the absence of a subsidy.

It has an editor-in-chief (J. S. Wang of Peking University) and an editorial board of about 50 physicists, a fraction of whom constitute a steering committee for actual administration of the journal. The other editors help with the processing of manuscripts by performing such tasks as collecting referees' opinions. Refereeing, authors' revisions, and ultimate acceptance or rejection, all seem to take place in very much the same way as they do in Western journals. As with the latter, a sizable majority of the papers submitted -- perhaps three fourths or so -- are ultimately accepted, at least in solid-state physics. Before the Cultural Revolution, *Wuli Xuebao* paid authors of articles. It does not do so now. It publishes brief communications (letters) as well as full papers; it also publishes occasional review articles. (There seems to be no journal of Chinese physics devoted purely to review articles.)

As for the economics of publication, the philosophy of *Wuli Xuebao* (and presumably of Chinese journals in general) seems to be to subsidize pre-run expenses and to market the journal at essentially run-off cost. This makes it easily available not only to groups and institutions with a peripheral interest in physics, but also to individuals; if the circulation can be correctly gauged from the figure of 15,000 copies that we were given as the size of a printing, this policy is very successful. Time delays (from submission of an article to publication) are comparable with those in many Western non-physics journals, being often more than a year, but are rather longer than those in many Western physics journals.

REPORTS A large part of the work in solid-state physics now being done is recorded only in reports, whose distribution outside the initiating institution is limited to those groups known to be interested in the subject of the reports. Identification of such groups or individuals seems to occur mainly via the "grapevine," including especially the assumption of responsibility by administrators to ensure that adequate liaison is maintained between potentially related activities. There seem to be no central master lists of reports, such as those available in the United States through NTIS, STAR, and so on, nor is there any automatic distribution of reports to libraries of large institutions. However, we were told that "major" reports are mentioned in the title listings of current literature for specific subdisciplines (see the discussion of secondary services below), and that these sometimes prove quite useful.

CONTACT WITH WORK OUTSIDE CHINA

TRAVEL At present, there seems to be essentially no attendance by Chinese physicists at international meetings. As for extended visits for study or research, we were told that there are a few Chinese physicists currently on assignments in Europe. The only other scientific travel of which we are aware is that of delegations, like the one in solid-state physics that visited the United States in the spring of 1975. These, of course, do not provide intimate working-level communication, as sabbaticals and more focused research visits do, although they are very valuable in providing perspective and in paving the way for the latter.

PUBLICATION ABROAD Chinese physicists do not seem to publish any of their work in foreign journals, even in the form of preliminary announcements. Thus, they miss out on such benefits as correspondence and reprint exchange, to which such publication might lead.

CENTRAL ASSISTANCE TO THE DISTRIBUTION OF FOREIGN PUBLICATIONS A large number of foreign journals -- no doubt the great majority of important ones in physics -- are centrally reprinted in China for low-cost circulation. Libraries in research institutes and universities have several possible channels for obtaining foreign journals: they can subscribe to the reprinted version; they can obtain the original publisher's version by subscriptions centrally processed in Peking; or they can negotiate directly with the foreign publishers. Presumably each library will adapt its use of these channels to the needs of the community it serves, striking the requisite balance in speed, convenience, and economy.

We did not learn of any foreign journal being regularly translated into Chinese for circulation in China, in the manner in which the AIP serves Western readers by translating leading Soviet journals and, formerly, *Wuli Xuebao*. However, a few books of especially wide use have been translated from English or Russian into Chinese.

SECONDARY SERVICES As far as abstracting and indexing services are concerned, Chinese physicists seem to rely primarily on the material gathered by services in the various Western countries and in the Soviet Union. We were told, however, that they reprocess much of this material centrally, translating it into Chinese and arranging it in title listings for specific subfields of physics, including in these listings some Chinese-generated material not in the foreign sources. In our visits to libraries, we found that although such journals as *Chemical Abstracts, Physics Abstracts,* and *Referativnyi Zhurnal* are available in all major institutions, *Science Citation Index,* which many U.S. scientists now find to be the most useful secondary service of all, is almost never available. Foreign title listings, designed to fulfill the current-awareness function, are also practically never available. Perhaps the Chinese feel that their reprocessed version fulfills this function, although it certainly loses the important virtue of timeliness.

LIBRARIES: RECEIPT OF FOREIGN MATERIAL We visited libraries or spoke to librarians in many of the institutions that we visited. They always told us that their libraries were generously funded, and our inspections of their holdings confirmed this. The coverage of foreign books and journals in physics was always impressively inclusive; while no library in any country ever has all the materials that could be considered useful, the coverage of important physics books and journals seemed usually to be as complete as at major institutions in the United States. A few journals, such as *Physical Review Letters,* are received by air mail, hence quite promptly. Many other journals are received directly from the foreign publishers, even though a slightly delayed version could be obtained less expensively through the Chinese reprinting service. (In one case we were told that the journals obtained by direct subscription amounted to about half the total; subscriptions for most of these were handled through a national center.) All libraries in the country are in a mutual-help network, and interlibrary loans are apparently fairly common. Institutions, such as Futan University, that publish journals of their own are apt to have exchange agreements with similar institutions in foreign countries, so they may obtain the journals of the latter without transfer of money.

<u>LIBRARIES: ORGANIZATION AND ADMINISTRATION</u> Most large Chinese universities, like their U.S. counterparts, have separate departmental libraries for physics, for chemistry, and for various other disciplines. Materials used by research workers are housed in these libraries, where they are usually convenient to the place of work; material for large-scale routine use by students is, however, often kept in the central library. Research institutes are more likely to have a single library, as is appropriate considering their more specialized areas of concern and the more compact housing of their staffs. It sometimes happens that even a university has only a central library; as in other countries, this no doubt significantly retards use by research workers. In one such institution we found a very awkward distribution of research-related materials, in that current periodicals, bound periodicals, books, and abstract journals in the same field were stored in a multitude of widely separated locations.

The libraries with which we made contact seemed to be well staffed. The staff members in charge of physics collections have varied backgrounds, most of them with some scientific or technical training, and some, though perhaps a minority, with formal training in librarianship. Decisions on acquisitions and other library policies usually seemed to be reached collectively through discussions involving research and teaching staff and students. This is undoubtedly a manifestation of the greater attention to library users fostered by the Cultural Revolution.

There is a Chinese numerical indexing system for books, analogous to the Dewey and UDC (universal decimal classification) systems, but different from these.

<u>LIBRARIES: USE OF THE SCIENTIFIC LITERATURE</u> Language is a major barrier to use of the foreign literature. True, all Chinese physics students study a foreign language (usually English, but often Japanese, German, Russian, or other), and they are sometimes given explicit instruction and practice in the use of the foreign scientific literature. Most of the libraries with which we made contact did not supply any translation service for their customers, although we were told that the Institute of Physics does supply assistance in Russian and French.

Photoreproduction of journal articles is not yet widely available, although it can be had at some libraries; here it is particularly useful for students and staff who engage in extended work projects at factories and in similar activities. Where full-page reproduction is not available, microfilm copying is sometimes extensively used.

Although some staff members at the universities and research institutes seem to keep fairly well abreast of current developments in the foreign literature, we encountered several indications that the great majority of Chinese physicists do not use this literature as promptly or as effectively as might be expected from its excellent availability in their libraries. In one library many of the most important books and journals had not been checked out for a number of years. In some cases Chinese physicists had not yet become aware of certain developments, published long enough ago to have been received by their libraries, that tied in closely with their own special interests. In other cases, items in the foreign literature were apparently receiving very serious consideration from Chinese physicists, in ignorance of the fact that they had subsequently been discredited. We cannot estimate the relative importance of various possible causes for this inadequate use of the literature, such as language difficulties, ideological antipathy to archival knowledge, or overstrong spirit of national self-reliance, or the mere tendency, often deplorably prevalent in the United States, to disparage work by people or groups with which one has no personal contact.

Actually, the information-gathering habits of Chinese physicists may well be very similar to those that Western physicists would have if faced with the same problems. For example, one group, whom we queried about their sources of awareness of papers in the literature, replied that references in other papers were the principal source, with journal browsing and word of mouth next. This is very similar to the known pattern for U.S. and British physicists, as described, for example, in the recent NAS study, *Physics in Perspective.* Abstract journals and title listings, which are somewhat less used by British physicists than the other sources mentioned, were used even less by these Chinese physicists.

Chinese universities often exert themselves to make their libraries useful to the general public and in particular to factory workers. The latter are encouraged to visit the libraries; materials for which duplicates are available can be checked out to them, and other materials may be copied. At Futan University, we were told that the library had begun providing to factory people materials they have not requested but that the university thinks may be of value to them.

C. TECHNOLOGY TRANSFER

A major topic of interest to us was the transfer of technology from the research laboratory to production. We saw a number of examples of successful transfer. We probably were able to get a fairly complete picture of the methods used, but, of course, we have difficulty judging whether or not the system works as smoothly, efficiently, and effectively in practice as in theory. We could not judge, either, which institutions that we visited were best solving the problems of transferring technology.

Technology transfer within China occurs through a number of channels which should, in principle, be relatively effective. Mainly it involves personal contacts rather than reports or publications. The Chinese have adopted a number of measures to stimulate personal exchanges, such as student-faculty groups at factories. There is obvious difficulty in adopting Western technology to China's needs because of China's present relative isolation. The main centers of advanced technical knowledge are the research institutes (many under the Chinese Academy of Sciences) and the universities. Since the universities reopened after the Cultural Revolution, most work in solid state physics has been applied, with much of it directly oriented toward factory production. The universities have concentrated on advanced technology, generally not available or in short supply in the factories. The main areas are semiconductors, electronics, lasers, magnetism (ferrites, magnetic bubbles), and superconductivity.

UNIVERSITY TO FACTORY

As discussed in the chapter on education, most students spend extensive periods of time in factories, where they learn production methods from the workers. Faculty members accompany the students so that they can continue their course work. In this way, both students and faculty come in direct contact with practical problems. In turn, student-faculty groups may help solve problems that arise from needs of society. This usually occurs with more advanced students doing thesis or "graduate practice" work in the last 6 months of their studies.

Examples at Tsinghua University are the design of a machine for making gloves, now in production at a factory, and a process-control computer that is in the final interfacing stage. The latter, if finally judged to meet the standard, will go into production either at the university or in a factory. Other examples are given in Chapter Four, Section C.

The faculty, we were told, often gives short courses designed for a particular group of workers; this occurs, for example, when the university has developed a product of potential interest to the workers. Such a course was given at Futan University on a new light source for photographic printing designed and developed at the University. This project is in the process of being transferred to a factory for manufacture. On a more practical level, many correspondence courses are given in various fields of technology. An example, also from Futan University, is the teaching about and implementing of electrical machinery for commune mechanization. Faculty learn about needs when they go to the countryside as part of this program.

Products developed by university staff and students may be built in factories directly under university supervision. The university factories make a wide range of products: components such as Si-chip integrated circuits (made by almost all universities), instruments such as dual-trace oscilloscopes (Peking University), devices such as Si-control-rectifiers (Peking University), and equipment such as step-and-repeat cameras (Tsinghua University). Peking University developed the GaAs range finder contracted by the railroad company.

When large-scale production is required, production may be transferred from the university to a factory chosen by the local bureau in charge of factories. One example is the transfer of the task of making diffusion furnaces designed by staff at Tsinghua University to the Number One Semiconductor Equipment Factory in Peking, which formerly made and repaired measuring scales of the sort used in stores. Another is the transfer of production of the computer designed by the mathematics department at Futan University to a factory in the neighborhood that formerly made doorknobs.

INSTITUTE TO FACTORY

The research institutes in China were originally designed to be similar to those in the USSR, that is, primarily for basic research and having little contact with industry. Considerable changes were made after the Cultural Revolution to make the work more practical.

The way products developed at research institutes are transferred is less clear, although there appear to be close connections between institutes, universities, and factories. In the laser area, there is an institution known as the "experimental laser station" in Shanghai that develops products and their applications from ideas and designs originating from research institutes including the Institute of Optics and Fine Mechanics. At the Institute of Optics and Fine Mechanics, ideas for products are developed further toward the production stage by a design institute (one being the Laser Equipment Station). It is not clear that workers in research institutes have as direct access to factory problems as do the faculty-student groups that go to factories as part of the teaching programs. Nevertheless, a number of examples have been given of problems transferred from institute to factory, such as quartz, ruby, and diamond production from the Institute of Physics. At the Institute of Semiconductors, one of the main activities is to improve reliability of semiconductor products. The Institute is conducting testing and failure analysis in close coordination with a number of semiconductor factories.

The institutes, in general, are working on relatively exploratory projects, such as lasers and semiconductor microwave devices, which will be transferred to factories someday if successful. When they are, we were told, personnel may go with the project to help transfer the knowledge.

FACULTY-STUDENT TEAMS IN FACTORIES

Less sophisticated products may be developed at the factory by student-faculty teams in residence. Examples are the design of simple agricultural machinery, such as a rice transplanter for a small factory at Wuhsi, and help in design at the Shanghai Machine Tools Factory. The groups are said to be welcomed by the factories, even when their contributions cannot be very great (as at the Shanghai Machine Tools Factory, where there are many engineers). Factories such as those in communes that are short of technical personnel probably welcome the visiting groups.

FACTORY TO UNIVERSITY OR INSTITUTE

Factories are urged to be self-reliant. However, if a technician (or engineer) needed help in solving a problem, he would, if necessary, go to an expert in a university or institute. An example was given us of a design problem which was solved by staff members at Futan University with the use of their computer. Other examples are given in Chapter Four, Section C.

There appears to be little red tape involved in these informal arrangements. However, a university would not volunteer its help to a factory; it would have to be asked. This may be a handicap if the factory is backward but determined to "go it alone." It was stated that teachers at the universities may come from the factories, if their expertise is called for.

TECHNICAL MEETINGS

As we discussed earlier in this chapter, there are many meetings on special topics (such as semiconductor reliability) that help provide information exchange for people within a specialty. However, there is little opportunity for someone in a different field to learn of these problems and perhaps help solve them by another approach. Since unifying background principles are neither stressed nor considered important, technical meetings are confined to rather narrowly defined engineering topics.

EXCHANGE BY TRANSFER OF PERSONNEL

An important method for transfer of technology in China is to send people (factory workers and technicians) to a place where the technology is being used, in order to learn on the job for a period of some months. Thus, the housewives in the Number One Semiconductor Equipment Factory in Peking learned to read circuit diagrams and wire circuit boards at Tsinghua University, and the university staff gave them considerable help in getting started in the early years. Some 30-40 staff members of Futan University spent several months at the former doorknob factory, and the factory came to be used by student-faculty teams as part of their training. The textile factory at Tsun Hua got started by sending a group of workers to another textile factory in production to learn the various skills required. They were given some old machines by a factory that was buying new equipment. In agriculture it is also common to send people from one commune to another for temporary periods to learn new methods. Communes appreciate the technical skills brought by student-faculty teams sent out to learn for a few months.

The strong dependence on person-to-person contacts for technology exchange within China probably works reasonably well because the scientific and technical establishment is relatively small and because there is little transfer between specialties. As the establishment grows, it may be necessary to rely more on publications to initiate contacts and to otherwise enhance technology transfer. Studies in the developed countries have shown that person-to-person contact is by far the most common form of technology transfer, although publications play an essential role. This very effective method unfortunately cannot be used to transfer technology from the developed countries to China, where, except for the occasional visitor, publications from those countries must be relied upon.

6

REFLECTIONS ON OUR VISIT

A. INTRODUCTION

Earlier chapters present detailed accounts of what we learned about research, education, and information transfer in solid state physics in the People's Republic of China. On our visit, each day was crowded with impressions which greatly stimulated reflection on the Chinese society and our own, especially on the contrasts and similarities in the problems both countries face and in the approaches both countries use in their search for solutions. In this chapter we present some of those reflections.

Americans think of China as a nation with a rich heritage of culture and power in the world. The development of an atomic bomb and the launching of satellites have demonstrated that the People's Republic can perform the most demanding and sophisticated technical tasks. It is, thus, almost a shock to hear the Chinese themselves state that in many ways the People's Republic is an underdeveloped country. But this is indeed the case. Eighty percent of the population is needed in agriculture to feed the nation. A bicycle is worth several months' of a typical farmer's salary. Improvements in agricultural productivity are under way. One sees tractors at work in the fields. But there is no point in having tractors do the labor of many farmers unless the farmers thereby released can be put to work in other productive labor. To create those jobs, China is attempting to build industry. The decision to decentralize the development process has led to the creation of many highly dispersed, relatively small-scale factories rather than the development of a few giant factories. China has a great need for technical manpower with training and motivation to contribute effectively in such a technically unsophisticated and highly dispersed environment, and it is anxious to have such manpower without unnecessary delay. The importance of the development of self-reliance in technical training is immediately evident, for most of the technical personnel will be widely dispersed. The desire and ability to roll up one's sleeves to tackle everyday practical problems are also, clearly, important qualities to cultivate in the education of engineers who are to fit such an employment pattern. We believe the Chinese have shown great wisdom in identifying the character of the bulk of the technical work force they need at this stage of development.

We visited the universities which the Chinese count on for educating scientists and engineers to carry out technically the most sophisticated research, and the research institutes at which much of that research will be performed. As was appropriate, we were viewing that end of the spectrum of technical activities most dependent on the forefront of knowledge and on sophisticated instrumentation, and most demanding of a high technical knowledge level of the scientists and engineers.

To support a solid state research effort on the same general scale and with the same sophistication as in the United States requires a high technical competence in the society. We need only think of the many and varied suppliers of research equipment and materials available to us. But in China, "self-reliance" is not just a catch phrase; it is often a necessity. Many Chinese researchers today are forced to build their own equipment, such as lock-in amplifiers, ellipsometers, or scintillation counters. In this context it makes sense to work in areas of solid state physics that promise immediate benefits. Thus the heavy emphasis on the engineering aspects of solid state physics that we observed, both in education and research, is fitting. But as we have remarked, China has a spectrum of technical tasks. Many policies which are appropriate for the bulk of the activity are not necessarily most appropriate for the technically most sophisticated aspects, and policies which are appropriate for today may need modification as China achieves its most immediate goals. This is the context in which our reflections should be viewed -- as a broad recognition of the general validity of many objectives of Chinese technical development, with some added thoughts about aspects that might benefit from changes in emphasis.

In this chapter we discuss the choice of research topics, the extent of originality in research, the teaching of solid state physics, the problem of specialization versus breadth, and short-term versus long-term goals. We reflect, also, upon the basis of decisions on resource allocation and upon the individual versus the mass line. We conclude with our thoughts on the importance of taking a broad view of self-reliance.

B. THE CHOICE OF RESEARCH TOPICS

The relatively recent origin of large-scale research by the Chinese has presented them with the difficult task of choosing which of many fields to tackle. They are wisely limiting the fields to a small number. The policy of science serving the people has provided the guidelines under which they have emphasized the practical, near-term aspects.

The choice of areas of research, (e.g., magnetic bubble materials, microwave ferrites, and ultrasonic holography), as well as the absence of many possible areas of research, (e.g., experimental studies of magnetic phase transitions, dilute magnetic alloys, ultrasonic investigations of Fermi surfaces or elastic constants), indicated strongly that the choice was dictated by immediate or possible technological applications. Some of the research in these areas was directed toward a detailed understanding of phenomena in terms of models, such as the magnetic creep work at the Physics Institute in Peking and the magnetic ac loss calculations at Peking University. More common themes seemed to be an empirical approach in improving materials or exploratory research aimed primarily at developing a competence in a particular area. There were occasional instances when we felt that experiments were inadequately supported by theoretical understanding, and this sometimes may be the reason for the largely empirical approach.

In selecting fields, one would suppose that it would be useful to examine those fields which have had an important economic impact in the rest of the world, and from these select those best suited to China's needs. The field of semiconductors clearly fits these criteria. The heavy emphasis on semiconductors strikes us as sound. No other field of solid state physics approaches it in terms of technical importance, as it forms the basis of all present-day electronics. Magnetism is clearly another field of broad economic significance. We were surprised, however, by the nature and emphasis of work in low-temperature physics. We also wonder why there was such a small emphasis on strength of materials, although here our inability to visit the Institute of Metallurgy may have unduly distorted our view.

Within the broad applied areas in which scientists had chosen to work, we were sometimes surprised by the selections and omissions. In the field of semiconductors, we saw little or no work on charge-coupled devices, display devices such as light-emitting diodes, or infrared devices, yet we saw a great deal of work on glassy semiconductors. There was a heavy emphasis on semiconductor lasers without concomitant work in fibers and film optics. We recognize that some of the apparently omitted areas may, in fact, be pursued in laboratories not open to foreigners and under restrictions as to dissemination of the work.

Important areas in solid state physics that the Chinese currently perceive as having no immediate or obvious technical applications are simply omitted. A few such examples would be: Fermi surfaces, band structures, all kinds of spectroscopy (such as x rays, Mössbauer effect, ultraviolet, infrared, nuclear magnetic resonance, and electron spin resonance) high-vacuum surface work, and superfluidity of helium. Many of these techniques are, of course, vital to the understanding of practical phenomena at an atomic level and to diagnostic and analytic instrumentation. They have contributed immensely to the rapid advancement of the semiconductor industry, for example. In part their omission reflects the general lack of interest of the Chinese scientists in pursuing an understanding at the atomic level.

Altogether, we believe the selection of fields is good, but not uniformly so.

C. THE EXTENT OF ORIGINALITY IN RESEARCH

We have remarked on the fact that we were impressed with the quality of the solid state scientists we met. They are bright, dedicated, eager, and hardworking. The older scientists have a broad knowledge of physics. Only a handful of the more narrowly trained recent graduates are in the work force at present. It was therefore puzzling that we did not see many particularly outstanding or original research efforts. One exception is the well-publicized structure of insulin.

We have, of course, seen work that eminently qualifies for publication, but most of it in applied rather than basic physics journals. Most of the work we saw was specifically oriented toward special developmental or educational goals and did not add distinctively new building blocks to the world's fund of broadly utilizable knowledge. However, we did learn of some significant contributions to this fund that could well merit publication in scientific journals of worldwide circulation. Some examples are:

- Relaxation Oscillations of Planar Gunn Diodes (Institute of Semiconductors, Academy of Sciences, Peking)
- Heating in Semiconductor Junction Lasers (Institute of Physics and the Institute of Semiconductors, Academy of Sciences, Peking)
- Long-Term Effect of Radiation on Monkeys (Institute of Biophysics, Academy of Sciences, Peking)
- Materials for Glassy Semiconductors (Institute of Ceramics, Shanghai)
- Phase Diagram of $LiIO_3$ (Institute of Physics)
- Self-Focusing in Glass Laser Rods (Institute of Optics and Fine Mechanics, Shanghai)
- Spontaneous Parametric Down-Conversion from 265 nm to the Visible (Institute of Optics and Fine Mechanics)
- Interpretation of Domain Wall Creep in Permalloy Films (Institute of Physics)
- Analysis of Losses Due to Coupled Effects of Eddy Currents and Domain Rotation (Peking University)
- Renormalization Group Techniques in Theory of Phase Transitions (Institute of Physics)

We speculated a good deal about possible reasons for the lack of highly original or innovative research, given the evident quality of the scientists themselves. There are a number of factors which may contribute to this situation, falling roughly into three categories: the consequences of the great emphasis upon immediate applicability of the research, the results of the sociological context in which research is performed in China, and an effect of the focus on narrow specialties. We will touch upon these factors briefly regarding their effect on the originality of research, while broader views of these subjects will follow later in this chapter.

The dictates of the Cultural Revolution, that education and research must "serve the people," have had an impact on research. Mathematics departments are converted to computer design groups and research on ultrasonic determination of Fermi surfaces is abandoned in favor of studies of noise pollution. Focus on the solution of immediate technical problems is unlikely to lead to innovative basic research. That is not to say that original ideas are not an important part of solving practical problems, but if pressures for quick and reliable solutions are strong, the proposed solutions are most likely to involve the smallest possible deviation from established practice or to be copies or modifications of solutions to similar problems already solved in Western technology. This may indeed be the most effective policy to achieve the technological development that is one of the goals of Chinese society. It is not a policy that will allow Chinese technology to surpass that of the West.

We did not determine whether the initiative for the establishment of a research program came from the individual research group or from the central authorities. The duplication of effort that we did observe was suggestive of high-level decisions on which areas of research were to be emphasized. To the extent that such central decision making determines the detailed development of research projects, the research efforts could hardly be expected to show much in the way of innovation.

We have sampled the solid state research effort in China at only one moment in time, a "snapshot" taken only a few years after the Cultural Revolution. Many of the research programs we saw could best be described as designed "to get their feet wet," to develop expertise in an area that they anticipate will be technologically important. The projects were developing effectively but were still in their early stages. When the scientists' self-confidence is established in these new areas, then will be the time to judge the qualitative nature of the research and to determine whether it is innovative or pedestrian. Thus, in many instances it is simply too early in the development of a project to categorize the innovative aspects of the research, and we may have a false impression of the balance that will ultimately develop in Chinese research.

We have spoken above of the effect of emphasis on immediate relevance on the qualitative nature of research, an effect that we would expect to be evident both in China and in the West. The second question that comes to mind is the qualitative effect upon research of the concept of research as a group or collective effort, with important decisions being group, not individual, decisions. Is such a context conducive to the generation and development of novel ideas? We can only speculate, of course, on the answer, since the context is so different from our own.

In the environment of group decision making, what is the fate of an innovative but unconventional idea? Will it be proposed to the group, or will the inventor of the idea be wary of offering a proposition which may seem out of line? If proposed, how will it be accepted by the group? Many ideas, in their initial form, are not clearly defined and, particularly if they seem to contradict existing dogma or fashion, may simply appear to be wrong. Such an idea needs an individual who believes in it to develop it, to rework it, and hopefully to prove it by calculation or experiment in order for it to become recognized and accepted. In the West, many good ideas have been initially rejected by experts, only to prove correct after dogged pursuit by individuals who were convinced of their merit. Would this be possible in China?

The concept of establishing the "mass line" can be very effective in many kinds of decision making. Input from many people can assure that all aspects of a problem are recognized, that many alternative solutions are considered, and that the final proposed solution to a problem is likely to be a satisfactory one. The Chinese successes that we have seen, in establishing themselves rapidly and firmly in newly developing technologies and in overcoming difficult hurdles, bear witness to the success of such collective efforts. We feel, however, that this approach is unlikely to lead to radically new solutions to problems, and may in part be responsible for the apparent lack of innovative research noted during our visit.

There may well be implications for the nature of research from the broader social context. Assuming that the "new idea" is accepted by the research group, is the process of obtaining the required bureaucratic approval at higher levels sufficiently tedious to discourage pursuit of the idea? Do the realities of obtaining funding for support tend to encourage "safe" proposals (proposals on problems known to be in favor or for which one can predict a satisfactory outcome)?

Finally, we would note that the high degree of focus on particular specialties, visible both in the educational program and in the apparent lack of cross-discipline, cross-specialty seminars (see Chapter 5), may also contribute to a pedestrian research program. Novel suggestions are frequently the result of combining ideas from different disciplines in an unusual way, and creative solutions to difficult problems often result from the application of techniques adapted from another field of endeavor. Narrow training and highly focused research efforts are not conducive to the novel juxtaposition of ideas.

D. THE TEACHING OF SOLID STATE PHYSICS

The present educational system, which has evolved since the Cultural Revolution, emphasizes the training of engineers and technicians to fill an urgent need in the present state of China's economic development. The students are trained to work on highly practical problems and the curricula are aimed at preparing them for quite specific jobs. The level of physics and mathematics reached in particular areas is probably comparable to that of U.S. undergraduates in science and engineering, but Chinese students have a much broader and more detailed coverage of their particular specialty than would be true in the United States, at the sacrifice of general knowledge of math, physics, and related subjects not of immediate relevance to the specialty. As a consequence, we saw a lot of "solid state engineering" rather than "solid state physics," in the current sense of these terms in the United States. The objectives of the present system appear to be well tailored to the short-term needs of the People's Republic of China.

Long-term needs, in our opinion, are not adequately met at present. The fear of recreating an intellectual "elite" divorced from the interests of the society and the masses played a major role in the Cultural Revolution, and it has suppressed the development of young scientists with advanced training and knowledge. Graduate work is either nonexistent or just beginning. Where it is contemplated, it has a different connotation from graduate study in the United States, which implies a broad-based theoretical background knowledge of fundamental principles.

The Chinese report that they are highly successful in seeing that students who enter college master the work of the specialty which they choose. We were told that this results in part from the new atmosphere of students and teachers helping one another. The faculty does not view examinations as a set of hurdles over which the students must jump in order to proceed, but views its responsibility as preparing the students with the training required for jobs that await them on graduation. In part, it was said, the high success rate results from the structure of the program. The large amount of work experience running throughout the program gives strong concrete motivation. Theoretical topics are presented when needed and, thus, have clear relevance. The ratio of students to teachers is low, and the work in factories and on projects assures a large amount of student-teacher contact.

There is a real danger that the education a student receives will rapidly become outmoded since it is based on narrowly defined specialties, has a good deal of the current state of the art, and only those basic principles deemed necessary for the specialty are taught. The Chinese realize this danger and commented that they are attempting to promote habits of self-study. They plan to use correspondence courses to enable them to upgrade their education continually. Experience in the United States as a result of World War II and the discovery of the transistor has led us to go in the opposite direction, emphasizing breadth, general depth, and broad scientific knowledge while deemphasizing the current state of the art.

In areas such as semiconductors in which there is a high pace of technological change, the Chinese at best will be forced to make constant curriculum changes, which will be hard to do with curricula that are so tightly integrated.

The curricula are not only highly specific but also place little emphasis on understanding phenomena at the atomic level. Yet many modern solid state physics problems must be solved at that level unless they are to be consigned to cut-and-try methods for solving technical problems. In the United States much of the discussion of atomic level phenomena follows the graduate course in quantum mechanics in order to avoid superficiality. The Chinese would probably also be hard-pressed to discuss atomic phenomena learnedly without adding graduate work.

A substantial fraction of the new faculty being added to each university that we visited are graduates of that university itself in the curriculum that they will be teaching. The procedure poses a danger that the curriculum will become stagnant. Although the universities are presenting further study opportunities for these young faculty, it is our impression that much of this study remains confined to the specialty concerned. We seriously doubt, therefore, that the Chinese will effectively deal with the problems of inbreeding and stagnation.

The low student:faculty ratio and the quasi-tutorial training that the Chinese students enjoy is an enviable situation for which many educational institutions in the United States would like to strive. Budgetary considerations in the United States usually preclude this because the salaries of faculty are a very significant part of the budget and because a very large portion of college-age youths in the United States attend college. In China, where the budgetary cost of manpower is low, there seem to be important opportunity costs associated with the current use of science faculty with advanced training, since they are a scarce commodity in a country with many needs in education and research. Thus the faculty could educate more students, teach at a more advanced level appropriate to graduate work, and take part in a broader spectrum and higher level of research (not only that done in conjunction with research performed by undergraduate students).

We were surprised that economic considerations in education were never mentioned. We conclude that perhaps the Chinese educational decisions are rather more controlled by social or ideological factors.

E. SPECIALIZATION VERSUS BREADTH

A common theme that we found in China is that scientists pay close attention to their own specialties, but very little attention to other areas. For instance, low temperature specialists typically show no interest in semiconductors or in magnetism. This tendency is reinforced by the means the Chinese use to communicate research results: publication of privately circulated reports rather than journals, the presentation of talks at special-purpose conferences rather than at more general scientific meetings, and the absence of general-interest seminars at the institutes and universities. While their approach provides strong and rapid dissemination of information within a known community of interested workers, the absence of broader channels undoubtedly cuts down on stimulus between fields. Physics is replete with examples of the use of techniques (experimental and theoretical) that have been taken from one area to solve problems in another. Many of the most important advances in science and technology have resulted from such cross-fertilization. There appears to be no reason why a broader circulation of research results could not exist simultaneously with the present closely-coupled specialist-to-specialist system. What would be required, however, is a major change in outlook by Chinese scientists -- a genuine development of the mass line to realize the value of and generate the means for broadening the awareness of Chinese scientists in fields outside their specialties.

We have already commented upon a corresponding narrowness in the training of scientific personnel, resulting from the post-Cultural Revolution emphasis on developing in the student specialized state-of-the-art knowledge in a specific area.

In order to surpass the West in technology, China will require broadly trained people who are able to pursue basic science and to understand physics on the fundamental or atomic level. There are some such scientists who were trained abroad in an earlier era, but the Chinese are not now educating people with these qualities. This lack is recognized by some of the scientists with whom we met, but what we saw gives us little confidence that the problem will be resolved. The single most important suggestion we have for our Chinese colleagues in the field of education is that they institute some curricula, extending from undergraduate through graduate work, aimed at preparing broadly trained physicists. Likewise we feel they would be well advised to develop graduate programs which will enable graduates of their present specialized program to broaden their fields through graduate work.

Perhaps appropriate Chinese officials could help give the faculties impetus to develop broader curricula by explicitly recognizing that scientists trained in this way will be essential to help China achieve its desired development.

F. SHORT-TERM VERSUS LONG-TERM GOALS

We have remarked that most research on solid state physics in the People's Republic of China has clearly visible practical objectives. As a starting point, such a program makes good sense since the Chinese have many technical needs that their relatively few scientists and engineers are called upon to meet.

Aside from the Institute of Physics, all the institutes we visited had an applied mission, with nearly all the research directed toward short-term goals. Experimental physicists at the universities work closely with students who have had only a very limited training and who are unable to do research which requires a deep understanding of phenomena at the atomic level. Indeed, nearly all the basic research on solid state physics that we saw was being done at the Institute of Physics. However, even there research is more directly applied than in earlier days, judging from past accomplishments.

We have remarked that most of the programs and problems appeared to be device-oriented or were chosen in areas with practical applications. Almost always the engineering aspects were stressed, such as sample size, diffusion temperature, and alloy composition at the expense of considerations at the atomic or molecular level. We noted numerous examples of remarkable achievements in catching up, but generally we felt (as specifically discussed with respect to lasers on page 67) that the present approach is never likely to reduce the time lag to zero.

We have also remarked on the nearly total absence of efforts to understand phenomena at the atomic level, and the related absence of work involving any form of spectroscopy (radio frequency, microwave, infrared, visible, ultraviolet or Mössbauer). Such tools are necessary in order to develop a new technology. Many technical programs involve a system with many variables. Optimization then requires a good basic understanding, for which fields such as spectroscopy are vital. Without a basic understanding, one is forced to proceed on a cut-and-try basis, which is frequently costly and slow, and is unlikely to lead to actual optimization.

There is a real likelihood that these characteristics of Chinese solid state physics will be compounded as the graduates of the present (rather narrow) specialties in the universities become a larger component of the scientific work force.

The problem of how much effort should be focused on clearly seen, near-term objectives and how much on basic research (whose potential payoff is difficult to predict and is likely to be realized only in the long term) is common to all countries. In the United States, there was a period in the 1950s and 1960s in which many industrial laboratories carried on a good deal of basic research that was often not clearly relevant to the companies' products. Many companies cut back such expenditures sharply during difficult economic periods, arguing that the payoff from such research was as likely to go to their competitors as to themselves. Many American scientists have emphasized that the support of basic research should be primarily a government function since the benefits go to the society as a whole. Government policy on the funding of basic research has also been a subject of much discussion and controversy in the United States.

Despite such controversy, the necessity for support of basic research, if the United States is to remain a technological leader, can be clearly demonstrated and is widely accepted. The really significant advances are unforeseen in research planning -- it takes a scientist to discover them. The maser and laser in the United States resulted from basic work on microwave spectra of gases and of paramagnetic salts, not from a research program planned to produce coherent microwave or optical radiation. The discovery of the ability to generate energy by nuclear fission or fusion came from Einstein's effort to understand the cosmos, and from the efforts of other physicists to understand the nucleus of atoms, not from a program aimed at producing new energy sources. The discovery of superconductivity did not come from a program aimed at producing high-field magnets, more compact electric generators, or potential computer components, but rather from an exploration of the properties of matter at a new frontier, the frontier of low temperature.

The essential nature of important basic discoveries is that they cannot be foreseen. Support for basic science is often, then, the most difficult to defend against competing uses of funds in the budget process. However, it is our clear experience in the United States that strong support of basic research has been a major ingredient in developing the strength we possess in fields of high technology.

The question arises: Will the People's Republic of China conclude that it must encourage and support basic research in solid state physics? China today does not operate under a clear directive to develop basic science. However, Chinese leaders may already realize that they need such plans if they seriously intend to catch up with or surpass other countries in selected areas of technology. They may also conclude that such plans may have political benefits. A country that decides to climb Mount Everest may also decide that being a leader in basic science has distinctive advantages.

For the fact is, should China wish to have its scientists play an important role in world science, they will need to attend important international scientific meetings and to publish papers in major international journals of science. The currency they will need for these activities is first-class, innovative basic science. Whether or not they choose to participate internationally, we believe their own internal needs will require them to enunciate a policy supporting basic science in Chinese research institutes and universities if they seriously wish to catch up with the world's leading countries in technology.

G. THE BASIS OF DECISIONS ON RESOURCE ALLOCATIONS

OBJECTIVES AND LIMITATIONS OF THIS SECTION

The goals of individuals, organizations, and countries invariably exceed the finite resources that are available to them. Therefore, not all the goals that they perceive to be desirable can be pursued. Choices must be made. These choices are made, in practice, on the basis of a combination of several factors: intuition derived from experience, rational economic principles derived from the societal system in which the choice is being made, and basic philosophical and ideological principles accepted by this system.

It would be very useful in such a report as this if we were able to describe in detail how these factors enter into the choices of solid-state research areas, developmental projects, and educational patterns in China. Unfortunately, our opportunities to discuss decision making were far too limited to give us an adequate sense of it. But because decision mechanisms are so important, we feel that it is worthwhile for us to pose what seem to be some relevant questions, to recall details that we have observed that may give clues to some of the answers, and to add a few speculations. We hope thereby to aid future observers of Chinese science, technology, and education in achieving a more complete understanding than ours.

Though there always are -- and indeed always should be -- roles for intuition in decision making, we in the West frequently try to base decisions on allocations of resources as much as possible on formal considerations such as economics, within any given ideological context. Economic considerations involve weighing the benefits anticipated from acquiring a certain knowledge or capability -- weighted, if necessary, by the probability of succeeding in such acquisitions -- against the costs of the research, development, or educational effort invested. In this balance of benefits and costs one must, when scarce resources are involved, take account of the "opportunity cost" of the resources invested (i.e., the benefits that could be obtained from a different use of these resources). This is particularly important with regard to trained manpower, a precious and still quite limited resource in China. One must also take account of the increase in efficiency of a project as the investment in it moves from minimal to adequate, and of the diminution in efficiency when the investment becomes excessive.

The relative importance of such economic analysis, as compared with intuitive judgments, varies greatly as one proceeds from the area of basic research to the opposite extreme of final-state development.

Thus, for concrete development, work goals are set using as much rational principle and as little intuition as possible; but in phenomena-oriented scientific work the ratio is reversed. In the latter, one is moving into the scientific unknown, but even so, goals should be set so that the work possesses focus. The goals are often purely scientific in nature and, of necessity, based upon intuition. As the research progresses, one frequently makes discoveries which suggest goals not previously perceived. Thus the goals may change or proliferate.

ALLOCATIONS OF MANPOWER AND RESOURCES TO SPECIFIC TECHNOLOGICAL GOALS

Chinese solid state physics work, as we observed it, is predominantly located at the development end of the spectrum. That is, it is largely concerned with learning how to make advanced materials, how to optimize their useful properties, and how to build devices from them ranging from tiny diodes to massive laser systems. The primal motivations for the work are presumably a need for military hardware, as well as Chairman Mao's statement that China can and should catch up with and surpass foreign technology. These are relatively concrete general goals that should be convertible into economic variables that can be used to analyze specific projects and aid in making choices. We were not told about any attempts at formal analysis of this kind, although they may exist.

One would suppose that it would be useful to examine those fields which have had an important economic impact in the rest of the world, and from these select those best suited to China's needs. As we have noted, some of the solid state areas most actively pursued in China (such as semiconductors and magnetism) seem eminently appropriate according to this criterion, while others (such as diamond synthesis and superconducting wire) do not. But, of course, judgments on such matters must necessarily be tentative, as we have very scant knowledge about other factors in China that are usually also taken into consideration, such as military needs and contemplated "prestige" projects.

If it is indeed true that many of the developmental and applied research projects that we saw were not chosen on the basis of even roughly quantitative economic analysis (a premise that we realize might be incorrect), there are several possible interpretations. One is that the work is not perceived by the Chinese as being principally developmental in character, and it is too early for economic considerations to be formally taken into account in the planning. Another is that it is assumed that work reported in the foreign literature has already gone through an adequate economic selection process, so that it is not necessary to repeat the process. Still another possibility is that techniques have not yet been developed for performing economic evaluations of projects; certainly, the techniques appropriate to a socialist economy must be very different from those that apply in a capitalist one. Concepts like rent-on-capital and return-on-investment must be redefined in dealing with the Chinese economy. It is hard to say, finally, what role deep-seated ideological considerations may play in what (to a Westerner) would seem to be basically economic decisions.

If the speculations underlying the preceding paragraphs are incorrect and there is indeed detailed economic planning in R&D decisions, it could be that the local scientific staff at research institutes and universities take no part in it, and so would not have mentioned it to us. Such a state of affairs would explain the repeated emphasis on many of the same fields (such as lasers and semiconductors) that we found in many different institutions; however, it would seem a little inconsistent with the general policy of maximizing local responsibility.

A particularly interesting and important question deals with the channels through which the ultimate users of a product or service can make their judgments of its value felt in decisions about its development. In the United States such judgments are sensed in the open-market response of customers to similar products or services already available, and they are sometimes researched in market surveys and the like. On ideological grounds one would expect the Chinese to have a high regard for such ultimate-user input, for it truly reaches deep into society and embodies the principles, "serve the people" and "follow the mass line." However, we did not learn about channels through which such an input can be reached.

ALLOCATIONS OF MANPOWER AND RESOURCES TO RESEARCH

We have commented several times in this report on the potential value of exploratory research to a nation's economy and on the long time scale of basic research. We feel that Chinese technology could be powerfully invigorated by an active exploratory research program. Why? Because it would have numerous indirect as well as direct effects. Among these are the accumulation of knowledge unique to China; the invention of truly novel solutions to problems; the generation of unexpected opportunities for developing new materials and device systems; the stimulation of communication within and outside of China; the stimulation of teaching from older to younger generations; and the inspiration of new workers to high achievement. These effects could influence the future economy of China far more deeply than the predictable effects of satisfying currently recognized national needs. Yet we were not told of any significant discretionary budgets that are presently available for this purpose at the various research institutions.

The relative resources going to research with longer-term benefits, as compared with specific development projects, depends, of course, very much on the time scale envisioned in the planning process. Private industry in the United States usually professes to look no more than 5 to 10 years ahead, and only occasionally more, because of the economic uncertainties in the fluctuating economy. Thus development predominates over research; even so, there is a significant amount even of basic research in U.S. industry. Government-supported projects in the United States often take a much longer view. For a gross level of economic development, one would expect that the viewpoint would be even more long-range in a socialist country than in a capitalist one; one must recognize, however, that China's short-range needs may be especially pressing. As we have remarked, it would be most interesting to know by what criteria the balance between short-term and long-term R&D is determined in China.

Another matter about which we can only raise questions is duplication of research. It is not wise to rely completely on one or even two small groups for the tricky task of ferreting out new knowledge in a field of interest. On the other hand, if one sets too many groups to work on the same topic, one loses the opportunity to investigate other topics that may, in the long run, prove important. How are decisions made concerning how much duplication is desirable?

Whereas progress in development projects can be monitored straightforwardly by the performance of devices or systems, research, with its longer time scale, must be evaluated by more subjective criteria. However, evaluation is very important for deciding on expansion, contraction, or discontinuance of research projects. One must judge the work itself, the consequences of the results, and the ultimate integration of the consequences into the societal structure. Poor measurements and judgments of these activities can be very costly and wasteful.

How are such evaluations made in China? We do not know. But it is clear that what is probably the most effective channel for evaluating the quality of research work in the West is currently not very feasible in China. That channel is the evaluation by the world scientific community that is constantly taking place in the published literature. The English solid state physicist, John Ziman, has commented perceptively in his book, *Public Knowledge: The Social Discussions of Science,* that it is precisely this aspect of criticism and re-criticism, leading to an ultimate consensus, that gives science its power and distinguishes it from other intellectual disciplines. This concept should be easily appreciated by the Chinese, who have come to think in terms of "criticism" and of the "mass line" for practical everyday decisions of their society. Thus we feel that the allocation of resources and determinations of research directions could be helped by some of the measures we suggest in other parts of this chapter, such as more extensive publication of research findings and greater exchange of information with the rest of the world.

SOME CONCLUDING REMARKS

We have commented at length about the current Chinese campaign against "elitism." Insofar as this campaign prevents the rise of an authoritarian managerial class whose personal domination can suppress the creativity of individual junior research workers (as has indeed happened in the past in some countries), it can foster good research management. But good research decisions also require the recognition that certain individuals have talents for a particular activity -- research -- that vastly exceed those of other individuals. Work assignments must reflect this recognition, although it is not necessary to attach a higher position in society to talented researchers than to those whose talents lie elsewhere. We do not yet know how Chinese decision makers handle this matter.

After research workers have discovered or produced a result, the consequences of that result need to be studied in terms of how it relates to previous knowledge, what it implies about future knowledge, and how it can be put to concrete use in society. It often happens that the research workers can foresee (or think they foresee) societal uses that are not generally recognized. This introduces a conflict between people who expect society to welcome their new result and people who are reluctant to accept it. In this situation the burden of proof falls to the researchers, at least as a matter of practice if not principle. In the U.S. system this conflict is eventually resolved by the marketplace, which either fosters the new result with economic nourishment or starves it into an archival position. In China, planners either nourish it by making a place for it in the plan, or starve it by not doing so. We do not presently know the explicit process though which this occurs, but it would be interesting to investigate.

H. THE INDIVIDUAL VERSUS THE MASS LINE

All the projects we saw seemed to be group efforts of a few to a half dozen people working together, rather than one person plus a technician or graduate student, which might be typical in the United States. In this section we discuss how this difference may affect the initiation and development of ideas. Our thoughts were stimulated by our observation of both the impressive Chinese ability to establish and develop programs in new areas and the apparent lack of dramatic technical or scientific innovations.

On numerous occasions we were told of accomplishments made possible by mobilizing the will and the energies of one or another group -- by "developing the mass line." On the largest scale, the group may be the entire citizenry mobilized to further a national objective. One such example is the development of a national consciousness about the importance of self-reliance. That the Chinese have been highly successful in developing the mass line is evident from the fact that wherever one goes one finds certain basic principles quoted repeatedly.

Belief in the primacy of the mass line is so strong in some circles as to be tantamount to the statement, "where there's a will there's a way." Many Chinese have great faith that a determined group working in concert, applying their collective thought, can overcome many seemingly impossible obstacles. Other groups in the People's Republic probably view the benefits as somewhat more limited.

The mass line may be developed when someone, either within or outside a working group, takes a problem or an idea to the group, opening a discussion session on the issues. The majority conclusion becomes the mass line. This procedure occurs in groups ranging from small professional teams to the entire nation, where major policy issues or decisions are presented to the people for discussion. It is clear that the discussion process can provide an opportunity for input from the group. It certainly guarantees that the group is informed, and the group process may lead to a heightened degree of enthusiasm. The possibility of multiple inputs from the group also serves to test the wisdom of the concept being discussed, perhaps leading to modifications that make the concept either more workable or more palatable. The extent to which the members of the group really affect the concept, as opposed to merely being informed of it, no doubt varies from case to case. Of course, the role of the group leaders can be very important in determining the nature and outcome of the discussion.

An example of the belief in "going to the masses" arose in our visit to the Shanghai Machine Tools Factory, as we were discussing problems faced by their engineers in the design of advanced machine tools. At one point we asked what steps an engineer would take if confronted with a problem for which he did not know enough mathematics. The reflex answer was that he would "go to the masses" -- that is, consult with a group of technicians, workers, and cadres. Since one would not expect such a group to know more mathematics than an engineer, we were surprised by the answer and pursued the matter further. Eventually others among our hosts spoke up to describe means of handling the problem, such as consulting engineers at other factories, consulting at a university, or having the engineer enroll in an appropriate university course. The initial response, however, illustrates how broadly accepted is the theory that a determined group of ordinary people can solve problems if they put their heads together. The final answer expresses the recognition that there are some problems which require expert knowledge. The fact that there were two such different answers illustrates how readily some people would confuse what struck us as two separate issues: solving a problem which requires specific training and solving a problem for which the solution may be found in people's everyday experience.

Closely related to the concept of developing the mass line is the idea that individual activity may be detrimental to the basic objective of serving the people. We were told, for example, that the emphasis on publishing research results in scientific journals tended to make the scientists strive for self-glorification. Before the Cultural Revolution, we were told, publication was often used as a means for advancing the status of the author instead of communicating results to people who needed them. As we remark in Chapter Five, research results are rarely published in journals, but are presented instead in reports which are circulated only to groups thought to be interested, in topical conferences, in seminars of specialists, or in personal visits.

Some of our Chinese hosts remarked that formerly scientists in China were little concerned with solving China's problems. As part of an educational elite, they were cut off from the workers and peasants and were primarily concerned with their own well-being. Scientists simply pursued their own work, tending to ignore circumstances outside their own laboratories.

As we mention in Chapter One, the belief that self-interest motivated China's intellectuals was said to be a major impetus to the Cultural Revolution. One important legacy of the Cultural Revolution has been the diminishing of the role of the individual in favor of collective effort. To be sure, specific individuals are praised and held up as examples. At the Shanghai Machine Tools Factory, we were given a brochure showing pictures of particular workers who had made noteworthy contributions to the factory's work. In discussing these examples, however, our Chinese hosts always made it clear that the motive of the model individual was to serve the people. Such concrete examples are effective means of inspiring others to new levels of achievement. It is the common experience of people of all eras and all parts of the world that tales of heroes may inspire countless others. Nevertheless, while the Chinese frequently use examples of the accomplishments of individuals, they do so within the overall context that the individual must "serve the people" and be continuously on guard against the sin of working for self-glorification.

One could say that modern China believes in sin and in redemption. To hold the wrong view is an evil that must be rooted out, using strong means if necessary. The widespread reference to the errors of Confucius and the meetings devoted to criticizing Confucian thought are examples of the way in which a whole mode of thought or action can be classified as evil. During the Cultural Revolution public criticism was heaped on certain teachers, government and university officials, and others who were judged to be committing errors. By such means the errant person was re-educated to renounce publicly his past practices and resolve to follow the new line.

Anyone who has participated in or observed such practices must feel a strong need to know what is the correct line, in order to avoid the consequences of error. As a result, there must often be a strong desire on the part of each individual to avoid deviation from the truth as perceived by the group to which he belongs.

Earlier, we pointed out our surprise at the lack of originality in the work we saw, considering how good we felt the Chinese scientists to be. Among other explanations, we speculated that the emphasis on group activity is acting as a conservative force, inhibiting the growth of unconventional ideas. It may be that scientists in the People's Republic of China, working primarily in groups and with little stimulus to work as individuals, will evolve a new way of making brilliant advances. Perhaps they will show that the group spirit and group activity can be as effective as the alternative approach of encouraging the creativity of individuals. We did not see signs that they had yet found such an approach.

It is our belief that group activity is an effective method for carrying out a task for which the necessary steps can be charted in advance, but is not an effective way to approach a task requiring a high level of innovation. In our Western experience, the latter, such as the discovery of important new concepts in science and the invention of startling new technology, is generally accomplished by an individual who possesses unusual intellectual power, a mind that revels in thinking new thoughts, and an unfettered spirit that delights in rebelling against conventional ideas. We leave China with the hope that innovation by individuals will not be lost in the pressures of group activity and that individual inventiveness will be encouraged, albeit designed to serve the people, not the inventor himself. Though we speak necessarily from our own cultural viewpoint, we have great respect for China's drive toward egalitarianism and its stress on the common good. At the same time, we believe that the possibilities for unconventional individual contribution to science -- which we feel is critical to the development of science -- could usefully be more widely absorbed into China's ideological and organizational framework.

I. A BROAD VIEW OF SELF-RELIANCE

Everywhere we went we were shown technical accomplishments achieved by the Chinese with little or no outside help, other than information that could be gleaned from books or articles published abroad. Indeed, the Chinese take great pride in what they have accomplished on their own. The workers and peasants have been exhorted by Chairman Mao to operate under the "principle of self-reliance," overcoming obstacles without help from outside. This principle is widely applied in China today, but it is particularly important in the technical fields, where it in essence calls on China to lift itself by its own bootstraps.

The reasons behind the emphasis on this principle are no doubt manifold. Limited transportation facilities today, and historically, have necessitated a large degree of local self-sufficiency. The "principle of self-reliance" encourages this system of regional independence. This principle is aimed at developing a "can-do" spirit on the part of peasants and workers. It is also aimed at developing national pride, not just local pride. No doubt it stems in part from strong historical feelings concerning the role of various foreign countries in China prior to 1949. And without doubt a major component is the memory of the difficulties China faced when the Soviets abruptly ended their aid program in 1960, halting projects even at midpoint.

Under the policy of self-reliance, the Chinese have undertaken their scientific development program with virtually no foreign help since the Soviet pullout. While the task they have faced has been difficult, they have made substantial progress. The confidence and skills they have acquired will be extremely helpful in the future.

Nevertheless, while we felt great respect and admiration for the accomplishments of their scientists under the principle of self-reliance, we were also struck by the problems it posed for them, specifically by the isolation that has resulted from this policy. We have commented previously on several of the disadvantages, as we see them:

- Due to the language barrier, Chinese success in keeping up with scientific developments reported in the literature of other countries has suffered.

- The number of foreign scientists who have visited the People's Republic is so small, and other opportunities for foreign contact so few, that Chinese scientists are strongly influenced by individual visitors. Occasionally, we noted, they have been encouraged to undertake tasks which seem inappropriate to the People's Republic's own goals and perhaps have not been encouraged to move in more fruitful directions. Talking with more visitors might lessen the number of such errors.
- The fact that Chinese scientists do not often attend international conferences not only robs the world's scientists of the opportunity to learn from the Chinese, but also excludes the Chinese scientists from the oral communication network through which the latest developments are rapidly disseminated, the merits debated, and the incorrectness of some earlier announcements brought to the attention of the world's scientists.
- Since Chinese scientists do not publish in foreign journals or send reprints or preprints of their work to them, they do not establish those close relationships with selected foreign research groups or scientists that would plug the Chinese into the network of preprints and reprints of special interest.

The Chinese, despite their effective and laudable efforts at self-reliance, are still dependent on contributions from other countries in developing advances in science or technology. Not only do they wish to learn of important new discoveries, but also they need to know which new ideas turn out to be of less value than had been originally thought. In following foreign developments, they have magnificent help from well-supported, well-run libraries, as well as a system of direct acquisition of foreign journals (sometimes via airmail) and reprinting of others. Despite the good availability of these journals, we concluded that the language proficiency of many scientists was not high enough for them to achieve the full benefit of the foreign literature. This result is not surprising -- the foreign languages they must learn (now usually English) bear no familial relation to Chinese, nor do the symbols bear a relation to Chinese characters.

Nevertheless, the foreign literature is of vital importance. In the United States, we have found it highly useful to translate selected foreign journals into English. We believe the Chinese would benefit, therefore, were they to undertake a program of translating a small group of selected foreign journals. They might include an abstract journal, one or more journals of rapid publication, selected index categories of more general journals, and one or more major review journals. Such an availability might also stimulate the broader interest in science that we remarked upon above.

Much Chinese physics that is published is in *Wuli Xuebao*, a journal which has procedures and standards comparable to leading journals in other parts of the world. While it is the custom in all other countries for scientists to publish from time to time in journals of another country, the Chinese do not appear to do so. We feel sure that scientists in other countries would benefit from having articles by Chinese scientists published in their journals, and that the editors of those journals would welcome Chinese authors. As a way of making the rest of the world aware of China's developing strength, nothing could be more effective than publication of articles by Chinese physicists in the major non-Chinese journals. It would be necessary, in most instances, that the articles be written using the Western alphabet because of the practical problem of typesetting.

In addition to publishing in the foreign journals, we believe that Chinese scientists would benefit if they sent reprints of articles or reports to selected non-Chinese scientists. In general, such material would not need to be translated since most major research organizations have access to a scientist who reads Chinese. In response, the Chinese scientists would undoubtedly receive preprints of articles from the foreign scientists to whom they sent material.

Publication in foreign journals or sending preprints or reprints from China would represent changes from the present pattern. We did not discover any official prohibition of either, but it is evident that some form of official encouragement would be necessary for the pattern to change. We feel sure scientists around the world would delight in the announcement of such encouragement, which would lead to positive steps of friendship between the scientists of the People's Republic of China and those of other nations.

We note that still another consequence of self-reliance is that China's young scientists do not have the chance to study at the great scientific centers abroad, a chance that we know greatly benefits young American physicists.

We found ourselves in great sympathy with the principle of self-reliance. Whether it is fact or myth, Americans of all walks of life like to think that self-reliance is a prime American characteristic. We admire the courage and self-reliance represented by our ancestors, who struck out across the sea to re-establish themselves in a new land, relying on nothing but their own strength and vision. Self-reliance characterized the American frontier as it moved west. In short, since we place self-reliance high on our own scale of values, we found it natural and easy to admire the many accomplishments the Chinese have made under this principle.

However, we also recognize the great help American scientists have received from scientists of foreign countries. There is no denying that, through the 1920s, physics in Western Europe was substantially in advance of physics in the United States, though we had luminaries such as Michelson, Millikan, Compton, Davisson, and Germer, to name a few. It was common for young Americans to go to Europe to study after completing their graduate work. The famous Born-Oppenheimer approximation is the result of one such international collaboration, between the young American, Robert Oppenheimer, and Max Born. Many of our best young physicists eagerly sought to work with the famous physicists of Europe. By the 1930s the situation had begun to change. Partially as a result of political developments, important European scientists came to the United States. But in parallel, we were cultivating our own scientists. Oppenheimer, for example, founded a great school of theoretical physics at the University of California at Berkeley. Having studied in Europe just at the time that quantum mechanics burst upon the world, he taught one of the first graduate courses in that subject. His students, as young faculty members at other American universities, played a major role in rapidly diffusing the Oppenheimer course, helping to spread the teaching of quantum mechanics to all American graduate students. This example is but one of many illustrating how scientific exchange helped American physics develop its strength. In going abroad our young physicists were given the chance to study with the best European physicists. On their part, the Europeans had the pleasure of working with those talented young colleagues.

In our own experience, therefore, we have considered ourselves self-reliant, while at the same time reaching out to partake of the world's resources.

As we examine the Chinese application of the principle of self-reliance and compare it with our own experience, we are convinced that a much broader tapping of the world's scientific resources would be possible for our Chinese colleagues without damaging the principle of self-reliance. Our American experience convinces us that there is a great possibility for the Chinese to strengthen and catalyze their scientific development without diminishing the marvelous "we can do it" spirit with which they are imbued, or becoming vulnerable to sudden switches in international relations (such as the Soviet pullout).

In particular, attending international meetings, exchanging reprints and preprints with selected groups in foreign countries, and spending extended time in foreign laboratories are all steps that would speed the development of Chinese science without impinging, in our judgment, on the sound principle of independence and self-reliance. Especially effective would be a program of sending young Chinese scientists abroad for graduate study or postdoctoral study. At least, we in America have benefited from such exchanges.

At present the People's Republic carries on reciprocal scientific exchange on a small scale. The Chinese Delegation in Solid State Physics that visited the United States in the spring of 1975 and our own delegation's trip to China are examples. But such visits do not begin to compare in benefit with extended visits (several months to a year) or with postdoctoral study as means of producing real scientific transfer. We believe the People's Republic would find that these deeper forms of exchange would provide handsome benefits. We are convinced that the world scientific community would be eager to help develop such deeper relationships with scientists of the People's Republic of China.

Appendix A

LETTER TO CHINA'S SCIENTIFIC AND TECHNICAL ASSOCIATION

July 24, 1975

Members of the American Solid State Physics Delegation greatly enjoyed their opportunity to meet and discuss science with the Chinese Solid State Physics Delegation which visited the United States this spring. We look forward eagerly to our visit to China, as it will afford us a chance to renew acquaintance with members of the Chinese delegation, to see the work taking place in their laboratories and classrooms, and to meet other solid state physicists active in the field.

GENERAL OBJECTIVES OF THE SOLID STATE PHYSICS DELEGATION

The Solid State Physics Delegation wished to make an in-depth study of major areas of solid state physics research and teaching in the People's Republic of China. One of the principal criteria in selecting members of this delegation was the wide range of scientific interests of each individual. Although each delegation member will be interested in seeing work in his own area of expertise (see attached name list), the main purpose of this visit is to learn about work in the areas which are of major interest to Chinese solid state scientists. In addition, some members of the group would like to meet with those who plan or administer the publication and distribution of scientific literature in China, especially in physics, and who coordinate other means of communication among scientists, such as conferences.

To promote deeper discussions with our Chinese colleagues during this one-month visit, the delegation would like to visit only a small number of institutions and to stay at certain institutions for two or three days. At each institution the delegation would like to divide into subgroups, typically three or four, each of which would see a different aspect of the solid state work at the institution. It is our hope that in this manner each subgroup will be able to obtain a more thorough impression of the work being undertaken. Because only one member of the group has command of technical Chinese, the delegation will be dependent on technical translation by our hosts for the various subgroups.

In order that the entire delegation be able to discuss the different observations of the subgroups, we wish to reserve about four half-days in the schedule for consultation among the delegation members. Two suggested dates for such meetings are given in the attached schedule.

The delegation consists entirely of scientists who are themselves working actively in science. Therefore, the delegation has a strong interest in the scientific and technical content of the work presented. Although a broad survey of the work at a given institution is useful as an introduction to the visit, the delegation wishes to place special emphasis on the subgroup's hearing scientists present their own work. Where appropriate, we hope that such discussions may take place in the laboratories where the work was done, so that actual apparatus can be shown. In addition to hearing a scientist describe his or her work, the delegation has the strong wish to be able then to ask questions of the scientist and to carry on a give-and-take discussion.

The delegation is anxious to meet and talk with a broad spectrum of Chinese solid state physicists. We are especially anxious to meet younger scientists and to discuss their work with them, since that generation is so important to the future of science in the People's Republic of China, yet is so little known in the United States.

To enhance the opportunity for dialogue, the delegation hopes to invite host scientists to informal discussions in the hotel in the evenings. Accordingly the delegation requests that one evening be set aside for each institution visited, though not necessarily on the same day of the visit.

To assist the Scientific and Technical Association in its planning, we enclose a proposed itinerary. We request that the Scientific and Technical Association send an outline of the itinerary, including the institutions to be visited and the number of days at each, to the Committee on Scholarly Communication during the month of August. To the extent that details are not available at that time, we request that a detailed schedule for the whole month be given to the delegation upon our arrival in Peking.

We look forward very much to this visit and hope that you will correspond with the Committee on Scholarly Communication if you have any questions or suggestions.

SUGGESTED ITINERARY

The American group wishes to propose the following itinerary. We recognize our limitations in selecting research institutions to be visited and welcome the suggestions of our Chinese hosts. We stress that we are interested in seeing what is considered by Chinese physicists to be the most important work. In listing areas of research under various institutions, we are simply naming some work we are aware of, in no order of priority. We trust that our hosts will select the appropriate subjects for investigation.

September 4	Arrival in Peking via Japan Airlines #781	
September 4-15	PEKING	
	1. Institute of Physics	3 days
	solid state theory	
	magnetic films and ferrites--magnetism in general	
	lasers	
	crystallography and crystal growth	
	low temperature physics	
	high pressure	
	ultrasonics	
	semiconductors	
	2. Institute of Semiconductors	2 days
	materials science	
	lasers	
	integrated circuits	
	microwave devices	
	3. Institute of Biophysics--subgroup	1 day
	molecular biology	
	cell structure	
	engineering techniques	
	biophysics of receptors	
	4. Peking University	1 day
	semiconductor factory	
	low temperature physics and other areas of work	
	5. Tsinghua University	1 day
	Sightseeing	3 days
	Consultation among delegation members	1/2 day
September 16-20	SIAN	
	Chiaotung University	1 day
	Sightseeing, including rural commune	2 days
	Travel to and from Sian	1 day
September 21-23	NANKING	
	Nanking University	1 day
	Sightseeing	1 day
	Group consultation	1/2 day
	Travel	1/2 day
September 24-27	FUCHOU	
	Fukien Institute of Matter Structure	1 day
	Sightseeing	1 day
	Travel to and from Fuchou	1 day

September 28- October 2	SHANGHAI	
	1. Futan University	1 day
	2. Institute of Metallurgy low temperature physics other aspects of metals	1 day
	3. Institute of Silicates--subgroup 4. Institute of Optics and Fine Mechanics--subgroup	1 day
	Attend October 1 celebration	
October 2	Depart Shanghai for Tokyo, Japan Airlines #782	

Appendix B

ITINERARY

Tuesday	September	2	Arrive in Tokyo by separate routes
Wednesday		3	Meeting to discuss final details and draw up framework for report
Thursday		4	Arrive in Peking Discussion of itinerary with Chinese hosts
Friday		5	Institute of Physics
Saturday		6	Institute of Physics Evening: Movie on the climbing of Mount Everest
Sunday	September	7	Great Wall and Ming Tombs
Monday		8	Institute of Physics Afternoon: Talks by members of the delegation
Tuesday		9	Institute of Semiconductors Evening: Welcoming banquet hosted by Wu Yu-hsun
Wednesday		10	Institute of Semiconductors Afternoon: Institute of Semiconductors (Group I) Institute of Biophysics (Group II) Evening: Discussions with Chinese scientists in the hotel
Thursday		11	Tsinghua University Afternoon: Tsinghua University (Group I) No. 1 Semiconductor Equipment Factory (Group II) Evening: Reception given by U.S. Liaison Office
Friday		12	Peking University Afternoon: Opening ceremonies of the Third National Games Evening: Talks by delegation members given at the hotel
Saturday		13	Peking University Afternoon: Free for delegation group discussion

Sunday	September 14	Imperial Palace Summer Palace
Monday	15	Drive to Tsunhua County Visit Sha Shih Yu brigade Evening: Documentary movie on Sha Shih Yu brigade
Tuesday	16	Visit county exhibition center, textile factory, metal shop, and electrical factory Return to Peking by car Evening: Banquet given by U.S. delegation in honor of Peking hosts
Wednesday	17	Free morning Afternoon: Flight to Sian Evening: Banquet hosted by Shensi Provincial Revolutionary Committee
Thursday	18	Chiaotung University
Friday	19	Morning: Visit to Bell Tower and Shensi Provincial Museum Afternoon: Drive to Hua Ch'ing villa and hot springs and tomb of Ch'in Shih Huang Ti Evening movie: Hai Hsia
Saturday	20	Morning: Visit to Big Goose Pagoda and Pan p'o neolithic village Afternoon: Flight to Nanking
Sunday	September 21	Morning: Sightseeing at Sun Yat-sen mausoleum and Ling Ku pagoda Afternoon: Visit to Nanking River Bridge, Hsuan Wu Lake and Zoo Evening: Banquet hosted by Kiangsu Provincial Revolutionary Committee
Monday	22	Nanking University
Tuesday	23	Nanking University Afternoon: Free for delegation group discussion Evening: Continuation of delegation discussions
Wednesday	24	Morning: Train to Wuhsi Afternoon: Sightseeing at Turtle's Head Park and boat-ride on Tai Hu Lake, with stop at workers' sanitorium Evening: Performance by primary school children for hotel guests
Thursday	25	Morning: Visit to silk filature factory Afternoon: Visit to commune Evening: Group discussions
Friday	26	Morning train to Shanghai Discussion of schedule Evening: Shopping
Saturday	27	Futan University (Group I, all day) Institute of Optics and Fine Mechanics (Group II, all day) Evening: Music and dance performance

Sunday	September 28	Shanghai Industrial Exhibition Shanghai No. 1 Machine Tools Plant Evening: Informal gathering in hotel with Chinese scientists
Monday	29	Institute of Ceramics Evening: Thank-you banquet for the delegation's three escorts, Mr. Lu, Mr. Wang, and Ms. Wu
Tuesday	30	Morning: P'en P'u Neighborhood (Group I) Shanghai Historical Museum (Group II) Shopping (Group III) Afternoon: Visit to Hong Chiao Commune (Group I) Free afternoon (Group II) Evening: National Day celebrations in stadium, followed by long drive through festive streets and view of the city from top of Cathay Mansions
Wednesday	October 1	National Day festivities in Chung Shan Park Afternoon: Boat-ride on Whampoo River Evening: Banquet given by Shanghai Revolutionary Committee
Thursday	2	Free morning Afternoon: Departure for Tokyo
Friday	3	Wrap-up discussions on report
Saturday	4	Continue wrap-up discussions Depart Tokyo

Appendix C

DELEGATION'S BIOGRAPHICAL DATA

CHARLES P. SLICHTER

Professor of Physics and in the Center for Advanced Study
University of Illinois, Urbana, Illinois 61801

Born: January 21, 1924 in Ithaca, New York

B.A.	1946	Harvard University
M.A.	1947	Harvard University
Ph.D.	1949	Harvard University (Physics)

ABBREVIATED CAREER

Woods Hole Underwater Explosive Research Lab	Civilian Scientist	1943-1946
University of Illinois	Instructor to Professor	1949-present
Morris Loeb Lecturer	Harvard University	Spring 1961
Bell Telephone Laboratories Murray Hill, New Jersey	Member of Technical Staff while on sabbatical	9/1970-7/1971

Fellow, American Physical Society
Member, National Academy of Sciences (Chairman, Physics Section), American Philosophical Society, American Academy of Arts and Sciences.
Member, Corporation of Harvard University
Member, President's Scientific Advisory Committee (1965-1969)
Recipient, Irving Langmuir Prize in Chemical Physics of the American Physical Society (1969)

RESEARCH INTERESTS

Nuclear magnetic resonance, electron spin resonance applied to problems of chemistry or solid state physics
Diffusion, atomic and molecular motion in solids
Superconductivity
Magnetism of metals and insulators

SELECTED PUBLICATIONS

Principles of Magnetic Resonance. Harper and Row, New York, Evanston, and London, 1963, 246 p.
Nuclear magnetic resonance multiplets in liquids. With H. S. Gutowsky, D. W. McCall. J. Chem. Phys. 279-292 (1953).
A note on the fluorine resonance shifts. With A. Saika. J. Chem. Phys. *22*, 26-28 (1954).
Electron spin paramagnetism of lithium and sodium. With R. T. Schumacher. Phys. Rev. *101*, 58-65 (1956).
Experimental verification of the Overhauser nuclear polarization effect. With T. R. Carver. Phys. Rev. *102*, 975-980 (1956).
Nuclear spin relaxation in normal and superconducting aluminum. With L. C. Hebal. Phys. Rev. *113*, 1504-1519 (1959).
Low field relaxation and the study of ultra slow atomic motions by magnetic resonance. With D. Ailion. Phys. Rev. *135*, A1099-A1110 (1964).
Effect of applied fields on the optical properties of color centers. With C. H. Henry and S. E. Schnatterly. Phys. Rev. *137*, A583-A602 (1965).
Order-disorder transition in NH_4Cl. I. Phenomenological theory. With H. Seidel, P. Schwartz, and G. Fredericks. Phys. Rev. *B4*, 907-911 (1971).
Pressure-induced electronic changes in compounds of iron. With H. G. Drickamer. J. Chem. Phys. *56*, 2142-2160 (1972).
Conduction-electron spin density around Fe impurities in Cu above and below T_K. With J. Boyce. Phys. Rev. Letters *32*, 61-64 (1974).

JOHN BARDEEN

Professor of Electrical Engineering and Physics (Emeritus) and in the Center for Advanced Study
University of Illinois, Urbana, Illinois 61801

Born: May 23, 1908 in Madison, Wisconsin

B.S. 1928 University of Wisconsin (Electrical Engineering)
M.S. 1929 University of Wisconsin (Electrical Engineering)
Ph.D. 1936 Princeton University (Math, Physics)

ABBREVIATED CAREER

Gulf Research and Development Corp Pittsburgh, Pennsylvania	Geophysicist	1930-1933
Society of Fellows, Harvard University	Junior Fellow	1935-1938
University of Minnesota	Asst. Prof. of Physics	1938-1941
Naval Ordnance Laboratory	Physicist	1941-1945
Bell Telephone Laboratories	Research Physicist	1945-1951
University of Illinois	Professor of Electrical Engineering and of Physics	1951-1975

Fellow, American Physical Society; President 1968-1969
Member, National Academy of Sciences, National Academy of Engineering, American Academy of Arts and Sciences, American Philosophical Society
Member, President's Scientific Advisory Committee (1959-1962)
Recipient, Nobel Prize in Physics (1956 and 1972)

RESEARCH INTERESTS

Theoretical solid state physics, especially semiconductors and semiconductor devices
Low-temperature physics, including superconductivity and superfluidity
Surface physics

SELECTED PUBLICATIONS

Conductivity of monovalent metals. Phys. Rev. *52*, 688-697 (1937).

Surface states and rectification at a metal semiconductor contact. Phys. Rev. *71*, 717-727 (1947).

The transistor, a semiconductor triode. With W. H. Brattain. Phys. Rev. *74*, 230-231 (1948).

Electrical properties of pure silicon and silicon alloys containing boron and phosphorus. With G. L. Pearson. Phys. Rev. *75*, 865-883 (1949).

Diffusion in alloys and the Kirkendall effect. With C. Herring in *Atom Movements*, published by American Society for Metals, Cleveland, Ohio (1951). Also published as *Imperfections in nearly perfect crystals*, W. Shockley, ed., John Wiley & Sons, New York (1952), pp. 261-289.

Electron-vibration interactions and superconductivity. Rev. Mod. Phys. *23*, 261 (1951).

Theory of superconductivity. Encyclopedia of Physics, Vol. *15*, pp. 274-369, Springer-Verlag (1956).

Theory of superconductivity. With L. N. Cooper and J. R. Schrieffer. Phys. Rev. *108*, 1175-1204 (1957).

Theory of the motion of vortices in superconductors. With M. J. Stephen. Phys. Rev. *140*, A1197-1207 (1965).

Effective interaction of He^3 atoms in dilute solutions of He^3 in He^4 at low temperatures. With G. Baym and D. Pines. Phys. Rev. *156*, 207-221 (1967).

Josephson current flow in pure superconducting - normal - superconducting junctions. With J. L. Johnson. Phys. Rev. *B5*, 72-78 (1972).

Theory of fluctuation superconductivity from electron-phonon interactions in pseudo-one-dimensional systems. With David Allender and J. W. Bray. Phys. Rev. *B9*. Feb. (1974).

NICOLAAS BLOEMBERGEN

Rumford Professor of Physics and
Gordon McKay Professor of Applied Physics
Harvard University, Cambridge, Massachusetts 02138

Born: March 11, 1920 in Dordrecht, Netherlands
Naturalized U.S. Citizen, 1958

Phil. Cand.	1941 University of Utrecht
Phil. Drs.	1943 University of Utrecht
Ph.D.	1948 University of Leiden
Hon. A.M.	1951 Harvard University

ABBREVIATED CAREER

University of Leiden	Research Associate	1947-1948
Harvard University	Society of Fellows	1949-1965
	Associate Professor of Applied Physics	1951-1957
	Gordon McKay Professor of Applied Physics	1957-Present
	Rumford Professor of Physics	1974-Present

Fellow, American Academy of Arts and Sciences, American Physical Society, Dutch Physical Society, Institute of Electrical and Electronics Engineers, Optical Society of America
Member, National Academy of Sciences
Correspondent of the Koninklyke Nederlandse Akademie van Wetenschappen, Amsterdam
Recipient: National Medal of Science (1974)

RESEARCH INTERESTS

Nuclear magnetic resonance, electron spin resonance, masers, lasers and non-linear optics

SELECTED PUBLICATIONS

Nuclear Magnetic Relaxation, Ph.D. thesis, Leiden (1948). Republished by W. A. Benjamin, Inc., New York (1961).
Nonlinear Optics. W. A. Benjamin, Inc., New York (1965).
Relaxation effects in nuclear magnetic absorption. With Purcell and Pound. Phys. Rev. *73,* 679-712 (1948).
Proposal for a new type solid state maser. Phys. Rev. *104,* 324-327 (1956).
Cross relaxation in spin systems. With S. Shapiro, P. S. Pershan and J. O. Artman. Phys. Rev. *120,* 2021-23 (1959).
Interactions between light waves in a nonlinear dielectric. With J. A. Armstrong, J. Ducuing, and P. S. Pershan. Phys. Rev. *127,* 1918-1939 (1962).
Light waves at the boundary of nonlinear media. With P. S. Pershan. Phys. Rev. *128,* 606-622 (1962).
The stimulated Raman effect. American Journal of Physics *11,* 989-1023 (1967).
Laser induced electric breakdown in solids. IEEE Journal of Quantum El. *10,* 375-386 (1974).
Observation of two-photon absorption without Doppler broadening on the 3S-5S transition in sodium vapor. With M. D. Levenson. Phys. Rev. Letters *32,* 645-648 (1974).

LEROY L. CHANG

Member of Research Staff
Thomas J. Watson Research Center
IBM Corporation, Yorktown Heights, New York 10598

Born: January 20, 1936 in Honan, China

B.S. 1957 Taiwan University
M.S. 1961 University of South Carolina
Ph.D. 1963 Stanford University
(Solid State Electronics)

ABBREVIATED CAREER

IBM Watson Research Center	Research Staff	1963-1968
MIT Department of Electrical Engineering	Associate Professor	1968-1969
IBM Watson Research Center	Research Staff	1969-Present

Member, American Physical Society, American Vacuum Society, American Institute of Electrical and Electronics Engineers

RESEARCH INTERESTS

General: semiconductor physics, materials and devices
Specific: diffusion studies, heterojunctions, field effects, tunneling spectroscopy, molecular beam epitaxy, superlattice properties

SELECTED PUBLICATIONS

Solubilities and Distribution Coefficients of Zn in GaAs and GaP. With G. L. Pearson. J. Phys. Chem. Solids *25,* 23 (1964).
Dependence of Diffusion Coefficient on the Fermi Level: Zn in GaAs. With H. C. Casey and M. B. Parish. Phys. Rev. *162,* 660 (1967).
Electron Tunneling between a Metal and a Semiconductor: Characteristics of Al-Al_2O_3-SnTe and -GeTe Junctions. With P. J. Stiles and L. Esaki. J. Appl. Phys. *38,* 4440 (1967).
Observations of an Atomlike Energy Spectrum with Large g-Values by Tunneling Spectroscopy. With L. Esaki and P. J. Stiles. Phys. Rev. Letters. *20,* 1108 (1968).
New Phenomenon in Semiconductor Junctions: GaAs Duplex Diodes. With L. Esaki. Phys. Rev. Letters *25,* 653 (1970).
The Growth of a GaAs-GaAlAs Superlattice. With W. E. Howard and R. Ludeke. J. Vac. Sci. Tech. *10,* 11 (1973).
Resonant Tunneling in Semiconductor Double Barriers. With L. Esaki and R. Tsu. Appl. Phys. Letters *24,* 593 (1974).
New Transport Phenomenon in a Semiconductor Superlattice. With L. Esaki. Phys. Rev. Letters *33,* 495 (1974).
Molecular Beam Epitaxy. With R. Ludeke. In *Epitaxial Growth,* ed. J. W. Matthews, Academic Press, New York, 1975, Chap. 2.2, p. 37.
Effects of Quantum States on the Photocurrent in a Superlattice. With R. Tsu, G. A. Sai-Halasz and L. Esaki. Phys. Rev. Letters *34,* 1509 (1975).

SAMUEL C. CHU

Professor of History and Director
of the East Asian Program
Ohio State University, Columbus, Ohio 43210

Born: 1929 in Shanghai, China
Naturalized U.S. Citizen, 1960

B.A. 1951 Dartmouth College
M.A. 1953 Columbia University
Ph.D. 1958 Columbia University

ABBREVIATED CAREER

Human Relations Area Files, Yale University	Research Assistant	1955-1958
State University of New York at New Paltz	Assistant Professor of History	1958
Bucknell University	Assistant Professor of History	1958-1960
University of Pittsburgh	Associate Professor of History	1960-1969
	Chairman, Committee on Asian Studies	1966-1967
	Executive Secretary, Council on Asian Studies	1967-1969
Ohio State Universtiy	Professor of History, and Director of the East Asian Program	1969-Present

Member, Association for Asian Studies (Member of Board of Directors, 1970-1971), American Historical Association, American Association of University Professors, National Committee on U.S.-China Relations, Asia Society

RESEARCH INTERESTS

Chinese history: Sino-Japanese relations, 19th-century Chinese social history, the Sino-Japanese War of 1894-1895

SELECTED PUBLICATIONS

Reformer in Modern China, Columbia University Press, New York (1965).
Chinese perception of Japan at the time of the Sino-Japanese War, 1894. Social Science Research Council (in press).

ANNE FITZGERALD

Professional Associate
Committee on Scholarly Communication
with the People's Republic of China
2101 Constitution Avenue, Washington, D.C. 20418

Born: June 30, 1949 in Washington, D.C.

B.A. 1971 Radcliffe College (Harvard University)
(in Chinese Language and Literature)

PROFESSIONAL EXPERIENCE

July 1971-January 1973
Department of State, People's Republic of China and Mongolian Affairs
April 1972--traveled to the People's Republic of China with Senators Mansfield and Scott

April 1973-present
Committee on Scholarly Communication with the People's Republic of China
Traveled in the United States with the following Chinese groups: Computer Group, Laser Group, Agricultural Sciences Group, Solid State Physics Group, Communications Techniques Group
Accompanied American Linguistics Group to China, October 1974

COMMITTEE ON SCHOLARLY COMMUNICATION WITH THE PEOPLE'S REPUBLIC OF CHINA

The Committee on Scholarly Communication with the People's Republic of China was formed in 1966 by the American Council of Learned Societies, the Social Sciences Research Council, and the National Academy of Sciences. It represents American scholars in the natural sciences, medical sciences, social sciences, and humanities. The activities of the Committee include exploring opportunities for, and coordinating the development of, scholarly communication between the People's Republic of China and the United States. Dr. Frank Press, Chairman, Department of Earth and Planetary Resources, Massachusetts Institute of Technology, Cambridge, Massachusetts, is chairman of the Committee.

THEODORE H. GEBALLE

Chairman, Department of Applied Physics
Stanford University, Stanford, California 94305

Born: January 20, 1920 in San Francisco, California

B.S. 1941 University of California, Berkeley
Ph.D. 1950 University of California, Berkeley

ABBREVIATED CAREER

Low Temperature Laboratory, University of California, Berkeley	Research Associate	1950-1952

Bell Telephone Laboratories	Member, technical staff	1952-1968
	Head, Low Temperature Physics Department	1958-1968
Stanford University	Professor of Applied Physics and Materials Science	1968-Present
Cavendish Laboratory Cambridge, England	Guggenheim Fellow	1975

Fellow, American Physical Society
Member, National Academy of Sciences, American Chemical Society
Recipient, Oliver E. Buckley Solid State Physics Prize of the American Physical Society, 1970

RESEARCH INTERESTS

Superconductivity: high temperature superconductors, transport and thermal properties, critical currents and ac losses, power lines
New materials: layered structures (two-dimensional effects), granular metals, magnetic interactions

SELECTED PUBLICATIONS

Physical Properties of SmB_6. With J. C. Nickerson, R. M. White, K. N. Lee, R. Bachmann, and G. W. Hull, Jr. Phys. Rev. B*3,* 2030 (1971).
Superconductivity in Layered Compounds with Variable Interlayer Spacings. With F. J. Di Salvo, R. Schwall, F. R. Camble, and J. H. Osiecki. Phys. Rev. Letters *27,* 310 (1971).
Intercalation Complexes of Lewis Bases and Layered Sulfides: A Large Class of New Superconductors. With F. R. Camble, J. H. Osiecki, M. Case, R. Pisharody, and F. J. Di Salvo. Science *174,* 493 (1971).
New Superconductors. Sci. Am. *225,* 22 (1971).
Specific Heat, Optical, and Transport Properties of Hexagonal Tungsten Bronzes. With C. N. King, J. A. Benda, and R. L. Greene, in *Proceedings of Thirteenth International Conference on Low Temperature Physics, Boulder, Colo., 1972,* edited by K. D. Timmerhaus, W. J. O'Sullivan, and E. F. Hammel (Plenum Press, New York, 1974), Vol. 3, p. 411.
Inclusion Compounds. With F. R. Camble, in *Treatise on Solid State Chemistry,* edited by N. B. Hannay (Plenum Publishing Corp., New York, 1973).
Superconductivity in H_xTaS_2. With S.F. Meyer, R. E. Howard, G. R. Stewart, J. V. Acrivos, F. J. Di Salvo, and D. W. Murphy. Bull. Am. Phys. Soc. *19,* 76 (April 1974).
Superconducting Materials Up to Now and Into the Future. With J. K. Hulm. IEEE Trans. Mag. *MAG-11,* 119 (1975).
Low Temperature Thermal and Electrical Properties of Chemical-Vapor Deposited Nb_3Ge. With J. M. E. Harper, L. R. Newkirk, and F. A. Valencia. J. Less-Common Metals (in press).
Heat Capactiy of 2H-$NbSe_2$ at the Charge Density Wave Transition. With J. M. E. Harper and F. J. Di Salvo. Phys. Letters (in press).

IVAR GIAEVER

Biophysicist and Coolidge Fellow
Physical Science Branch, Physical Science and Engineering
General Electric Research and Development Center
Schenectady, New York 12301

Born: April 5, 1929 in Norway
Naturalized U.S. Citizen, 1952

B.S. 1952 Norwegian Institute of Technology (Mechanical Engineering)
Ph.D. 1964 Rensselaer Polytechnic Institute (Theoretical Physics)
A, B, and C engineering courses at General Electric Company, 1955-1958.

ABBREVIATED CAREER

Mechanical Engineer	Norwegian Patent Office	1953-1954
Advanced Engineering Program	General Electric Co., Canada	1954-1955
Applied Mathematician	General Electric Co., New York	1956-1958
Physicist, Research Laboratory	General Electric Co., New York	1958-Present
Guggenheim Fellow, studying biophysics	Cambridge, England	1969-1970

Member, American Physical Society, Institute of Electrical and Electronics Engineers, National Academy of Sciences, National Academy of Engineering
Recipient, Nobel Prize in Physics (1973)

RESEARCH INTERESTS

Biophysics: surfaces, thin films, protein and immunology
Previous interests: superconductivity, electron tunneling, mechanical engineering, applied mathematics

SELECTED PUBLICATIONS

Energy Gap in Superconductors Measured by Electron Tunneling. Phys. Rev. Letters *5*, 147 (1960).
Tunneling into Superconductors at Temperatures Below 1°K. With K. Megerle and H. R. Hart, Jr. Phys. Rev. *126*, 941 (1962).
Detection of the A. C. Josephson Effect. Phys. Rev. Letters *14*, 904 (1965).
A Direct-Current Transformer. Spectrum IEEE *3*, 117 (1966).
Photosensitive Tunneling and Superconductivity. Phys. Rev. Letters *20*, 1286 (1968).
Tunneling, Zero Bias Anomalies and Small Superconductors. With H. R. Zeller. Phys. Rev. *181*, 789 (1969).
Subharmonic Structure in Superconducting Tunnel Junctions. With H. R. Zeller. Phys. Rev. B*1*, 4278 (1970).
The Antibody-Antigen Reaction: A Visual Observation. The Jour. of Immunology, Vol. 110, No. 5, 1424-1426 (1973).
Hepatitis B. Antigen: Visual Detection of a Metal Surface. With R. J. Laffin. Nov., 1974, Proceedings of the National Academy of Sciences.
Electron Tunneling and Superconductivity. (Copyright Nobel Foundation.) Science, *183*, 1253-1258 (1974).

JOHN J. GILMAN

Director, Materials Research Center
Allied Chemical Corporation
Park Avenue and Columbia Road
Morristown, New Jersey 07960

Born: December 22, 1925 in St. Paul, Minnesota

B.S. Illinois Institute of Technology
M.S. 1948 Illinois Institute of Technology
Ph.D. 1951 Columbia University (Metallurgy)

ABBREVIATED CAREER

Crucible Steel Company	Research Engineer in Metallurgy	1948-1952
General Electric Company	Research Associate	1952-1960
Brown University	Professor of Engineering	1960-1963
University of Illinois, Urbana-Champaign	Professor of Physics and Metallurgy	1963-1968
Allied Chemical Corporation	Director, Materials Research Center	1968-Present

Fellow, American Society for Metals, American Physical Society
Member, Metallurgical Society of the American Institute of Mining, Metallurgical and Petroleum Engineers; National Academy of Engineering
Presented the Campbell Memorial Lecture of the American Society for Metals, 1966

RESEARCH INTERESTS

Transformation in steels, elasticity and plasticity of crystals, radiation damage, fracture, the properties of dislocations and disclinations in solids

SELECTED PUBLICATIONS

Hardening of High-Chromium Steels by Sigma Phase Formation. Trans. ASM *43*, 161 (1951).
Electrolytic Etching: The Sigma Phase Steels. ASM *44*, 566 (1952).
Bend Plane Phenomena in the Deformation of Zinc Monocrystals. With T. A. Reed. Trans. A.I.M.E. *197*, 49 (1953).
Mechanism of Ortho King-Bank Formation in Compressed Zinc Monocrystals. Trans. A.I.M.E. *200*, 621 (1954).
Plastic Anisotropy of Zinc Monocrystals. Trans. A.I.M.E. *206*, 1326 (1956).
Glide Bands in Lithium Fluoride: Their Origins, Growth and Interactions. With W. G. Johnston. *Dislocation and Mechanical Properties of Crystals,* J. Wiley & Sons, New York (1957).
Dislocation Etch-Pit Formation in Lithium Fluoride. With W. G. Johnston and G. W. Sears. J. Appl. Phys. *29*, 747 (1958).
Sources of Dislocations in Crystals. J. Appl. Phys. *30*, 1584 (1959).
Direct Measurements of the Surface Energies of Crystals. J. Appl. Phys. *31*, 2208 (1960).
Mechanical Behavior of Ionic Crystals. *Progress in Ceramic Science, 1,* p. 146, Pergamon Press (1961).
Dislocations in Lithium Fluoride Crystals. With W. G. Johnston. Solid State Physics, *13* (1962).

An Electromechanical Effect in Semiconductors. With J. H. Westbrook. J. Appl. Phys. *33,* 2360 (1962).
Debris Mechanism of Strain Hardening. J. Appl. Phys. *33,* 2703 (1962).
Dislocation Mobility in Crystals. J. Appl. Phys. *36,* 3195 (1965).
Dynamical Dislocation Theory of Crystal Plasticity: I) The Yield Stress, II) Easy Glide and Strain-Hardening. With P. P. Gillis. J. Appl. Phys. *36,* 3370 (1965).
The Nature of Ceramics. Scientific American *217,* 112 (1967); also in *Materials,* W. H. Freeman Co., San Francisco (1967).
Dislocation Motion in a Viscous Medium. Phys. Rev. Letters *20,* 157 (1968).
Dislocation Dynamics and the Response of Materials to Impact. Appl. Mech. Reviews *21,* 767 (1968).
Escape of Dislocations from Bound States by Tunneling. J. Appl. Phys. *39,* 6086 (1968).
Quantum-Tunneling as an Elementary Fracture Process. With H. C. Tong. J. Appl. Phys. *42,* 3479 (1971).
Disclination Loops in Polymers. With J. C. M. Li. J. Appl. Phys. *41,* 4248 (1970).
Flow Via Dislocations in Ideal Glasses. J. Appl. Phys. *44,* 675 (1973).
Stress-corrosion Cracking in Plastic Solids Including the Role of Hydrogen. Phil. Mag. *26,* 801 (1972).
Theories of Microstructural Defects. With J. C. M. Li. *Polymeric Materials,* Amer. Soc. Met., Metals Park, Ohio, p. 239 (1975).
Metallic Glasses. Physics Today, p. 46, May 1975.

W. CONYERS HERRING

Member of Technical Staff
Bell Telephone Laboratories
Murray Hill, New Jersey 07974

Born: November 15, 1914 in Scotia, New York

B.A. 1933 University of Kansas
Ph.D. 1937 Princeton University (Math, Physics)

ABBREVIATED CAREER

Massachusetts Institute of Technology	National Research Council Fellow	1937-1939
Princeton University	Math Instructor and Research Assoc. of Math and Physics	1939-1940
University of Missouri	Physics Instructor	1940-1941
Columbia University	Member of Science Staff, Div. on War Research	1941-1945
University of Texas	Professor	1946
Bell Telephone Laboratories	Member of Technical Staff	1945-1975

Fellow, American Physical Society
Fellow, American Academy of Arts and Sciences
Member, National Academy of Sciences, Institute for Advanced Study
Recipient, Oliver E. Buckley Prize in Solid State Physics of the American Physical Society (1959)

RESEARCH INTERESTS

Theory of electronic transport in metals
Fermi-Thomas method

Principal areas of past research: energy band theory, theory of thermionic emission, theory of surfaces and sintering, transport in semiconductors, exchange effects in magnetism
Other interests: sociology of science, publication and communication of scientific information

SELECTED PUBLICATIONS

A New Method for Calculating Wave Functions in Crystals. Phys. Rev. *57,* 1169-1177 (1940).
Thermionic Emission. With M. H. Nichols. Revs. Mod. Phys. *21,* 185-270 (1949).
Effect of Change of Scale on Sintering Phenomena. J. Appl. Phys. *21,* 301-303 (1950).
Some Theorems on the Free Energies of Crystal Surfaces. Phys. Rev. *82,* 87-93 (1951).
The Use of Classical Macroscopic Concepts in Surface-Energy Problems, in the book, *Structure and Properties of Solid Surfaces* (Gomer and Smith, eds., U. of Chicago Press, 1953), pp. 5-81.
Theory of the Thermoelectric Power of Semiconductors. Phys. Rev. *96,* 1163-1187 (1954).
Transport and Deformation-Potential Theory for Many-Valley Semiconductors with Anisotropic Scattering. With E. Vogt. Phys. Rev. *101,* 944-961 (1956).
Analysis of Phonon-Drag Thermomagnetic Effects in n-type Germanium. With T. H. Geballe and J. E. Kunzler. Bell System Tech. J. *38,* 657-748 (1959).
The State of d Electrons in Transition Metals. J. Appl. Phys. *31,* 3S-11S (1960).
Effect of Random Inhomogeneities on Electrical and Galvanomagnetic Measurements. J. Appl. Phys. *31,* 1939-1953 (1960).
Asymptotic Exchange Coupling of Two Hydrogen Atoms. With M. Flicker. Phys. Rev. *134,* A 362 - A 366 (1964).
Direct Exchange Between Well-Separated Atoms, in the book *Magnetism,* Vol. IIB (G. Rado and H. Suhl, Eds., Academic Press, 1966), pp. 2-181.
Exchange Interactions Among Itinerant Electrons. *Magnetism,* Vol. IV (G. Rado and H. Suhl, Eds., Academic Press, 1966).
Quantum Transport in High Magnetic Fields. J. Phys. Soc. Japan *21,* Supplement pp. v-xiii (1966).
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J. ROBERT SCHRIEFFER

Mary Amanda Wood Professor of Physics
University of Pennsylvania
Philadelphia, Pennsylvania 19104

Born: May 31, 1931 in Oak Park, Illinois

B.S. 1953 Massachusetts Institute of Technology
M.S. 1954 University of Illinois
Ph.D. 1957 University of Illinois (all in Physics)

ABBREVIATED CAREER

University of Chicago	Assistant Professor	1957-1958
University of Illinois	Ass't. and Assoc. Professor	1959-1962
Univ. Institute of Theor. Phys. Copenhagen, Denmark	Visiting Professor	Summer 1960
University of Geneva	Visiting Professor	Fall 1963
Univ. of Geneva and Univ. Institute for Theor. Phys., Copenhagen	Visiting Professor	Spring, Summer 1967
Cornell University	Andrew D. White Professor-at-Large	Six-year term starting Sept. 1969
University of Pennsylvania	Professor	1962-Present

Fellow, National Academy of Sciences (Comstock Prize, 1968), American Philosophical Society, American Physical Society, American Academy of Arts and Sciences
Recipient, Nobel Prize in Physics (1972)

RESEARCH INTERESTS

Theoretical solid state physics
Surface physics, especially the theory of chemisorption and catalysis
Displacive lattice phase transitions and non-linear field theory
Early work: Theory of superconductivity and the stron coupling electron-phonon interaction problem; theory of ferromagnetic and nearly ferromagnetic metals, and metal-insulator transition problems

SELECTED PUBLICATIONS

Effective Carrier Mobility in Surface Space-Charge Layers. Phys. Rev. *97*, 641-644 (1955).
Theory of Superconductivity. With J. Bardeen and L. N. Cooper. Phys. Rev. *108*, 1175-1204 (1957).
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Induced Covalent Bonding Mechanism of Chemisorption. With R. Gomer. Surface Science *25,* 315 (1971).

BOOK

Theory of Superconductivity. W. A. Benjamin, Inc., New York, 1964, 282 pp.

ROBERT H. SILSBEE

Professor of Physics and Director,
Laboratory of Atomic and Solid State Physics
517 Clark Hall
Cornell Universty, Ithaca, New York 14853

Born: February 24, 1929 in Washington, D.C.

B.A. 1950 Harvard University
M.A. 1951 Harvard University
Ph.D. 1956 Harvard Universtiy

ABBREVIATED CAREER

Solid State Division, Oak Ridge National Lab.	Member of the Staff	1956-1957
Cornell University	Instructor to Professor of Physics	1957-Present

Fellow, American Physical Society
Senior Fellow, National Science Foundation (1965-1966)

RESEARCH INTERESTS

Orientable molecules and Hahn-Teller systems, ESR in metals, and defect systems strongly coupled to the phonon field. Exploratory experiments are planned in conjunction with a group in neurophysiology using ESR and spin-labeling techniques.
ESR method as applied to a wide variety of systems, and theoretical and experimental studies of optical properties of defect systems.

SELECTED PUBLICATIONS

Focusing in Collision Problems in Solids. J. Appl. Phys. *28*, 1246 (1957).

Zero-Phonon Transition of Color Centers in Alkali Halides. With Fitchen, Fulton and Wolf. Phys. Rev. Letters *11*, 275 (1963).

R-Center in KCl; Stress Effects in Optical Absorption. Phys. Rev. *138*, A180 (1964).

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Reorientation of O_2^- in KCl at Low Temperature. Journal of the Physics and Chemistry of Solids *28*, 2525 (1967).

Hindered Rotation of 2 K of the NO_2 Impurity in KCl. With Bojko. Journal of Magnetic Resonance *5*, 339 (1971).

Generation and Detection of 55 GHz Phonons Using Paraelectric Resonance of $KCl{:}Li^+$. With Larson. Phys. Rev. *B6*, 3927 (1972).

Spin Flip Scattering Conduction Electrons from Transition Element Impurities. With Huisjen and Siebert. American Institute of Physics Conference Proceedings *5*, 1214 (1971).

TESR Measurements of Exchange, Crystal Field and Enhancement Parameters in Al:Er Alloys. With Siebert and Dodds. Phys. Rev. Letters *33*, 904 (1974).

Dynamical Jahn-Teller and Reorientation Effects in the EPR Spectrum of $CaF_2{:}O^-$. With Bill. Phys. Rev. *B10*, 2697 (1974).

Appendix D
CHINESE NAME LIST

INSTITUTE OF PHYSICS

GENERAL

施汝為 Shih Ju-wei
Institute Director
(Ph.D., Yale)

王汝敬 Wang Ju-ching
Planning Bureau
Escort for entire trip

吳令安 Wu Ling-an
Semiconductor Lasers
Interpreter and escort for entire trip

張子賢 Chang Tse-hsien
High Energy Physics
Interpreter (Ph.D., Chicago)

王晋雨 Wang Chin-yu

MAGNETISM

王金鳳 Wang Chin-feng (f)
Member of Solid State Physics Delegation
to U.S., 1975

潘孝碩 Pan Hsiao-shih
Responsible Person
(Sc.D., MIT)

章 綜	Chang Tsung Responsible Person Member of Solid State Physics Delegation to U.S., 1975
楊伏明	Yang Fu-ming Responsible Person
趙海源	Chao Hai-yuan
賈惟義	Chia Wei-yi
蒲富啓	P'u Fu-ch'i
于 淥	Yu Lu Gave talk and served as interpreter
郝柏林	Hao Pai-lin
王鼎盛	Wang Ting-sheng
陳冠冕	Chen Kuan-mien (f) Gave talk

CRYSTALLOGRAPHY

舒啓茂	Shu Ch'i-mao Gave talk
陸坤权	Lu K'un-ch'üan Responsible Person Gave Introduction
梁敬魁	Liang Ching-k'uei Gave talk
胡伯清	Hu Pai-ch'ing

賈壽泉	Chia Shou-ch'üan Gave talk
麥振洪	Mai Chen-hung Gave talk
李蔭遠	Li Yin-yuan (Ph.D., MIT)
張道汕	Chang Tao-san Gave talk
朱鏞	Chu Yung
張樂惠	Chang Lo-hui
常英傳	Ch'ang Ying-ch'üan

MAGNETIC LABS

韓宝善	Han Pao-shan Bubble Laboratory (Head)
張壽恭	Chang Shou-kung Bubble Laboratory
張鵬翔	Chang P'eng-hsiang Microwave Ferrite Laboratory
季松泉	Chi Sung-ch'üan Magnet Laboratory
陳尚朝	Chen Shang-ch'ao Sputtering Laboratory
李德忠	Li Te-chung Sputtering Laboratory
王煥元	Wang Huan-yuan Sputtering Laboratory

LASERS

張擇渤 Chang Tse-po
Responsible Person
Gave Introduction

顧世杰 Ku Shih-chieh
Semiconductor lasers
Gave talk

初桂蔭 Ch'u Kuei-yin
Non-linear Optics

戴建華 Tai Chien-hua
Optical data processing

包昌林 Pao Ch'ang-lin
Semiconductor lasers

陳正豪 Chen Cheng-hao
Holography
Gave talk

朱振和 Chu Chen-ho
Non-linear Optics
Gave talk

張洪鈞 Chang Hung-chün
Optical data processing
Gave talk

陳若松 Chen Jo-sung
Holography

周岳亮 Chou Yueh-liang
Gas discharge
Member, Laser Delegation to U.S., 1974

LOW TEMPERATURE

金 鋒 Chin Feng
Gave talk

管惟炎 Kuan Wei-yen
Responsible Person

冉唐鋒 Jan T'ang-feng

朱 元 貞	Chu Yuan-chen Gave talk
林 山	Lin Shan
趙 秀 芝	Chao Hsiu-chih
陳 肖 蘭	Chen Hsiao-lan Spokesman
王 文 奎	Wang Wen-k'uei
吉 光 達	Chieh Kuang-ta
李 宏 成	Li Hung-ch'eng
程 鵬 翥	Cheng P'eng-chu
徐 鳳 枝	Hsü Feng-chih
曾 峰 培	Tseng Feng-p'ei
鄭 家 祺	Cheng Chia-chih
羅 啟 光	Lo Ch'i-kuang
殷 博	Yin Po
錢 永 嘉	Chien Yung-chia
田 淑 琴	Tien Shu-ch'in

HIGH TEMPERATURE &
HIGH PRESSURE

何寿安	Ho Shou-an Responsible Person Gave Introduction
沈主同	Shen Chu-t'ung High-Temperature & High-Pressure Synthesis Gave talk
王莉君	Wang Li-chün High-Temperature and High-Pressure Synthesis
陳祖德	Chen Tsu-te Dynamic High Pressure Gave talk
商玉生	Shang Yü-sheng Dynamic High Pressure
趙正甫	Chao Cheng-fu P-V Relation
鮑忠興	Pao Chung-hsing P-V Relation Gave talk Member of Solid State Physics Delegation to U.S., 1975

ULTRASONICS

王佑卿	Wang Yu-ch'ing Responsible Person
周靜華	Chou Ching-hua Gave talk
張守玉	Chang Shou-yü
翁文生	Weng Wen-shen
應崇福	Ying Ch'ung-fu
白玉海	Pai Yü-hai Gave talk

黄振儼	Huang Chen-yen
孫承平	Sun Ch'eng-p'ing
羅曾義	Lo Tseng-yi
周立中	Chou Li-chung Gave talk
孫增銘	Sun Tseng-ming
周献文	Chou Hsien-wen
林仲茂	Lin Chung-mao Gave talk

PLASMA LABS

陳春先	Chen Chün-hsien Responsible Person Electromagnetic plasma lab Gave Introduction
鄭少白	Cheng Shao-pai Electromagnetic plasma lab
佘永柏	Sheh Yung-pai Laser plasma lab Gave lecture
李克學	Li Ke-hsüeh Laser plasma lab
張遵逵	Chang Tsun-kuei θ-Pinch lab Gave Introduction
高鵬	Kao P'eng θ-Pinch lab

LIBRARY

劉再立	Liu Tsai-li Responsible Person
刁維漢	Tiao Wei-han
盧惠芳	Lu Huei-fang

INSTITUTE OF SEMICONDUCTORS

王守武	Wang Shou-wu Director Head of Solid State Physics Delegation to U.S., 1975 (Ph.D., Purdue)
陳克銘	Chen K'e-ming Host at Institute
褚一鳴	Chu Yi-ming Responsible Person Semiconductor materials Gave talk
王啓明	Wang Ch'i-ming Lasers
杜宝勳	Tu Pao-shun Lasers
宋振華	Sung Chen-hua Integrated circuits
楊清沁	Yang Ching-hsin
彭湘和	P'eng Hsiang-ho
楊柳林	Yang Liu-lin Integrated circuits Gave talk
謝宗均	Hsieh Tsung-chün Integrated circuits Gave talk

趙學恕	Chao Hsueh-shu Microwave Gave talk
劉朝中	Liu Ch'ao-chung Microwave Gave talk
王仲明	Wang Chung-ming
吳錫九	Wu Hsi-chiu
林耀望	Lin Yao-wang Lab Introduction
方兆強	Fang Chao-ch'iang Lab Introduction
許振嘉	Hsu Chen-chia Lab
林芝英	Lin Chih-ying Lab
楊守田	Yang Shou-tien Lab
吳賽娟	Wu Sai-chuan Lab

INSTITUTE OF BIOPHYSICS

貝時璋	Pei Shih-chang Director (Ph.D., Tubingen) Head of General Scientific Delegation to U.S., 1972
龍新華	Lung Hsin-hua Responsible Person Administration Office
吳家振	Wu Chia-chen Responsible Person
劉蓉	Liu Jung Chemist

顧孝成 Ku Hsiao-cheng
Physics

沈恂 Shen Hsun
Physics

TSINGHUA UNIVERSITY

張維 Chang Wei
Vice Chairman,
Revolutionary Committee
Professor of Civil Engineering
(Ph.D., Berlin)

馬文仲 Ma Wen-chung
Vice Head,
Administrative Office of the Revolutionary Committee
Physicist

錢偉長 Ch'ien Wei-ch'ang
Professor of Mechanics
(Sc.D., Toronto)
Member, General Scientific Delegation to U.S., 1972

陳景良 Chen Ching-liang
Mechanical Engineering

史斌星 Shih Pin-hsing
Physics and Electronics

吳国華 Wu Kuo-hua
Teacher, Language Department

劉五一 Liu Wu-yi
Student
Automation Department

岳五一 Yue Wu-yi
Student
Electronics Department

陳南平 Chen Nan-ping

張鈸 Chang Ma

PEKING UNIVERSITY

周培源	Chou P'ei-yuan Vice Chairman, Revolutionary Committee Professor of Hydrodynamics Head of Science Delegation to U.S., 1975 (Ph.D., Caltech)
黄昆	Huang Kun Professor of Physics Member Solid State Physics Delegation to U.S., 1975 (Ph.D., Bristol)
張龍翔	Chang Lung-hsiang Officer, Revolutionary Committee
褚聖麟	Chu Sheng-lin Vice Chairman, Revolutionary Committee of Physics Department
倪孟雄	Ni Meng-hsiung Office Director Revolutionary Committee
王竹溪	Wang Chu-hsi Professor of Theoretical Physics (Ph.D., Cambridge)
韓文秀	Han Wen-hsiu Vice Group Leader, Educational Revolutionary Committee Department of Physics (recent graduate)
戴遠東	Tai Yuan-tung Teacher, Low Temperature
王岳	Wang Yueh Responsible Person Laser Physics
劉宏度	Liu Hung-tu Teacher, Laser Physics Gave talk
鄭小祿	Cheng Hsiao-lu Second-year student Laser Physics Gave talk
杜成森	Tu Ch'eng-sen Third-year student Low Temperature Gave talk

潘傳紅 P'an Ch'uan-hung
Third-year student
Theoretical Physics
Gave talk

郭長志 Kuo Chang-chih
Teacher, Laser Physics
Gave talk

楊玉梅 Yang Yü-mei
Third-year student
Low Temperature
Gave talk

CHIAOTUNG UNIVERSITY (SIAN)

劉若曾 Liu Jo-tseng
Vice Chairman, Revolutionary Committee

周惠久 Chou Hui-chin
Professor

汪應洛 Wang Ying-lo

趙富鑫 Chao Fu-hsin

嚴晙 Yen Chun
Professor of Radio Communication

沈文鈞 Shen Wen-chun

黄敞 Huang Ch'ang
Professor of Radio Communication

張世煌 Chang Shih-huang

屠善洁 Tu Shan-chi
Professor of Radio Communication

朱振華 Chu Chen-hua
Teacher
Gave talk

張屏英 Chang Ping-ying
Teacher, Semiconductors

王其平 Wang Ch'i-p'ing

李全福 Li Ch'üan-fu
Student
Gave talk

李 倫 Li Lun
Student

NANKING UNIVERSITY

高濟宇 Kao Chi-yu
Vice Chairman, Revolutionary Committee
Professor of Chemistry

徐效海 Hsü Hsiao-hai
Head, Office of Teaching and Research

歐陽容伯 Ouyang Jung-pai
Responsible Person, Revolutionary Committee of Department of Physics

鮑家善 Pao Chia-shan
Professor of Physics
Leading Member, Department of Physics

馮 端 Feng Tuan
Professor of Physics
Head, Crystal Physics

施士元 Shih Shih-yuan
Professor of Physics
Head, Atomic and Nuclear Physics

魏榮爵 Wei Yung-chueh
Professor of Physics
Head, Acoustic Physics

周松山 Chou Sung-shan
Secretary
University Revolutionary Committee

徐龍道 Hsü Lung-tao
Teacher
Department of Physics

張杏奎 Chang Hsing-k'uei
Teacher
Department of Physics

李 華	Li Hua Responsible Person, Low-Temperature Lab
張福生	Chang Fu-sheng Materials Lab
李 質	Li Chih Materials Lab
王業寧	Wang Yeh-ning Laser Lab
苗永智	Miao Yung-chih Teacher Department of Physics Holography Lab
翟宏如	Tsai Hung-ju Teacher Magnetism
劉公強	Liu Kung-ch'iang Teacher Magnetism
徐秀英	Hsü Hsiu-ying Teacher Crystal Physics
葛傳珍	Ke Ch'uan-chen Teacher Crystal Physics
邱 建	Ch'iu Chian Student Semiconductor Physics
王克剛	Wang K'e-kang Second-year Student
劉 景	Liu Ching Third-year Student
劉洪章	Liu Hung-chang Third-year Student

FUTAN UNIVERSITY

蔡祖泉	Tsai Tsu-ch'üan Responsible Person Revolutionary Committee Professor Electrophysics
谷超豪	Ku Chao-hao Professor of Mathematics
盧鶴紱	Lu Ho-fu Professor of Theoretical Physics
楊福家	Yang Fu-chia Professor of Physics Section Head
謝希德	Hsieh Hsi-te Professor of Semiconductor Physics
歐陽光中	Ouyang Kuang-chung Teacher, Mathematics
章志鳴	Chang Chih-ming Teacher, Laser Physics
孫鑫	Sun Hsin Teacher, Physics
鄭紹濂	Cheng Shao-lien Educational Revolution Committee
朱紹龍	Chu Shao-lung Teacher
張君炎	Chang Chün-yen Head, Library
呂誠哉	Lu Ch'eng-ts'ai Head, Laser Lab
金跃根	Chin Yao-ken Laser Lab

楊志昌	Yang Chih-ch'ang Laser Lab
洪永青	Hung Yung-ch'ing Lab
李鴻和	Li Hung-ho Lab
李乃煌	Li Nai-huang Student
徐志學	Hsü Chih-yueh Student
李一民	Li Yi-min Student

INSTITUTE OF OPTICS AND FINE MECHANICS*

Lu Ming
Chairman, Revolutionary Committee

Gan Fu-hsi
Researcher and Vice Chairman
Revolutionary Committee

Wang Ke-wu
Interpreter

Lin Tsun-chi
Researcher
Lasers
Member of Laser Delegation to U.S., 1974

Yang Hsi-cheng
Official of the Revolutionary Committee

Ni Bao-cheng
Official of the Revolutionary Committee

Chen Shih-jen
Lab: Reaction of glass under pressure

*The Chinese characters for these names are not available.

Fu Wen-piao
Lab: Glass materials for high-powered lasers

Yang Hsiang-chuan
Lab: Coherent spontaneous parameter amplification in the visible spectrum

Liou Li-jen
Lab: Laser switch

Yuan Gang (f)
Lab: YAP crystal growing

Ye Sheng-kuei
Lab: Nd YAG crystal growing

Lin Fu-cheng
Lab: Thermally induced birefringence of YAG rods in (001) direction

Huang Kuo-sung
Lab: Relation between thermal distortion in thermo-optic properties of Nd glasses-YAG crystal dislocation

Guang Pei-jen
Lab

INSTITUTE OF CERAMICS (SHANGHAI)

郑希泉
Cheng Hsi-ch'üan
Responsible Person
Revolutionary Committee

田克温
T'ien K'e-wen
Responsible Person for Scientific and Technical Group

余金樑
Yu Chin-liang
Division Responsible Member
Member of Solid State Physics Delegation to U.S., 1975

張綬庆
Chang Shou-ch'uang
Professor

陳文通
Ch'en Wen-t'ung
Head, Office of Revolutionary Committee

唐元芬	T'ang Yuan-fen Scientific worker Crystal growth laboratory
徐良瑛	Hsu Liang-ying Scientific researcher Crystal growth laboratory
張道林	Chang Tao-lin Scientific researcher Crystal growth laboratory
金吉人	Chin Chi-jen Scientific researcher Crystal growth laboratory
王文	Wang Wen Scientific researcher Crystal growth laboratory
張星三	Chang Hsing-san Scientific researcher Crystal growth laboratory
劉建民	Liu Chien-min Scientific researcher Crystal growth laboratory
殷庆瑞	Yun Ch'ing-jui Scientific researcher Crystal growth laboratory
亓曾篤	Yi Tseng-ma Scientific researcher Crystal growth laboratory
温樹林	Wen Hsu-lin Translator Crystal growth laboratory

Appendix E:

PHYSICS CURRICULA AT CHINESE UNIVERSITIES

CURRICULUM IN LASER CRYSTAL PHYSICS AT NANKING UNIVERSITY

BASIC MATHEMATICS (3 semesters, 6 class hours per week)

Analytic geometry, differential and integral calculus, elementary differential equations, introduction to partial differential equations, series expansions and Fourier analysis, and heat flow and wave equations are discussed. (A high school math refresher course is offered to those entering students who need it.)

BASIC PHYSICS

- Mechanics (40 lecture hours)
- Light (geometry and physical optics) (30-40 hours)
- Thermodynamics, including molecular physics (35 hours)
- Electromagnetics, including electronics and ac circuits and elementary machinery (70 hours)
- Quantum Mechanics (one semester in the first half of third year). This includes the one-dimensional Schrödinger Equation plus results for three-dimensional cases.

LASER CRYSTAL PHYSICS SPECIALTY (two semesters in second and third years)

Principles of lasers, phenomenological introduction of Einstein A and B coefficients (no quantum mechanical time-dependent perturbation theory), crystallography, crystal growth, physical properties of crystals (including tensor analysis). (The material follows roughly Yariv's text, *Introduction to Optical Electronics*.)

NOTES

1. The basic mathematics program is quite similar for the other physics options. It is taught by math department members, but separately for each physics option.

2. The basic physics program has larger individual variation in emphasis for the different physics options.

3. There is no basic chemistry course in the curriculum, although students learn about phase diagrams and chemical potential in thermodynamics.

4. The students' study time per week is roughly as follows:

22 hours of lectures (this includes 4 hours of lab work, 3 hours in a foreign language during the first two years [usually English], 2 hours political science, 2 hours physical education)

6 hours of question-and-answer period (tutorial)

30 hours of self-study, problem solving, and homework. (The students are encouraged to consult textbooks, in addition to the lecture notes especially prepared for each course.)

CURRICULUM IN LOW TEMPERATURE AT NANKING UNIVERSITY

Math is emphasized the first year, starting with calculus and differential equations, and is followed in the second year by partial differential equations. A number of courses are tailor-made for low temperature. For example, thermodynamics is taught with emphasis on cryogenics, and electromagnetism is combined with superconductivity.

The course in superconductivity covers approximately the following topics:

- Macroscopic superconductivity (i.e., Kittel)
- Maxwell's Equations
- London Equations (for superconductors)
  Electromagnetic properties of superconductors
  Coherence length and penetration depth
- Energy of type-I and type-II superconductors
- Vortex structure
- Critical state model for type-II superconductors
- Quantum mechanics (no second quantization)
- Ginzburg-Landau Equations
- Simplified BCS Theory
- Simplified Josephson Effect

Theory is heavily interspaced with practice. Students spend time in the first year running the nitrogen and helium liquefiers. Part of the second year is spent in the laboratory making and testing tunnel junctions or laboratory-sized magnets. We can give no example of a graduate exercise. The program has evidently changed since Lounasmaa's visit in 1973, since most subjects are now taught in connection with the low-temperature program rather than as the separate subjects he listed.

CURRICULUM IN MAGNETISM AT PEKING UNIVERSITY

FIRST YEAR

The students work in the ferrite core "factory" of the university. Actually this is a very small-scale, antiquated operation with hand-operated equipment (e.g., for punching the ferrite strip material and for producing the strip material). The students move from step to step along the production line for the cores, spending several weeks at each step. Thirty percent of the students' time is spent in this "factory."

During the first year, the students study ferrite magnetism, in addition to mathematics and other courses, the details of which we did not ascertain.

SECOND YEAR

The students work part-time in factories located in Peking, in place of the university-based factory of the first year. Also, they spend 3 months living at a factory (presumably away from Peking) where they spend 1½ days per week in active production work, while they attend classes taught by their professors (who travel with them to the factory; the professors continue the structured course work, as well as learning, themselves, of practical problems) and more practical lectures by the experienced workers.

During the second year, the students study alloy magnetism and toward the end of this year, ferromagnetism more generally.

THIRD YEAR

Work continues in factories (10-15%), but now a great fraction of the time is devoted to the graduation project, a specific research problem usually generated from factory suggestions of a problem area of importance in production.

The course work continues through part of this year.

We were shown a copy of the lecture notes used in the second- and third-year courses in magnetism. These were written by a group of faculty members, starting in 1971, and changes are still being made. Sections 5-8 were written by Professor Chu, who guided our visit through the magnetism program at Peking University. The table of contents of the notes is as follows:

1. Macroscopic Law of Ferromagnetism
2. Origin of Magnetism
3. The Relation of Technical Magnetism and the Free Energy of Magnetic Materials.
4. Domains
5. Magnetization of Materials
6. Permanent Magnets
7. Magnetic Excitation Spectrum
8. Microwave Resonance and High Frequency Properties

A quick glance showed that a reasonably detailed discussion of the mathematical details of Weiss theory, domain walls, anisotropy and exchange energies, relaxation effects, and the like were covered and that the properties of specific materials were presented as examples. Thus, considering the limited time available for the formal course, a reasonable level of understanding of applied magnetism was engendered. From what we could tell, little attention was paid to the microscopic (electronic) quantum theory of magnetism, although the Heisenberg model was studied as a phenomenological model.

CURRICULUM IN MICROELECTRONICS AT FUTAN UNIVERSITY

Mathematics consists of 200 total class hours, of which the first 90 are devoted to integral and differential calculus and ordinary differential equations, and is the same for all physics specialties. Those in microelectronics are taught, in addition, infinite series, partial differential equations (potential equation, diffusion equation, and Poisson's equation), and an introduction to computers. In a 3-month period toward the end of the course, each student has access to a total of a half hour of time on the computer in the mathematics department, during which problems related to the physics of semiconductors are solved. Students studying semiconductor microwave devices or radio engineering receive an additional 45 hours of instruction, during which they are introduced to Maxwell's equations in vector form and wave propagation, including propagation in rectangular and elliptical wave guides.

The general physics course includes mechanics, electricity (with dc and ac circuits), and some atomic physics. Little attention is given to optics or kinetic theory; these subjects are taken up as required in later specialized courses. There is a chemistry course dealing with oxidation-reduction principles and reaction kinetics, which was said to provide a rather incomplete background for the chemistry required for integrated circuit technology. Students later learn what is needed as they work in the integrated circuits laboratory.

More specialized courses in the curriculum are:

- Transistor circuits, including an introduction to PN junctions and junction transistors from a phenomenological point of view, characteristics of transistors, bistable circuits, oscillators, and amplifiers. It is similar in content to courses given undergraduate electrical engineers in the United States.
- Semiconductor and solid state physics, including simple ideas of energy bands, transition probabilities, and physical principles of transistors.
- Integrated circuit technology, including photolithography, oxidation, diffusion, and masking.
- Principles of the design and fabrication of integrated circuits.
- Principles of computer science.
- Physics of transistors.

Course work is closely tied in with laboratory experiments and experience in transistor workshops. There is close interaction with industry.

In addition, students take courses in political science, English, and physical education.

"JULY 21 SCHOOL" OF THE SHANGHAI MACHINE TOOL PLANT

The course for training machine-tool design engineers takes 3 years of full-time study. Two groups of students have completed the course, and a third group is in progress. From the total pool of 6,000 factory workers, only about 100 per class are trained.

The students take political study (Marx, Lenin, Mao), study production labor, and for 2 months a year they return to their regular jobs so "they will not quit thinking of themselves as workers." They also have military training and study agriculture. Their technical course consists of higher math (partial differential equations and

Fourier analysis), engineering mechanics, electrical engineering, hydraulics, design and manufacture of machine tools, drawing, and English. The purpose of the course is to produce a worker "with a high scientific and technical skill, and also with a high political consciousness."