Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. High Schools: Report of the Content Panel for Chemistry

Committee on Programs for Advanced Study of Mathematics and Science in American High Schools, National Research Council

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LEARNING AND UNDERSTANDING:
IMPROVING ADVANCED STUDY OF MATHEMATICS AND SCIENCE IN U.S. HIGH SCHOOLS

REPORT OF THE CONTENT PANEL FOR CHEMISTRY

Conrad Stanitski, Editor

Committee on Programs for Advanced Study of Mathematics and Science in American High Schools

Center for Education
Division of Behavioral and Social Sciences and Education
National Research Council

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

William R. Robinson, Purdue University
Keith Sheppard, Columbia University
Myra Thayer, Fairfax County Public Schools
David Thissen, University of North Carolina, Chapel Hill

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Philip C. Curtis and Kirsten Sampson-Snyder. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

1
Introduction

The National Research Council's (NRC) Committee on Programs for Advanced Study of Mathematics and Science in American High Schools (parent committee) formed a chemistry panel to compare and evaluate the Advanced Placement (AP), the International Baccalaureate (IB), and alternative programs for advanced study in chemistry with respect to their pedagogy, content, assessments, and outcomes (the charge to the panel is presented in Appendix B). The chemistry panel met twice (in June and July 2000) to address its charge from the parent committee. The panel was chaired by a member of the parent committee, who served as liaison to the committee and consolidated the panel's findings and recommendations into this report. Panel members also included high school chemistry teachers with AP, IB, and New York State Regents examination experience, along with experienced college and university chemistry professors noted for their work in chemical education. Biographical sketches of chemistry panel members are provided in Appendix A.

Neither independent researchers nor the AP or IB program has published systematic data about the programs. Thus few data on the ways in which AP and IB courses are actually implemented in U.S. high schools, the long-term consequences to students who take AP or IB courses, or the effects of an increasing number of students who arrive at college with multiple AP and IB credits to use toward advanced placement or to meet graduation requirements were available to the panel. Because important data about the programs have not yet been published by either the programs or independent researchers, the panel focused its analysis on what the programs say they do, using available program materials such as course guides, released examinations, teacher manuals, program goals, and mission statements.

The chemistry panel carefully reviewed a substantial volume of background materials related to the AP and IB programs; those materials are listed in Appendix C. The findings and recommendations reached by the panel and presented in this report were consensus opinions, arrived at by reading the background materials and holding extensive discussions. Panel members also contributed written materials that were incorporated into this final report.

The remainder of this report is divided into four chapters. Chapter 2 presents an overview of advanced study in chemistry for high school students. Chapters 3 through 5 respond to the questions under the panel's charge. Chapter 3 focuses on the students who enroll in the AP Chemistry course and the IB program, what is taught and how well it is being taught, the grade levels at which these advanced courses are offered, and the background and prerequisites needed to take and succeed in the courses. Chapter 4 addresses those who teach AP and IB Chemistry courses, including their academic preparation, credentials, and appropriateness for the task. Chapter 5 provides an analysis of the assessments and outcomes associated with the AP Chemistry course, the IB Chemistry program, and their affiliated examinations. Throughout these chapters, key findings appear in italic type. The report concludes in Chapter 6 with a summary and recommendations regarding the AP Chemistry course and the IB program, including the panel's consideration of whether advanced study options in high school should be associated with opportunities for students to earn college or university credit.

2
Overview of Advanced Study Programs in Chemistry in U.S. High Schools

CHARACTERISTICS OF AP CHEMISTRY

In addition to recommending that at least 290 minutes per week be allotted to AP Chemistry courses, the College Board characterizes the AP Chemistry course as follows:

> The AP Chemistry course is designed to be the equivalent of the general chemistry course usually taken during the first college year. For some students, this course enables them to undertake, as freshmen, second-year work in the chemistry sequence at their institution or to register in courses in other fields where general chemistry is a prerequisite. For other students, the AP Chemistry course fulfills the laboratory science requirement and frees time for other courses.
>
> AP Chemistry should meet the objectives of a good general chemistry course. Students in such a course should attain a depth of understanding of fundamentals and a reasonable competence in dealing with chemical problems. The course should contribute to the development of the students' abilities to think clearly and to express their ideas, orally and in writing, with clarity and logic. The college course in general chemistry differs qualitatively from the usual first secondary school course in chemistry with respect to the kind of textbook used, the topics covered, the emphasis on chemical calculations and the mathematical formulation of principles, and the kind of laboratory work done by the students. Quantitative differences appear in the number of topics treated, the time spent on the course by students, and the nature and variety of experiments done in the laboratory. *Secondary schools that wish to offer an AP Chemistry course must be prepared to provide a laboratory experience equivalent to that of a typical college course.* (College Entrance Examination Board [CEEB], 1999a, p. 1)[2] (Note: Italics added for emphasis by the College Board.)

Thus by design, AP Chemistry courses (and all other AP courses) are modeled after typical college-level introductory courses in the discipline. As a result, these high school courses are supposed to follow trends in college-level introductory general chemistry (not introductory chemistry, which typically denotes remedial or non–science major chemistry courses).

[2] These publications are commonly refereed to as *Acorn Books* because of the distinctive logo on their covers.

The College Board goes on to say that:

> *The AP Chemistry course is designed to be taken only after the successful completion of a first course in high school chemistry.* A survey of students who took the 1986 AP Chemistry Examination indicates that the probability of achieving a grade of 3 or higher on the AP Chemistry Examination is significantly greater for students who successfully complete a first course in high school chemistry prior to undertaking the AP course. Thus it is strongly recommended that credit in a first-year high school chemistry course be a prerequisite for enrollment in an AP Chemistry class. (CEEB, 1999a, p. 1) (Note: Italics added for emphasis by the College Board.)[3]

Whether schools offering AP courses follow this recommendation probably depends on local practice. In any case, the *chemistry panel unanimously agrees that, unless truly exceptional circumstances dictate, students should not take advanced chemistry as their first chemistry course in high school.*[4] Although the College Board also recommends against this practice, it does happen, and the panel believes it is detrimental to the student, who is academically short-changed by such circumstances. It is in the first course that the requisite concepts are learned and the laboratory skills developed that are needed to legitimize advanced study in the second high school chemistry course.[5]

An appropriate background in mathematics is needed to succeed in AP Chemistry, and the College Board addresses this matter as well: "*In addition, the recommended mathematics prerequisite for an AP Chemistry class is the successful completion of a second-year algebra course*" (CEEB, 1999a, p. 1) (Note: Italics added for emphasis by the College Board.)

The College Board also is explicit regarding the place of AP Chemistry in the total science curriculum: "The advanced work in chemistry should not displace any other part of the student's science curriculum. It is highly desirable that a student have a course in secondary school physics and a four-year college preparatory program in mathematics" (CEEB, 1999a, p. 2).

Because of the structure of the AP program, the AP Chemistry course can be a stand-alone course offered by a high school in the absence of any other AP course offerings at that high school or other high schools in the district. Moreover, students who enroll in and complete AP

[3] The College Board (2001b) reports that in 2001, of the 55,000 students taking AP Chemistry, 3,000 were in the ninth or tenth grades, and 28,000 were in the eleventh grade. However, it is unclear from these data what percentage of students take AP Chemistry as their first course in the subject. Of the 28,000 students in the eleventh grade taking AP Chemistry, it is possible that many or most of them took introductory chemistry in the tenth grade. Additional research is needed to determine the actual proportion of students who take AP Chemistry as their first course in the subject.

[4] Exceptional circumstances that would enable some students to succeed in an advanced course in chemistry as their first exposure to the discipline could include students who have had unusual preparation in science and mathematics or who have proven that they can acquire the concepts taught in introductory chemistry on their own. The panel emphasizes that such exceptions would be made only in very rare cases.

[5] There are few data about the extent to which this practice occurs. The panel believes that gathering such data is important, and calls on the College Board to gather and publish data describing the ways in which their courses are implemented in schools and the effects of those courses on student learning and achievement.

Chemistry, or any other AP courses, are not required by the College Board to take the AP examination developed by the College Board and administered by the Educational Testing Service.[6]

Administered each May, the AP Chemistry examination is 3-hour examination consisting of 2 sections. The first section (90 minutes) consists of 75 multiple-choice questions and represents 45 percent of the final grade. The College Board uses some common multiple-choice questions from year to year as a consistency check on the performance of the students taking the exam. The second section of the examination (also 90 minutes) represents 55 percent of the final grade and consists of several short-answer and essay-style questions that purportedly provide for a more in-depth assessment of students' understanding of chemical principles. The questions may require calculations, a short essay response, or the determination of reaction products. Section II contains both required questions to which all students must respond and opportunities for students to choose two of four additional questions that they think they are best prepared to answer.[7] The examinations are collected and sent to a central location, where they are graded by a national team of graders.[8] All of the examinations are graded during a 1-week period. The College Board has developed procedures to ensure uniformity in the scoring process.[9] The AP score (1–5) is determined by a complex formula that factors in how well others who took the test performed, how scores were distributed over the past 3 years, and how well college students at the end of their introductory course performed on the AP examination.

CHARACTERISTICS OF THE IB PROGRAMME AND IB CHEMISTRY

Whereas the AP program is a collection of individual, unrelated courses, the International Baccalaureate Diploma Programme is a comprehensive 2-year curriculum consisting of six academic areas.[10] IB courses may be taken at either the Standard Level (SL) or Higher Level (HL).[11] Chemistry is included with Group 4, the Experimental Sciences. IB Diploma candidates must take one subject from each of the six subject areas, with at least three and not more than

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[6] Although the College Board has no such requirement, some state and local school districts are now requiring students to take the examination. In these circumstances, the district or state sometimes pays for part or all of the costs to students of taking the exams.
[7] For example, in 2001 the AP Chemistry examination required that students answer questions 1, 4, 5, and 6 and allowed them to choose between questions 2 and 3 and between questions 7 and 8.
[8] Graders are drawn from a pool of experienced high school AP teachers and college faculty with expertise in the discipline. Individuals are nominated or apply to become graders.
[9] For example, more than one grader reads each paper, and large discrepancies between assigned scores are resolved by third and sometimes fourth readers.
[10] Although AP courses are not traditionally offered as an integrated program, the panel notes that for several years the College Board has offered an International Diploma for Advanced Placement. This program is designed for students who plan to pursue undergraduate studies outside the United States or Canada. The total number of students seeking this diploma is relatively small. To earn the diploma students take four AP courses in three different subject areas and must receive an average grade of 3 or higher. In 2000, the College Board initiated a pilot test of a new AP Diploma that is similar to the IB Diploma in many respects. To qualify for this diploma, students must take one AP course from each of the following areas: languages and literatures; sciences; mathematics; history and social sciences. They must also take one additional AP course in any area. In addition, students must earn an average grade of 3 on all exams taken. Additional information is available at http://www.collegeboard.org/ap/students/benefits/int_diploma.html [4/24/02].
[11] SL courses entail 150 hours of class time, while HL courses require 240 hours. HL courses are generally taught over 2 years.

four being HL. The other courses taken are SL. Thus, a chemistry student can take either the HL or SL version of the IB Chemistry course and related examination. IB students are permitted to take two science subjects simultaneously from Group 4.

Students can and do take individual IB courses without working toward an IB Diploma. These students are known as certificate candidates, as opposed to diploma candidates. Only diploma candidates are required to take one subject from each area, as well as to fulfill additional requirements. Approximately 65 percent of IB students work for and complete the requirements for a diploma.

IB Diploma candidates must also complete three other requirements: (1) the interdisciplinary Theory of Knowledge course; (2) an extended essay of approximately 4000 words; and (3) participation in the school's Creativity, Action, Service (CAS) program involving sports, artistic pursuits, and community service work. Unlike the AP program, the IB program seeks to provide interdisciplinary preparation for university work rather than attempting to meet particular university course requirements, although strong performance in IB courses is used to grant advanced placement at colleges and universities (International Baccalaureate Organisation [IBO], 1999).

All Group 4 subjects include required practical (laboratory) work, which makes up a significant portion of the course.[12] Although this laboratory work focuses primarily on the assessment of laboratory skills, it also offers opportunities for students to perform experiments and experience first-hand the benefits and limitations of scientific methodology. Individual teachers plan the Practical Scheme of Work (PSOW) for students in their classes. Thus, the laboratory experiences of students in different IB classrooms will vary. The PSOW should represent the breadth and depth of the subject syllabus, but students are not required to conduct an investigation for each topic in the syllabus. To ensure quality and to foster improvements, teachers are required to submit copies of their PSOW annually to the IBO for moderation and feedback.

As noted above, the College Board recommends that at least 290 minutes per week be allotted for an AP chemistry class (174 total hours per year, assuming a 36-week academic year). Of this total, 54 hours is recommended for laboratory work. By comparison, IB recommends a total of 240 hours for HL and 150 hours for SL courses per academic year. Of this time, it is recommended that 60 hours for HL courses and 40 hours for SL courses be devoted to investigative activities that, along with the Group 4 project, comprise the internal assessment (IA) component of the course.

A common core curriculum applies to both HL and SL chemistry courses. The core material taken by SL students is a subset of the HL program. At the SL level, the core topics make up about 60 percent of the material, while at the HL level the core represents 75 percent of the covered topics. Both SL and HL students also study optional topics that their teacher selects from among a list of topics included in the course syllabus. SL students study three options of 20 hours each, while HL students study two options of 30 hours each chosen by the school. The only option available exclusively to SL students is higher physical organic chemistry (15 hours).

[12] The IBO recommends that 25 percent of the course be devoted to practical (laboratory) work.

Options available to both SL and HL students (15 and 22 hours, respectively) include medicines and drugs, human biochemistry, environmental chemistry, chemical industries, and fuels and energy. The options available to HL students only (22 hours) are modern analytical chemistry and further organic chemistry. Additional hours of internally assessed practical work are required for both SL and HL options.[13] Further, both SL and HL students must spend 10–15 hours on an interdisciplinary Group 4 project, which is a common element of all IB science programs and constitutes 10 hours of the internally assessed practical scheme of work.[14]

The IB Chemistry examination is given annually and is taken at either the SL or HL, depending on the student's course of study. The SL exam consists of three papers. The first paper (0.75 hour) consists of 30 multiple-choice questions. The second paper (1 hour) contains short-answer questions and brief calculations in Part A and offers students a choice of answering one of two more-extended questions in Part B. The remaining paper (1.25 hours) consists of one or two questions based on the course options completed by an individual student. The HL examination also comprises three papers with the same distribution as that of the SL examination, but with topics examined in greater depth. The time allotted for the first HL paper is 1 hour, for the second 2.25 hours, and for the third 1.25 hours.

IB examinations are sent to examiners around the world who mark and return them to the IBO offices in Cardiff, Wales. During the grading process, examiners measure each student's performance against seven grade descriptors, given in the form of levels of performance that candidates can demonstrate on the examination. To ensure uniformity in the grading across examiners who are not centrally located, a representative sample of graded examinations from individual examiners is sent to the chief examiner for moderation. IB examination grades (1–7) are based on established criteria that represent an *absolute standard* of quality; thus, the interpretation of a student's performance is criterion-referenced. A grade of 7 represents "excellent performance," while grades of 4 and 1 represent "satisfactory" and "very poor" performance, respectively. All IB group subjects, including chemistry, have a significant IA component involving laboratory work and a project, which constitutes 24 percent of a student's final grade. The IA component is internally assessed at the student's school by the teacher and is also externally moderated by the IBO. Final IB scores for each student are a combination of the results of the IA and the external scoring of the examination papers, but are reported to the school as a single total.

QUALIFICATIONS FOR TEACHING ADVANCED HIGH SCHOOL COURSES IN CHEMISTRY

[13] SL options require an additional 5 hours of practical work that is internally assessed; options that are suitable for both SL and HL require an additional 5 hours for SL students and 8 hours for HL students; and options exclusively for HL students require 8 hours of internally assessed practical work.

[14] The Group 4 project is an interdisciplinary activity that involves all of the IB science students at the school in identifying and investigating an issue, usually of local interest. The project requirements emphasize sharing concepts and theories from across the disciplines and the processes involved in scientific investigation, rather than producing products.

To provide a chemistry course consistent with the criteria noted above for an advanced study course in chemistry at the high school level, those who teach such a course must be adequately prepared. *The chemistry panel takes this to mean a B.S. or B.A. degree in chemistry, and preferably an M.A. or M.S. degree in chemistry*. The preparation of AP and IB Chemistry teachers is discussed in detail in Chapter 4.

DEFINITION OF ADVANCED STUDY IN CHEMISTRY FOR HIGH SCHOOL STUDENTS

The chemistry panel agrees that the prerequisite first-year high school course in chemistry should provide students with an introduction to the atomic-scale view of matter, including its connection to macroscopic physical and chemical properties and to the language used to express these relationships, using the periodic table as an organizing entity. Moreover, as befits the nature of chemistry as an experimental science, the introductory (first-year) course should include experimentation and the use of scientific methodology.

Members of the panel also agree that *any* high school course in chemistry that is labeled as advanced study, whether or not it is structured according to an established curriculum and assessment such as AP or IB, should enable students to develop the ability to explore the chemistry concepts and laboratory practices introduced in the first-year course in greater depth and, where appropriate, to conduct some form of research. Under the guidance of a qualified advanced study instructor, desirable features of such advanced study would include some combination of the following characteristics:

- Application of basic ideas to more complex materials, systems, and phenomena
- Use of modern instrumentation, methods, and information resources
- Integration of concepts within and between subject areas, including extensions to other disciplines
- Use of appropriate mathematical and technological methods
- Extended use of inquiry-based experimentation
- Development of critical thinking skills and conceptual understanding
- Use of appropriate tools for assessing student performance and attitude that reflect current best practices
- Promotion of communication skills and teamwork

These characteristics are consistent with visions for undergraduate education articulated in the National Science Foundation's (NSF) *Shaping the Future* (1996) and the National Research Council's *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* (1999) reports. These two reports summarize what undergraduate science, mathematics, engineering, and technology (SME&T) courses, including introductory courses in chemistry, should encompass if they are to serve the dual objectives of enhancing scientific literacy and providing adequate preparation for a diverse, talented technical workforce.

Catalyzed by programs sponsored by NSF, the American Chemical Society, and other organizations concerned with improving undergraduate science education, some college and university chemistry courses are being revamped to achieve the objectives that those reports recommend (see, e.g., *ChemConnections*;[15] *Chemistry: Structure and Dynamics* [Bodner, Rickard, and Spencer, 1999]; Landis and Peace [1998]; *The Chemical World: Concepts and Applications*, 2nd edition [Moore, Stanitski, Wood, Kotz, and Joest, 1998]; and the *Discovery Chemistry* curriculum developed at the College of the Holy Cross[16]). However, many faculty who oversee undergraduate programs in chemistry have not yet confronted and addressed these issues.

FINDINGS AND CONCLUSIONS

Although exceptions exist among schools and teachers, *the chemistry panel finds that in general, the material taught in advanced courses (as specified in the guidebooks provided by the College Board and the IBO) fail to meet many of the criteria outlined in the previous section)*. In addition, the panel finds the AP and IB final examinations to be formulaic and predictable from year to year in their approaches and question formats. Thus, with sufficient practice in taking such examinations and enough drill on the major concepts that the examinations are likely to test, students can score well primarily by rote, without actually understanding the major concepts associated with the topics being tested.

The panel also agrees that laboratory should be a significant component of an advanced chemistry course, and assessment of laboratory skills should be a major part of the final examinations. However, the examinations reviewed for this study led the panel to conclude that the AP and IB final examinations do not adequately test understanding of laboratory techniques or the interpretation of laboratory data. In fact, it was only recently that the College Board added a question to the AP assessment that purportedly tests laboratory-based knowledge and skills. The panel notes that the final IB examination does emphasize laboratory-based knowledge and skills through assessments other than the final examination. For example, the IBO recommends that 25 percent of the time in the course be spent on investigations and projects, and that 24 percent of the final grade be awarded for this component. Additionally, all IB science examinations contain a required data analysis question on the second paper.

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[15] http://mc2.cchem.berkeley.edu/ [4/23/02].
[16] http://www.holycross.edu/departments/chemistry/discovery/ [4/23/02].

3
Quality and Content of the Learning Experience for Students

MOTIVATION FOR TAKING ADVANCED COURSES IN HIGH SCHOOL

The motivation to take an AP or IB Chemistry course comes from a wide range of external as well as internal sources. Some students simply enjoy science, and such courses offer the opportunity to learn about chemistry in greater depth than is offered by a first-year course. Other students may want to take the most rigorous program of studies offered by their high school (with less regard for the specific courses taken); others may want to develop an academic profile that is sufficiently competitive to gain admission to highly selective colleges. Still others may enroll more from parental or peer pressure than from a real desire to undertake a second course in chemistry. Students and parents increasingly may see the completion of these courses as a way to enhance a student's transcript when applying for college admission (CEEB, 1994). Parents may also believe that students in AP and IB courses have access to better teachers and more resources and that the atmosphere will be more academically focused than in other courses.

Completing an AP Chemistry course and passing the examination at the minimum level designated by individual colleges and universities may make a student eligible to earn college course credit, to place out of first-semester or first-year college chemistry, or to receive credit for completion of a general education or distribution requirement in science. Depending on the options available at the receiving institution and which option is selected, a student may be able to reduce the amount of matriculation time required for a degree, thereby saving tuition and other fees. Likewise, although the IB program was not designed to offer students opportunities for college credit, increasing numbers of colleges and universities are now offering such credit to IB students who have earned specified scores.[17]

IMPACT OF ADVANCED CHEMISTRY COURSES ON THE CURRICULUM

The availability of a selection of AP courses, including AP Chemistry, provides opportunities for students to extend their knowledge and academic skills beyond those required by first-tier courses. Despite these advantages, however, the existence of AP courses can also create curricular difficulties. The AP program of courses can have two negative effects on the

[17] If a particular college requests help, the IBO will work with the institution to develop appropriate policies related to credit and placement decisions that are based on IB examination scores (see, http://www.ibo.org [4/24/02]).

overall high school science curriculum.[18] The first of these is compression of that curriculum. Although there is variation among schools, the first-year chemistry course has generally been offered during the junior year. However, schools offering a range of AP science courses have helped foster a national shift toward offering biology to ninth-grade students and chemistry to tenth-grade students so the final 2 years of high school can be used for advanced work, including AP Chemistry. Alternatively, this shift allows for making physics available in the eleventh grade, thereby offering opportunities to focus on advanced work in the twelfth grade. The panel believes that such a shift does not coincide well with the academic preparation and intellectual skills of high school freshmen and sophomores, and therefore believes that the science concepts being taught may be too abstract for the age of many students at that level.

Curriculum compression may also prevent students from being able or electing to take the full range of first-year courses in science (biology, chemistry, and physics) during their high school years. Such students may substitute AP Biology or AP Chemistry for first-year physics, thereby leaving them with significant lacunae in their quantitative understanding of physical science concepts. This practice is contrary to the College Board's recommendation (CEEB, 1999a, p. 2). Moreover, those who take first-year chemistry as sophomores but elect not to take AP Chemistry in their junior or senior year have a 2-year hiatus between their study of high school chemistry and the time at which they enter college and major in a discipline requiring them to take general chemistry. This time lag, extended in chemistry by 1 year because of curriculum compression, can cause difficulty for some students in making the transition from high school to college chemistry.

Advanced mathematics is the gateway to advanced science, particularly advanced chemistry and physics. The College Board recommends that students taking AP Chemistry previously have completed 2 years of algebra and 1 year of geometry in addition to having taken the first-year chemistry course. To take AP Chemistry as a junior, a student must complete these mathematics prerequisites by the end of the sophomore year. Thus, these mathematics requirements also compress the mathematics curriculum. The result is that Algebra I must be completed in eighth grade. Given the small percentage of minority and rural youth who either have access to or enroll in Algebra 1 in grade 8, the need to have completed these course by the end of grade 10 in effect sets up a de facto homogenous grouping of students that continues throughout the 4 years of high school. Such tracking has serious implications with regard to which students are able to take advantage of advanced courses in chemistry and other sciences, and thereby raises issues of access and equity with regard to the benefits of college admission, credit, and placement that currently accrue to students who have such opportunities for advanced study (see Chapters 2 and 10 in the parent committee's report for more discussion of these issues).

COURSE CONTENT

The IB curriculum, in some sense, flanks the AP course, with expectations that are either higher or lower than those for AP Chemistry. The IB SL course is at a lower level than AP with respect to the content coverage; the IB HL course is at a somewhat higher level than AP in terms

[18] The issues associated with compression of curriculum are discussed in detail in Chapter 10 of the parent committee's report. The present discussion serves only to raise the issue as it may pertain to chemistry.

of the topics discussed, especially in light of the HL options. The AP curriculum deals in greater depth than IB with concepts related to kinetic molecular theory, chemical kinetics, and equilibrium. In contrast, the IB curriculum at least introduces concepts from organic chemistry, an area generally not included in the AP course. The IB courses also provide students with some opportunities to develop conceptualizations of the material presented; most such opportunities are lacking in AP courses. In IB courses, chemical concepts are often taught within a context, and examination questions are designed to assess several aspects of a concept, not merely one or two. To cite one example, enthalpy changes in solution are linked to thermal changes, as well as experimental design and sources of error. Bond dissociation energies are associated with environmental changes such as stratospheric ozone depletion. In these aspects, the IB course is broader in content and outlook than its AP counterpart. A comparison of the differences between the two approaches is summarized in Table 1.

TABLE 1. Comparison of AP and IB Chemistry Courses

AP	IB
1 level	2 levels: SL or HL
1 year	1 or 2 years for SL; 2 years for HL
Less conceptualization of topics	Deeper conceptualization of topics
Molecular-level interpretation of KMT [kinetic molecular theory]	More descriptive (macroscale) approach to KMT
More quantitative treatment of kinetics and equilibrium	Less quantitative treatment of kinetics and equilibrium, but better conceptualization of the topics than in AP
No organic chemistry, biochemistry, or environmental chemistry	Organic chemistry, biochemistry, and environmental chemistry concepts covered in SL and HL programs
Consideration of phase diagrams, colligative properties, and Nernst equation	No consideration of phase diagrams, colligative properties, and Nernst equation
Minimum of 90 minutes per week recommended (not required), preferably in one session, to be spent engaged in laboratory work	Laboratory work required, making up 25% of teaching time; required Group 4 project (student-designed research investigation) makes up 10 hours of work. (The project's intention is that students analyze a topic or problem that can be investigated in each of the science disciplines offered by a school. The topic can be set in a local, national, or international context.)

MATERIALS USED

A list of suggested textbooks is given in the *Advanced Placement Program Course Description: Chemistry* (CEEB, 1999a, 2001a). These suggested textbooks are drawn from among the textbooks that are most frequently used in introductory college chemistry courses. In many cases, especially in classes taught by inexperienced teachers, the textbook forms the basis of the AP Chemistry course. In an effort to finish the book, many of these teachers may try to cover all of the text before the May examination date. The broad scope of these textbooks contributes to an emphasis on breadth of coverage at the expense of depth of understanding.

Because of the unique structure of the IB Chemistry courses, the IBO maintains that there are no suitable textbooks that can serve as the basis for its courses. Instead, the IBO publishes and disseminates a document, *Chemistry Bibliography*, which lists general resources. It is divided into Pre-IB, Core/General, Core and Higher Level, Organic, and General/Organic Textbooks. It lists resources for each option and suggests sources for practical work (laboratories), comprehension exercises/review material, post-IB, and demonstrations, as well as periodicals and a list of data/useful sources of information (including Web sites). Teachers are encouraged to select the materials that best align with the common core and optional topics that they teach in their classrooms.

LABORATORY WORK

The average length of a high school class per day (42–58 minutes) poses a challenge with regard to the amount of material that can be presented and actually learned in advanced chemistry courses. Increasingly, schools have adopted block-scheduling options, allowing up to 90 minutes for class and laboratory sessions. Even with this additional time allotted to laboratory work, however, time can be a true barrier to meaningful laboratory activities, especially those that are investigative in nature rather than applying a confirmatory or validation approach to preexisting knowledge. Investigative laboratories can occupy large amounts of time, and the amount of time recommended by the College Board for more traditional laboratories may not be sufficient for these new paradigms and approaches. In addition, college and university chemistry courses typically have affiliated weekly 3- or 4-hour laboratory periods during which students can perform actual investigative experimentation that includes multiple trials, replications, and the examination and evaluation of varying methodologies. This raises questions about the alignment of students' AP laboratory experiences with those available to college students. The panel notes that increasing numbers of high schools are working to find innovative ways of extending opportunities for laboratory work, which the panel commends.[19] The panel applauds the College Board's clearly expressed guidelines that AP Chemistry courses need to

[19] One reviewer of this report pointed out that a serious curricular problem is the increasing tendency for high schools to condense the AP course into one semester through the use of block scheduling. The panel contends that, to benefit most from the AP Chemistry experience, students should take the course throughout an entire academic year. The panel views as counterproductive any attempt to complete the AP Chemistry course in one semester. The panel contends that the material in a college-level chemistry course contains too many concepts to be mastered in this truncated period of time. A one-semester course also does not allow the practice time needed to fully grasp what are for most high school students sophisticated chemical and affiliated mathematical concepts.

have a weekly, extended laboratory period.[20] The College Board explicitly states that "*it is not possible to complete high-quality AP laboratory work within standard 45-to-50 minute periods*" (CEEB, 1999a, p. 35) (emphasis in original). The College Board recommends that a minimum of 90 minutes weekly be spent in laboratory instruction, preferably in one session. It would be desirable to know what percentage of AP Chemistry courses follow this recommendation.

High school chemistry laboratory experiences are of mixed quality as a result of variations in resources, time available for faculty to set up and maintain laboratory experiments, and the academic background of faculty who teach these courses. When done at all, laboratory work can tend more toward verification than problem-solving investigations. The chemistry panel believes it would be desirable to avoid the former exercises and instead emphasize inquiry-based experiments. Moreover, teachers and administrators would likely pay more attention and commit more time and resources to enhancing laboratory experiences if the culminating AP examination stressed and tested for the knowledge, skills, and techniques that are gained primarily, if not exclusively, through laboratory experiences.

The IB examination has more laboratory-based questions than its AP counterpart, but still relatively few. Unlike the AP program, however, IB includes a student's laboratory grade as a component of the final course grade. It should be noted that the IB program also requires students to prepare portfolios in which they demonstrate that they have the ability to plan, design, and analyze scientific experiments. While these components of the portfolio may draw on experiences in addition to those from laboratory, they contribute to the student's development of skills and understanding of scientific procedures provided by laboratory experiences. Finally, the IB program requires teachers to submit a detailed description of the PSOW completed by all students, as well as examples of work from each individual student. Guidelines for assessing laboratory work are detailed extensively in the IB Diploma Programme Guides.

The chemistry panel notes that in 1999, the AP examination introduced a required laboratory-based question in the free-response section (CEEB, 1999b). Should this question continue to be structured so as to assess students' understanding of laboratory techniques and data acquisition, this will be a positive step. The panel believes, however, that *all* of the subparts of the laboratory-based question should be directed to laboratory techniques, experimental design, and data acquisition and interpretation, rather than to theoretical constructs. Because the AP examination contains only one question about laboratory work, including experimental techniques, an AP student could score well enough on the other parts of the examination to earn college credit without ever having undertaken any of the suggested laboratory work.

The chemistry panel heard anecdotal accounts of AP Chemistry teachers who omit or defer laboratory activities to review previous AP examinations. In such circumstances, laboratory work, if done at all, is crammed into the course after students have taken the AP examination. This deplorable practice appears to result from teachers recognizing and taking advantage of the lack of laboratory questions on the examination. Such practices disregard the validity of laboratory work as a means of introducing, reinforcing, consolidating, and amplifying chemical principles. The fact that a number of colleges and universities require proof of sufficient chemistry laboratory work before granting credit or placement out of the general

[20] The College Board recommends but does not require that students participate in particular types of laboratory experiences.

chemistry course indicates that laboratory work is a weak link in the AP course because of the variability in the way the laboratory component is administered.

In contrast, the IBO requires that teachers assess student work, with samples being sent to the IBO for moderation. The IBO allows only 2–3 hours of work to be carried out after the deadline, which prevents teachers from leaving laboratory work until the end of the course. Further, the IBO provides detailed guidelines and rubrics for assessing practical work (IBO, 2001, pp. 15-32).

CURRICULUM AND METHODS OF INSTRUCTION

Given the broad scope of the AP and IB chemistry curricula, it can logically be inferred that large components of AP and IB Chemistry courses may be taught by the traditional method of "filling the open vessel"—lecture, note taking, and assessment by recall. These practices are in stark contrast with the constructivist model of learning recommended by the National Science Education Standards (NSES) (NRC, 1996) and other recent reports (NRC, 2000b). Those studies clearly demonstrate that students learn more deeply when they develop an understanding of the material while undertaking inquiry-based, problem-centered activities. Based on the materials examined, the chemistry panel agrees that neither AP nor IB appears to emphasize such approaches to learning. Rather, the breadth of topics included in AP and IB course outlines and syllabi indicates that far too much emphasis is being placed on covering a large body of information deemed necessary for success on the examination.[21]

The kinds and levels of questions that appear on both the AP and IB examinations reinforce the emphasis on broad but shallow coverage of topics. Thus, an overarching, largely unintended, but nevertheless real and perverse effect is that the exam-driven nature of both programs may cause the development of intellectual curiosity in students to fall victim to the pace of the courses—all in the name of "rigor."

The chemistry panel also is concerned that the current system of basing the AP Chemistry course on typical or average general chemistry courses (using information gathered through surveys of chemistry departments at colleges and universities that receive the greatest number of AP candidates [see, e.g., CEEB, 1999a]) precludes incorporating emerging best practices that are beginning to appear in some college-level chemistry courses. Further, because AP courses are based on average college general chemistry courses, these changes will not be reflected in AP courses until changes in college-level chemistry become widespread,.

A far better model would be to base AP Chemistry courses on best practices in the teaching of college chemistry, even if the resulting course were less similar to typical college courses than is now the case. The panel notes that neither the AP nor IB Chemistry course as yet accurately reflects recent efforts to restructure and change teaching and learning in general chemistry at the college/university level. Among such changes are emphases on "less is more" in terms of course coverage, a wider variety of assessment techniques, small-group and inquiry-based learning, and inquiry-based laboratories (National Research Council, 1999). *The AP and IB*

[21] The panel notes that the IB's IA component is not taught in a traditional manner and is consistent with the recommendations and emphases for teaching and learning in the NSES.

Chemistry courses also do not yet recognize the increasingly interdisciplinary nature of modern chemistry; its incorporation of highly important related fields, such as materials science and biochemistry; and the opportunities presented by such fields to teach related chemical concepts in a contextual manner. It is important to note that the College Board established the Commission on the Future of the Advanced Placement Program to make recommendations regarding the future of the AP program. The commission recommends in its recent report, *Access to Excellence: A Report of the Commission on the Future of the Advanced Placement Program* (Commission on the Future of the Advanced Placement Program [CFAPP], 2001), that leaders in the subject disciplines, pedagogy, and research be engaged to ensure that current reforms and best practices are reflected in AP examinations

QUALITY CONTROL

To be successful, an AP Chemistry course should be initiated only after a school's administrators and faculty have carefully considered the valid reasons for offering such a course. Such consideration should be followed by a thorough analysis of the resources—personnel, facilities, and supplies—available at the school to support the course. While these considerations would appear obvious, high schools are not bound by them (CEEB, 1999a). A school can offer an AP Chemistry course by administrative fiat, even when the personnel, facilities, and supplies available for the purpose are not up to the expectations of the College Board, as noted in the Acorn Book for chemistry. It is not unreasonable to expect the College Board to exercise some control over where AP Chemistry courses are offered and who teaches them. It is therefore encouraging to note that *Access to Excellence*, completed after the chemistry panel had conducted its deliberations, contains the recommendation to develop and implement standards for AP programs in schools and school systems, for AP teachers, and for professional development workshops and institutes for AP teachers. *Access to Excellence* also recommends that the College Board take a more proactive approach to leading educational reform by changing the emphasis of the AP program from one of replicating typical college courses to one of emulating best practices in the discipline. The report further recommends that leaders in the subject disciplines, pedagogy, and research be engaged to ensure that current reforms are reflected in AP examinations. The chemistry panel endorses these recommendations fully and is pleased to learn that the College Board is willing to serve as a forum and vehicle for stimulating educational reform.

The College Board's expectations for teacher qualifications are explicit: "if the objectives of a college-level general chemistry course are to be achieved, the teaching should be done by a teacher who has completed an undergraduate major program in chemistry including at least a year's work in physical chemistry" (CEEB, 1999a, p. 3). However, the College Board does not have a means of verifying that AP Chemistry teachers have these minimum qualifications or certifying them as competent to teach AP-level courses and associated laboratory activities. This lack of oversight and control is in addition to the College Board's lack of a mechanism for determining whether a school has adequate facilities and supplies before allowing it to offer an AP Chemistry course. Nor does a mechanism exist for making such a determination once an AP Chemistry course is being taught, or for preventing a school from continuing to offer the course if the school is found lacking until the shortcomings are addressed. The Commission on the Future of the Advanced Placement Program (2001) does not recommend certification of schools or teachers, but recommends instead that the College Board develop and disseminate AP quality standards for teachers, schools, and school systems. The commission (2001) also recommends that the College Board undertake a rigorous and systematic program of research to validate that (1) AP examinations actually test what is covered in the corresponding college courses and (2) students who earn specific scores on AP examinations have indeed mastered subject matter at a level equivalent to that of students who take these courses in college.

In contrast, before a school is authorized to offer an IB Chemistry course, the school must be authorized to offer the complete IB Diploma Programme. One factor in this authorization process is an evaluation of the qualifications of the people who will teach the individual IB courses. In the sciences, a school that is seeking authorization also must demonstrate a plan for an acceptable set of laboratory activities relative to its resources. Sample laboratory reports must be sent periodically to IBO headquarters for critical review (IBO, 1999). It should be noted, however, that IB program administrators provide minimal oversight to ensure that the program standards are maintained over time. However, assistant examiners who encounter schools experiencing difficulties with the program try to inform the IBO of these situations. Further, in the sciences, ongoing evaluation of a school's program continues through the IBO's moderation of sample laboratory reports and teachers' PSOWs that are submitted annually. Feedback is provided to the schools and teachers to promote improvements.

Students cannot take the IB examination without having taken the course. In contrast, students can register to take the AP Chemistry examination without ever having taken an AP course, although this is not typically the case. The obverse is also true: students who take an AP Chemistry course are not required by the College Board to take the examination. The College Board tracks only those students who take the examination. Although it does not have precise data about the number of students enrolled in AP courses, the College Board estimates that approximately 63 percent of students who are taking a course designated as AP sit for the AP examination in that subject. This, however, is the estimate for AP courses *in toto*. Currently, data are not available from the College Board for individual subject areas, such as chemistry. Consequently, the percentage of those students taking an AP Chemistry course who do not take the AP exam is not known.[22] Accordingly, the panel believes that statements by the College Board about the quality of AP Chemistry courses are suspect because they fail to account for the many AP courses nationwide in which large numbers of students may not take the examination. In addition, the AP examination results are not available until after the end of the academic year. Thus the final grade received in an AP Chemistry course is not specifically linked with the student's performance on the AP examination. Furthermore, since AP examination scores are not available until students have completed the course, there can be no grade-related consequence in the course from not taking the AP examination or, if taken, from doing poorly on the examination.

The panel also notes that commercial vendors, some of them linked with a university (e.g., the Michigan State University program), now offer AP courses on the Internet to individual students. This new development allows students who pay the necessary fees to take an AP course independently of whether their school offers an AP course in the same subject. Internet-based courses are self-pacing. The pace and calendar are established by the examination date,

[22] The College Board recently began to gather such data from school AP coordinators.

should the student choose to take the examination. In courses with a laboratory component, such as chemistry, arrangements for laboratory work may be irregular. In some situations, the laboratory work is done at a nearby campus or high school during weekends or other periods when several laboratory experiments are conducted in an intense burst of work. In these circumstances, the timing of laboratory activities may not correlate well with the chemical principles being studied at that point. Simulations of laboratory experiments are also used, although current simulations offer no opportunity for students to gain facility and dexterity in the proper manipulation and use of laboratory equipment.

COURSE CONTENT AND EXAMINATIONS

The 75 multiple-choice questions on the AP Chemistry examination (Section I) match closely the objectives stated in the Acorn Book for an AP Chemistry course. Despite the rather long list of chemical topics and concepts to be included in the AP curriculum, Section II of the examination asks questions evaluating a more limited set of topics. In addition, the panel finds that the topics tested in both parts of the examination are rather predictable from year to year and formulaic in the way in which the concepts are queried,[23] especially in Section II. Certain topics and the style of questions addressing them change little from year to year. One example is the standard question in Section II, Part B of the AP examination that is related to reactions and writing of their affiliated chemical equations. (Although this question could perhaps be described as a laboratory-based question, the panel believes that students can answer the question correctly by sheer rote memory without ever having done any of the laboratory work.) Given this type of predictability in the examination's coverage from year to year, together with teachers who are very familiar with the general content and structure of the test, students may be able to earn high scores on the examination without actually having mastered all the material. This is especially true when students are given a choice of which questions to answer in Section II.

Some of the IB questions are identical in content to the chemical systems described and covered in the syllabus, thus requiring only rote learning with little mastery or understanding. In fact, there is an injunction from the IBO to IB instructors against using chemical systems other than those on the examination when teaching a given topic.

AP examinations ask less than IB exams about the application of concepts, especially with respect to new contexts or chemical systems. There is heavy emphasis on algorithmic solutions, rather than the extension or application of concepts to new, unfamiliar but equivalent situations. Few of the questions test students' abilities to predict or explain observations. For example, students could successfully write and balance sets of chemical equations with little understanding of the principles of chemical reactivity involved and no knowledge of the associated phenomena. The tests assess primarily the acquisition of information, as opposed to analyzing students' understanding, application, and extension of concepts. The examinations thus do little to encourage inquiry-based learning.

The chemistry panel drafted samples that demonstrate how questions taken from the 1999 AP Chemistry examination could be modified to accomplish several objectives: requiring

[23] In large part, this level of predictability is based on the Educational Testing Service's emphasis on and close monitoring of exams to maximize their reliability from year to year.

critical thinking, combining qualitative and quantitative aspects of a chemical system within a given question, and applying concepts to chemical systems and situations not previously encountered. The suggested modified questions are presented in Appendix D. By using the approaches illustrated by these types of questions, the AP and IB programs would encourage teachers to teach in less algorithmic ways and students to learn in a different, more inquiry-based manner as recommended by the NSES.

The AP examinations have yet to address the shift in increasing numbers of introductory college/university chemistry courses toward including applications in biochemistry, materials science, or environmental chemistry. The IB program and examinations include some applications in biochemistry and environmental chemistry, but still lack attention to materials science.

4
Teachers and Teaching

TEACHER PREPARATION AND PROGRAM QUALITY

It should be self-evident that to teach a subject well requires at least a solid academic background in and working knowledge of the subject matter being taught. In addition to knowing the subject matter, however, a skilled chemistry teacher has the pedagogical insights necessary to present chemical concepts most effectively to different students. Clearly, no less should be expected of those who teach AP or IB Chemistry. To provide a chemistry course in line with the criteria for an advanced study course in chemistry at the high school level noted in Chapter 2, those who teach such a course must be adequately prepared. *The chemistry panel takes this minimum level of preparation to mean a B.S. or B.A. degree in chemistry that includes a full year of physical chemistry.* This view of the panel is congruent with that of the College Board, which recommends that an AP Chemistry teacher have completed an undergraduate major in chemistry, including a year's work in physical chemistry (CEEB, 1999a, 2001a). This expected level of preparation also is consistent with recommendations from the National Science Teachers Association (1998) and the finding of the National Commission on Mathematics and Science Teaching for the 21st Century (NCMST, also known as the Glenn Commission) that "the most consistent and powerful predictors of higher student achievement in mathematics and science are (a) full certification of the teacher and (b) a college major in the field being taught" (2001, p. 18). *The members of the chemistry panel would extend this recommendation to state that high school teachers who offer advanced courses in chemistry should also have earned an MA. or M.S. degree in chemistry, although the panel recognizes that realizing this goal would be difficult given the current and expected future shortages of science teachers*.

The reality is, however, that there is enormous variability in the subject matter preparation and backgrounds of chemistry teachers in the United States. There are well-prepared and experienced teachers who teach AP Chemistry at the level expected by the College Board. Yet despite growing demands for AP and IB Chemistry courses in more schools and in more states, the pool of teachers actually qualified to teach the courses is small (Blank, 1992). As the number of schools desiring to offer these courses increases while the pool of qualified teachers fails to keep pace, a point will be reached at which the ability of many schools to offer quality AP or IB Chemistry courses will be seriously compromised. If such is the case, the very credibility of many AP and IB Chemistry courses may be called into question.

Within the past decade, a significant effort has been made nationally to change the way in which chemistry and other science teachers are certified (National Research Council, 1997). A shift in an increasing number of states has led to the requirement that teachers have either a college major or a defined number of designated academic credits in the subject matter of the field to be taught (National Science Board, 1998). Currently, 29 states require that high school teachers have a degree in the subject matter they teach, rather than an education degree. As of 1993, 63 percent of all grade 9–12 teachers of science had a major in science, while nearly three-quarters (72 percent) had a major in science or science education. Although encouraging, these data fail to take into account the fact that two-thirds of all states permit a "broad-field" secondary science certification, which certifies teachers to teach across a range of science subjects (chemistry, physics, biology, and earth or space science). In at least eight states, the broad-field certification permitting teachers to teach more than one science encompasses the same number of semester credit hours as the states' single-science certification (Blank, 1992). Of the nearly 65 percent of those with a major in science who are teaching science in grades 9–12, almost one-third are doing so under a broad-field secondary science certification. More than half of teachers teaching physical science classes (chemistry, physics, earth science, or space science) do not have an academic major or minor in any one of the physical sciences (NRC, 2000a, pp. 50-51). Additionally, data from the Council of Chief State School Officers (1997) indicate that approximately half (53 percent) of those teaching chemistry do so as their primary teaching assignment.

These data raise serious questions concerning the adequacy of academic background preparation for many of those who teach even the first-year course in chemistry, let alone advanced courses in the subject. Additional research is required to document the relationship between teaching effectiveness in introductory courses and student performance in advanced courses. However, it appears logical that students in first-year courses who are taught by underprepared chemistry teachers are more likely to lack the foundational concepts and skills needed to complete advanced study work successfully, as compared with students whose teachers have mastered content knowledge and effective pedagogical approaches to teaching chemistry. The effect is compounded if the same teachers who teach the first-year courses inadequately are assigned to teach the advanced study chemistry course as well.

TEACHER SELECTION, DEVELOPMENT, AND SUPPORT

Many high schools have only one chemistry teacher. As noted, this individual also is likely to teach other science courses (CCSSO, 1997). For an AP Chemistry teacher in this situation, the AP assignment increases the number of required course preparations as well as the number of different laboratory preparations, along with their attendant difficulties. If this teacher also teaches nonchemistry courses (biology or physics, for example), he or she must remain informed about developments in those subject areas as well. Perforce, this reduces the amount of time the teacher has to remain abreast of developments in chemistry and thus adequately prepared for the AP Chemistry course.

As noted earlier, the chemistry panel believes strongly that an AP or IB Chemistry course cannot be taught appropriately by an instructor whose background in the content of the subject is insufficient. For example, it is the panel's position that a B.S. in science education does not adequately prepare an individual to accept an AP or IB Chemistry assignment without completing further coursework in chemistry. This view, too, is consonant with the recommendation of the College Board that a teacher of AP Chemistry have an undergraduate major in chemistry.

Data are unavailable about the exact qualifications and academic preparation of current AP or IB Chemistry teachers. The way in which those who teach AP or IB Chemistry are selected or assigned to do so also appears to vary considerably among schools. First-year teachers, veteran teachers, and those whose experience levels fall anywhere between these extremes may be given this assignment. In many school districts, seniority appears to play a significant role in the selection—even when the individual selected through seniority is not as well prepared as less senior colleagues.

PROFESSIONAL DEVELOPMENT

The College Board offers a variety of professional development opportunities to support AP Chemistry teachers. Such support includes summer institutes, workshops, and seminars. New AP Chemistry teachers are invited to attend 1- or 2-week summer institutes to learn the rudiments of teaching an AP course, its laboratory component, and the College Board's expectations for the course. There are also 1-day seminars held regionally to update AP Chemistry teachers on teaching developments and changes in the AP courses or examinations. In addition, teachers from schools that participate in AP courses are invited to videoconferences where they can learn from those who develop AP examinations and review AP courses. And an online discussion group is available for AP Chemistry teachers to share syllabi, compare teaching strategies, and discuss substantive issues related to the content of the course or chemistry in general. Frequently, college instructors participate in these discussions, providing a forum for discussions between high school and college faculty around the teaching of chemistry. Participation in the regional workshops and online discussion groups is free.

AP summer institutes are not free. The College Board supports some of them, and schools sometimes bear the costs for their teachers to attend, but not always. Absent such support, the length of the institutes (1 or 2 weeks) and their associated costs (travel, registration, meals, housing), if not covered by a school, district, or state, are a disincentive for teachers to attend, particularly when such attendance is voluntary and outside of paid contract hours. The structure and format of these institutes vary. Most offer sessions on pedagogy and an orientation to the AP Chemistry course, its laboratory, and the AP examination. However, the institutes do not address the major shortcoming of some AP teachers noted above—an inadequate background and the lack of a deep understanding of the chemical principles necessary to teach the AP course material successfully. As noted above, a deep conceptual understanding of the content and unifying concepts of chemistry is a critical requirement for effective teaching in the discipline.

The panel encourages the College Board to provide a substantial and sustaining level of guidance and oversight for the preparation of teachers, student learning, and support by school systems so that high school AP Chemistry courses can be of the high quality espoused by the College Board. Such efforts might include expanded and enhanced support for teachers, the establishment of creative partnerships for teacher professional development, and the development of comprehensive services for schools and school systems to help them design and implement successful AP programs. Recommendations contained in *Access to Excellence* support the panel's views in this regard (CFAPP, 2001, pp. 9-11):

- Provide unconditional support for preparing teachers, schools, and school systems to offer high quality AP programs—teachers' needs are paramount (Recommendation 2).
- Expand and enhance direct support for teachers (Recommendation 2a).
- Develop creative partnerships and tools to enhance teacher professional development (Recommendation 2b).
- Promote the development of online support for teachers (Recommendation 2c).
- Develop comprehensive services to help administrators, principals, and counselors design and implement successful AP programs (Recommendation 2d).

The IB program also holds professional development workshops for teachers. All new IB teachers are required to attend one of these workshops, preferably before they begin teaching. Most IB experimental science teachers agree that these workshops are critical for new teachers because of the complexity of the Group 4 subject syllabi and the requirements for the PSOW and the IA. IB teacher workshops for the experimental sciences frequently focus on designing laboratory experiences that will enable students to meet the specific IA criteria. Additionally, these workshops help new teachers develop strategies for managing the recordkeeping activities that are demanded by the IBO. International Baccalaureate of North America (IBNA) is responsible for conducting these workshops, but they most often are designed and led by experienced IB teachers. It is important to note that these workshops often are held in remote locales, making travel to attend them expensive and difficult, and thereby reducing the number of attendees.

5
Outcomes of AP and IB Chemistry Courses

USE OF AP AND IB CHEMISTRY EXAMINATION SCORES BY COLLEGES AND UNIVERSITIES

Colleges and universities vary significantly in the ways in which they handle credit and placement decisions based on AP and IB Chemistry examination scores (CEEB, 1994). The options include the following:

- No advanced placement or college credit granted
- Advanced placement granted, but no credit given
- College credit given, but no advanced placement
- College credit and advanced placement given

Some states legislate the awarding of particular levels of college or university credit to students with specified minimum AP scores. Statewide higher education systems in some states have well-articulated, shared policies among their institutions regarding credit and advanced placement for students meeting system-wide AP score standards; systems in other states leave the matter to the discretion of the institution or individual departments. Examples of the credit and advanced placement practices listed above are cited in the *College and University Guide to the Advanced Placement Program* booklet from the College Board (1994).

DEGREE TO WHICH AP AND IB CHEMISTRY PROGRAMS REFLECT EMERGING KNOWLEDGE OR APPROACHES IN CHEMISTRY

The consensus opinion of the chemistry panel is that neither the IB nor AP examinations reflect several significant recent developments in the focus of chemical research and in the teaching of chemistry at the college/university level. Practice in the field of chemical research has shifted to incorporate work at the intersection of chemistry with disciplines that in the past have been viewed as different from mainstream chemistry—biology, engineering, materials science, and environmental science. Major research programs now exist in materials science, bioinorganic and biopolymer chemistry, atmospheric chemistry, and nanotechnologies. To prepare students to understand such interdisciplinary research, increasing numbers of college and university general chemistry textbooks and laboratory curricula are incorporating organic and biochemical moieties to teach general chemical principles, thus breaking down the artificial barriers among subdisciplines and using these developments as opportunities to teach related chemical principles in a more contextual manner (see, e.g., *ChemConnections* modules;[24] *Chemistry: Structure and Dynamics* [Bodner, Rickard, and Spencer, 1999]; *The Chemical World: Concepts And Applications,* 2nd edition, [Moore, Stanitski, Wood, Kotz, and Joest, 1998]; Landis and Peace, [1998]); and the *Discovery Chemistry* curriculum from the College of the Holy Cross[25]). These textbooks and laboratory experiments also cover exciting new developments in materials science, such as those developed at the University of Wisconsin, Madison.[26] Because they offer a different focus and context for introductory chemistry courses, the authors of these texts have made the difficult decisions about what subject matter to deemphasize so that faculty will have sufficient time to teach the concepts these texts emphasize.

The AP topic outline and the associated examination do not yet reflect such changes. Although the College Board introduced aspects of organic chemistry into the AP Chemistry course in 1997, no questions about organic chemistry or biochemistry have yet appeared on the national examination. In contrast, the IB program does include some organic chemistry, biochemistry, and environmental chemistry, in part because it reflects a broader, international curricular base whereby students learn chemistry through a more holistic, spiral approach. Questions that are related to chemical principles of materials science are not part of either the IB or AP examinations.

The chemistry panel believes that to be effective, advanced courses in chemistry must reflect recommendations in the areas of content, pedagogy, and assessment incorporated in the NSES. Current practices in the way AP and IB Chemistry programs assess student learning on the written final examinations do not appear to be responsive to the changes in emphasis suggested by the NSES for assessment, teaching, professional development, or content. The AP and IB examinations continue to assess primarily the acquisition and retention of information as distinct from understanding, applications, and extensions of concepts. The exams offer little reinforcement of inquiry-based learning in these examinations. As noted above, the IB program does meet many of the NSES criteria through its IA protocol (e.g., portfolio assessment, use of rubrics, data analysis questions). The chemistry panel urges AP and IB staff and teachers to compare their current practices in instruction and testing against the changing emphases articulated in the NSES and the related recommendations of the American Chemical Society in *Chemistry in the National Science Education Standards* (1997) (e.g., emphasis on unifying concepts; use of inquiry-based teaching; cooperative and collaborative learning strategies; and incorporation of organic, environmental, and biochemistry topics). The AP program is silent with respect to recommending or supporting any particular teaching methodology. Its approach is outcome driven, with success being measured by examination scores, which in turn are content- rather than concept driven. The chemistry panel is disappointed that AP, as the predominant national-level advanced study program in the United States, has apparently not considered as part of its responsibilities the promotion of approaches and innovations in teaching and learning that are more aligned with recommendations in the NSES.

At the same time, however, the College Board is not likely to be successful in making such changes if it does so unilaterally. The College Board will require overt and explicit support and encouragement for such reforms from professional societies, from college and university

[24] http://mc2.cchem.berkeley.edu/ [4/23/02].
[25] http://www.holycross.edu/departments/chemistry/discovery/index.html [4/23/02].
[26] See http://mrsec.wisc.edu.

faculty who teach introductory chemistry courses, and from college admission offices that are prepared to accept students who take these kinds of revised courses.

SUCCESS IN CHEMISTRY BEYOND THE INTRODUCTORY LEVEL

Given the variability of AP and IB courses as implemented in different high schools, as well as the variability among college chemistry courses at different institutions, the success of individual AP students in higher-level college courses is also likely to vary considerably. During the past 25 years, several studies (all conducted under the auspices of the College Board)[27] have attempted to examine whether students who take AP courses in high school are successful in college and whether they are as well prepared as their non-AP counterparts for second- and third-level college courses in the discipline. While the data appear to indicate that AP students on average are well prepared, the methodology used in these studies makes it difficult to ascertain whether student success can be attributed to the AP program or to other factors, such as the colleges they attend, the classes they take, or their own academic backgrounds and abilities. The panel therefore takes a cautious approach to accepting the findings of these studies.

[27] These studies are published as in-house documents only. They have not been peer reviewed and do not appear in any scholarly publications, such as professional journals. This issue also is addressed in Chapter 10 of the report of the parent committee.

6
Summary and Recommendations

The AP and IB courses now being offered are taught effectively according to the expectations of the College Board and the IBO in some, but by no means all, schools. The content of the courses is bound inextricably to the nature and corpus of questions on the affiliated AP and IB examinations, which the chemistry panel finds to be flawed, as described in previous chapters. It should be noted that there is a growing tendency for IB Chemistry classes in the United States to be offered as 1-year courses, in order to conform with U.S. high school timetables. This practice contrasts with that of other countries, where virtually all IB Chemistry classes are taught over 2 years. Thus, in many IB Chemistry courses offered in the United States, too much information may be crammed into the course for the time available. The following sections summarize the panel's findings and recommendations regarding the AP and IB Chemistry courses and examinations and the qualifications and professional development of those who teach the courses.

FINDINGS AND RECOMMENDATIONS REGARDING THE AP AND IB COURSES AND EXAMINATIONS

1. **The chemistry panelists agree that advanced study options in high school chemistry should not necessarily be tied to the potential for earning college/university credit. The chemistry panel views these as two separate issues:**

   (a) The panel members are unanimous in agreeing that advanced study of chemistry at the high school level should provide students with a coherent, rigorous course that promotes further scientific literacy and prepares students to become part of a highly technological workforce, regardless of whether they continue studying chemistry at the tertiary level.

   (b) An advanced chemistry course that meets criterion (a) should be organized and delivered such that it would be equivalent to the two-course college/university general chemistry sequence, and such that college credit could be sought based on passing the placement examination that is administered by college or university departments of chemistry. That is to say, advanced study in chemistry need not be based on AP or IB. Indeed, many of the nation's top high schools for mathematics and science offer advanced courses that are neither AP- nor IB-based. Other legitimate alternatives should be explored.

2. Institutions awarding AP examination–based course credit or advanced placement should consider doing so only for a grade of 4 or 5, not for a grade of 3. The College Board is currently conducting studies on the validity of a grade of 3 for the awarding of college credit, and the panel applauds this effort. However, until that study is complete, it remains unclear whether students who have earned a score of 3 have achieved sufficient understanding of the subject matter at a level comparable to college courses to merit credit and placement out of the introductory course.

3. The chemistry panel recommends that to be effective, advanced courses in chemistry must reflect recommendations in the areas of content, pedagogy, and assessment contained in the National Science Education Standards (NRC, 1996).

FINDINGS AND RECOMMENDATIONS REGARDING THOSE WHO TEACH AP AND IB CHEMISTRY COURSES

1. The chemistry panel recommends that to be a qualified AP or IB teacher, the teacher must have a B.S. or B.A. degree in chemistry (which includes a two-semester physical chemistry course sequence with laboratories), and preferably an M.A. or M.S. degree in chemistry. The chemistry panel does not view a B.S. in science education as being adequate preparation for these teachers, nor does the College Board.

2. A qualified advanced study chemistry instructor should have experience with effective current and emerging approaches to chemistry teaching and assessment in the subject and their applications to the AP and IB Chemistry courses.

3. The qualified AP or IB Chemistry teacher should have a working familiarity with teaching technologies (e.g., Web, electronic media, laboratory instrumentation) and their appropriate uses.

4. There should be required periodic, funded professional development opportunities, including content instruction, research participation, and pedagogy workshops, for teachers of advanced courses in chemistry. This recommendation is consonant with the Glenn Commission's description of what constitutes professional development: "a planned, collaborative educational process of continuous improvement for teachers that helps them to do five things: (1) deepen their knowledge of the subject(s) they are teaching; (2) sharpen their teaching skills in the classroom; (3) keep up with developments in their fields and in education generally; (4) generate and contribute new knowledge to the profession; and (5) increase their ability to monitor students' work so they can provide constructive feedback to students and appropriately redirect their teaching" (NCMST, 2001, p. 18).

5. Professional development opportunities, such as the experience of teaching courses or laboratories at colleges or universities and undertaking original research in industry, at government laboratories, or in collaboration with college faculty, would be particularly valuable for AP and IB Chemistry teachers. High school–system personnel policies

should encourage rather than inhibit such professional development activities during the academic year.

6. **AP and IB Chemistry teachers can profit from discussions with each other. School districts and schools should find ways to initiate and sustain such conversations and to share them with a wider audience. Communication about areas of common interest between chemistry faculties in high schools and those teaching general chemistry in institutions of higher education would be extremely helpful for both communities (see also the recommendations under Vision 4 in *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* [NRC, 1999]).**

7. **AP and IB Chemistry teachers should be participating members of professional organizations such as the National Science Teachers Association and the American Chemical Society's Division of Chemical Education. Through such participation, teachers gain a sense of belonging to a community of professionals who are similarly inclined to excel in their teaching. They gain access to colleagues and resources that would have been largely inaccessible without membership.**

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Appendix A
Biographical Sketches of the Chemistry Panel Members

Dr. Conrad Leon Stanitski (liaison) is a Professor of Chemistry and Chair of the Chemistry Department at the University of Central Arkansas. His principal focus is on inorganic chemistry and on general chemistry for science and nonscience majors. He currently serves as the Chair-Elect of the American Chemical Society's (ACS) Division of Chemical Education and the ACS Committee on Education, has directed numerous ACS teacher training institutes, is an ongoing National Science Foundation (NSF) proposal reviewer, and has been an invited speaker at numerous international institutions. Dr. Stanitski has published many highly regarded textbooks in the field, including *Chemistry in Context: Applying Chemistry to Society*, *The Chemical World*, *Chemistry in the Community*, *Chemical Principles with Qualitative Analysis*, and *Chemistry for Health-Related Sciences: Concepts and Correlations*. Dr. Stanitski received his B.S. from Bloomsburg State College in Science Education, his M.A. from the University of Northern Iowa in Science Education, and his Ph.D. from the University of Connecticut in Inorganic Chemistry.

Dr. Arthur B. Ellis is Meloche-Bascom Professor of Chemistry at the University of Wisconsin at Madison and a Team Leader of the NSF-funded National Institute for Science Education. In addition to receiving numerous teaching awards, Dr. Ellis is currently involved in the creation of innovative instructional materials that integrate materials science into the chemistry curriculum. His research on the electro-optical properties of semiconductor interfaces has led to the development of new classes of online chemical sensors. He is currently serving a 2-year appointment to the National Research Council's (NRC) Committee on Undergraduate Science Education. Dr. Ellis received his Ph.D. from the Massachusetts Institute of Technology in Inorganic Chemistry.

Dr. Patricia A. Metz is an Associate Professor and Co-coordinator of General Chemistry at the University of Georgia. She specializes in the teaching and learning of chemistry and conducts research on curriculum development, instructional design, conceptual understanding, and assessment. She is responsible for the development of original guided-inquiry biochemistry and general chemistry laboratory classes for both chemistry and nonchemistry majors. Dr. Metz has published several articles related to instructional methods and diagnostic techniques. She received her Ph.D. from Purdue University in Chemistry Education.

Mr. John C. Oliver is a science teacher and department chair at Lindbergh High School in Saint Louis, Missouri, where he has taught a range of biology and chemistry classes, including both AP and IB Chemistry. His teaching efforts have been recognized by such awards as the

Woodrow Wilson National Fellowship and local and regional high school teaching awards from ACS. Mr. Oliver actively pursues a variety of enrichment coursework in such fields as physics, chemistry, laboratory techniques, and chemistry education and is a member of numerous professional organizations. He received his M.A.T. in science education from Webster College in Saint Louis and an A.B. in Zoology from the University of Missouri at Columbia, with a minor in Chemistry.

Mr. David Pysnik is a chemistry instructor at Sidney Central Schools in Sydney, New York. He teaches the New York Board of Regents Chemistry, which is similar in content to the AP program, but he does not teach AP Chemistry. Mr. Pysnik focuses on teaching through a research-based approach and has worked as a research associate at Ithaca college for the last 20 summers. He has developed mobile laboratory programs and has won the Catalyst Award from the Chemical Manufacturers Association, the Tandy Technology Scholars Award, the ACS Northeast Regional Award in High School Chemistry Teaching, and the Presidential Award for Excellence in Science and Mathematics Teaching. Mr. Pysnik received his B.S. from Juniata College and his M.S. from Indiana University.

Dr. A. Truman Schwartz is DeWitt Wallace Professor of Chemistry at Macalester College, where he previously served as Chair of the Chemistry Department and Dean of Faculty. His research interests include chemical education; physical chemistry of proteins, other biological macromolecules, and biological membranes; and calorimetry. Professor Schwartz has been honored with numerous teaching awards in chemistry at the college, state, and national levels. He is a member of ACS and the National Science Teachers Association, and a fellow of the American Association for the Advancement of Science. He received an M.A. at Oxford University as a Rhodes Scholar and a Ph.D. in physical chemistry from the Massachusetts Institute of Technology.

Dr. Glenda M. Torrence is a Science Resource Teacher at Montgomery Blair High School in Maryland, where she is actively involved with curriculum development for new and preexisting courses, interdisciplinary cooperation with the mathematics and technology departments, and the implementation of assessment methodologies for the chemistry department. She has taught chemistry courses at the University of Maryland at College Park and was nominated for the Presidential Teaching Award. Dr. Torrence received her Ph.D. in Physical Chemistry from the State University of New York at Buffalo.

Appendix B
Charge to the Chemistry Panel from the Parent Committee

Charge to the Parent Committee and Content Panels: The charge to the Committee is to consider the effectiveness of, and potential improvements to, programs for advanced study of mathematics and science in American high schools. In response to the charge, the committee will consider the two most widely recognized programs for advanced study: the Advanced Placement (AP) and the International Baccalaureate (IB) programs. In addition, the committee will identify and examine other appropriate curricular and instructional alternatives to IB and AP. Emphasis will be placed on the mathematics, physics, chemistry, and biology programs of study.

Charge to Content Panels: The content panels are asked to evaluate the AP and IB curricular, instructional, and assessment materials for their specific disciplines.
Below is a list of questions that the content panels will use to examine the curriculum, laboratory experiences, and student assessments for their specific subject areas. The content panels will use these questions to issue a report to the Committee about the effectiveness of the AP and IB programs for educating able high school students in their respective disciplines. In answering these questions, the content panels should keep in mind the Committee's charge and study questions.
The panels should focus on the following specific issues in advising the Committee:

I. CURRICULAR AND CONCEPTUAL FRAMEWORKS FOR LEARNING

Research on cognition suggests that learning and understanding are facilitated when students: (1) have a strong foundation of background knowledge, (2) are taught and understand facts and ideas in the context of a conceptual framework, and (3) learn how to organize information to facilitate retrieval and application in new contexts (see, for example, NRC, 2000b, handouts in packet).

1. To what degree do the AP and IB programs incorporate current knowledge about cognition and learning in mathematics and science in their curricula, instructions, and assessments?
2. To what degree is the factual base of information that is provided by the AP and IB curricula and related laboratory experiences adequate for advanced high school study in your discipline?
3. Based on your evaluation of the materials that you received, to what extent do the AP and IB curricula and assessments balance breadth of coverage with in-depth study of

important topics in the subject area? In your opinion, is this balance an appropriate one for advanced high school learners?

4. Are there key concepts (big ideas) of your discipline around which factual information and ideas should be organized to promote conceptual understanding in advanced study courses (e.g., Newton's Laws in physics)? To what degree are the AP and IB curricula and related laboratory experiences organized around these identified key concepts?
5. To what degree do the AP and IB curricula and related laboratory experiences provide opportunities for students to apply their knowledge to a range of problems and in a variety of contexts?
   To what extent do the AP and IB curricula and related laboratory experiences encourage students and teachers to make connections among the various disciplines in science and mathematics?

II. THE ROLE OF ASSESSMENT

Research and experience indicate that assessments of student learning play a key role in determining what and how teachers teach and what and how students learn.

1. Based on your evaluation of the IB and AP final assessments and accompanying scoring guides and rubrics, evaluate to what degree these assessments measure or emphasize:
   a) students' mastery of content knowledge;
   b) students' understanding and application of concepts; and
   c) students' ability to apply what they have learned to other courses and in other situations.
2. To what degree do the AP and IB final assessments assess student mastery of your disciplinary subject at a level that is consistent with expectations for similar courses that are taught at the college level?

III. TEACHING

Research and experience indicate that learning is facilitated when teachers use a variety of techniques that are purposefully selected to achieve particular learning goals.

1. How effectively do the AP and IB curricula and assessments encourage teachers to use a variety of teaching techniques (e.g., lecture, discussion, laboratory experience and independent investigation)?
2. What preparation is needed to effectively teach advanced mathematics and science courses such as AP and IB?

IV. EMPHASES

The *National Science Education Standards* (NRC, 1996) and the NCTM Standards (NCTM, 2000) propose that the emphases of science and mathematics education should change in particular ways (see supplemental materials).

1. To what degree do the AP and IB programs reflect the recommendations in these documents?

V. PREPARATION FOR FURTHER STUDY

Advanced study at the high school level is often viewed as preparation for continued study at the college level or as a substitute for introductory-level college courses.

1. To what extent do the AP and IB curricula, assessments, and related laboratory experiences in your discipline serve as adequate and appropriate bases for success in college courses beyond the introductory level?
2. To what degree do the AP and IB programs in your discipline reflect changes in knowledge or approaches that are emerging (or have recently occurred) in your discipline?
3. How might coordination between secondary schools and institutions of higher education be enhanced to optimize student learning and continued interest in the discipline?

Appendix C
Background Materials Provided to the Panel

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Appendix D
Suggested Modifications of Examination Questions

This appendix presents examples of the chemistry panel's suggested modifications to the questions on the AP Chemistry 1999 examination, Section II, to make the questions more contextual; to probe more carefully the depth of student understanding; to seek to assess higher-order thinking skills; to require the applications of chemical principles in an enlarged or new context; and to enjoin students to link concepts to chemical systems and macroscale phenomena, not merely see chemical principles as isolated facts. In particular cases below, the original question is given, followed by its suggested modification.

AP CHEMISTRY 1999, SECTION II, PART A, QUESTION 1

Original Question

$NH_3(aq) + H_2O(l) \leftrightarrow$ (doubled-headed arrow) $NH_4^+(aq) + OH^-(aq)$

In aqueous solution, ammonia reacts as represented above. In 0.0180 M $NH_3(aq)$ at 25 °C, the hydroxide ion concentration $[OH^-]$ is 5.60×10^{-4} *M*. In answering the following, assume that temperature is constant at 25 °C and that volumes are additive.

(a) Write the equilibrium-constant expression for the reaction represented above.
(b) Determine the pH of 0.0180 *M* $NH_3(aq)$.
(c) Determine the value of the base ionization constant, K_b, for $NH_3(aq)$.
(d) Determine the percent ionization of NH_3 in 0.0180 *M* $NH_3(aq)$.
(e) In an experiment, a 20.0 mL sample of 0.0180 M $NH_3(aq)$ was placed in a flask and titrated to the equivalence point and beyond using 0.0120 *M* $HCl(aq)$.
 (i) Determine the volume of 0.0120 *M* $HCl(aq)$ that was added to reach the equivalence point.
 (ii) Determine the pH of the solution in the flask after a total of 15.0 mL of 0.0120 *M* $HCl(aq)$ was added.
 (iii) Determine the pH of the solution in the flask after a total of 40.0 mL of 0.0120 *M* $HCl(aq)$ was added.

(SOURCE: CEEB, 1999b, p. 42)

Suggested Modification

The panel would suggest leaving much of question 1 alone, although it could stand to be condensed somewhat. As written, it tests the student's fundamental understanding of K_b, buffers, and titration stoichiometry. One or more of the following additional questions might be added:

Sketch a titration curve for part (e) using the information from (b), (c), and (d).

and/or

Compare the base strength and give the rationale for strength based on the type of site and associated structure for one or two other more obscure bases, given their respective K_b's.

AP CHEMISTRY 1999, SECTION II, PART A, QUESTION 2

Original Question

Answer the following questions regarding light and its interactions with molecules, atoms, and ions.

(a) The longest wavelength of light with enough energy to break the Cl-Cl bond in $Cl_2(g)$ is 495 nm.
- (i) Calculate the frequency, in s^{-1}, of the light.
- (ii) Calculate the energy, in J, of a photon of the light.
- (iii) Calculate the minimum energy, in kJ mol^{-1}, of the Cl-Cl bond.

(b) A certain line in the spectrum of atomic hydrogen is associated with the electronic transition in the H atom from the sixth energy level ($n = 6$) to the second energy level ($n = 2$).
- (i) Indicate whether the H atom emits energy or whether it absorbs energy during the transition. Justify your answer.
- (ii) Calculate the wavelength, in nm, of the radiation associated with the spectral line.
- (iii) Account for the observation that the amount of energy associated with the same electronic transition ($n = 6$ to $n = 2$) in the He^+ ion is greater than that associated with the corresponding transition in the H atom.

(SOURCE: CEEB, 1999b, p. 43)
(NOTE: On the exam, students were asked to answer *either* this question *or* the next question concerning reaction rates, but not both.)

Suggested Modification

A question containing some of the information assessed in the original version of Question 2 but considerably extended might look like this. This question now relates to a chlorofluorocarbon compound known as CFC-12 or Freon-12.

The Lewis structure of the CFC-12 molecule is: [structure would be given]

(a) Give the correct chemical name for this compound.
(b) Describe the geometrical shape of the compound and estimate the Cl-C-Cl angle.
(c) Identify the type of hybridization exhibited by the central carbon atom.
(d) The energy of the C-Cl bond is 327 kJ/mol bonds; the energy of the C-F bond is 485 kJ/mol bonds. Explain this difference.

or, alternatively,

(e) The energy of the C-Cl bond is 327 kJ/mol bonds. Would you predict the energy of the C-F bond to be higher or lower? Explain your answer.
(f) Calculate the frequency, in s^{-1}, of the radiation required to break a C-Cl bond.
(g) Calculate the wavelength (in nm) of the radiation required to break a C-Cl bond.
(h) Radiation of this wavelength falls within which region of the spectrum?
(i) What is the practical significance of the fact that radiation breaks C-Cl bonds in CFCs?

AP CHEMISTRY 1999, SECTION II, PART B, QUESTION 4

Original Question

Write the formulas to show the reactants and products for any FIVE of the laboratory situations described below. Answers to more than five choices will not be graded. In all cases a reaction occurs. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solution as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You need not balance the equations.

Example: A strip of magnesium is added to a solution of silver nitrate.

Ex:	$Mg + Ag^{+} \rightarrow Mg^{2+} + Ag$

(a) Calcium oxide powder is added to distilled water.
(b) Solid ammonium nitrate is heated to temperatures above 300°C.
(c) Liquid bromine is shaken with a 0.5 *M* sodium iodide solution.
(d) Solid lead(II) carbonate is added to a 0.5 *M* sulfuric acid solution.
(e) A mixture of powdered iron(III) oxide and powdered aluminum metal is heated strongly.
(f) Methylamine gas is bubbled into distilled water.
(g) Carbon dioxide gas is passed over hot, solid sodium oxide.
(h) A 0.2 *M* barium nitrate solution is added to an alkaline 0.2 *M* potassium chromate solution.

(SOURCE: CEEB, 1999b, p. 45)

Suggested Modification

The panel would like to see the reaction/equation question tied more closely to phenomena and laboratory observation. In each of the cases below, the original version (a, b, c, etc.) and a suggested revision (a', b', c', etc.) are given. (The panel also is not convinced that requiring ionic equations is the most appropriate strategy.)

(a) Calcium oxide powder is added to distilled water.
(a') Calcium oxide powder is added to distilled water. Write the equation for the reaction, and indicate whether the final solution will have a pH less than-, equal to-, or greater than 7.

(b) Solid ammonium nitrate is heated to temperatures above 300 ^{o}C.
(b') The vapors from 6 M HCl and 6M NH_3 combine to form a white cloud. Write the equation for the reaction.

(c) Liquid bromine is shaken with a 0.5 *M* sodium iodide solution.
(c') 5.0 mL of a 0.5 M solution of sodium iodide is shaken with 5.0 mL of a water solution of bromine and 5.0 mL of hexane, C_6H_{14}. Describe what you would observe, and write an equation representing the reaction.

(d) Solid lead(II) carbonate is added to a 0.5 *M* sulfuric acid solution.
(d') 0.5 M sulfuric acid is added to a small quantity of lead(II) carbonate in a test tube. Describe the first thing you would notice, and write an equation representing the reaction.

(e) A mixture of powdered iron(III) oxide and powdered aluminum metal is heated strongly.
(e') A mixture of powdered iron(III) oxide and powdered aluminum metal is ignited with a burning piece of magnesium. Sparks, flames, and a pool of molten metal are formed. Write the equation for the reaction. What is the molten metal, and what does this imply about the reaction?

AP CHEMISTRY 1999, SECTION II, PART B, QUESTION 6

Original Question

Answer the following questions in term of thermodynamic principles and concepts of kinetic molecular theory.

(a) Consider the reaction represented below, which is spontaneous at 298 K.

$$CO_2(g) + 2\,NH_3(g) \rightarrow CO(NH_2)_2(s) + H_2O(l) \qquad \Delta H^o_{298} = -134 \text{ kJ}$$

(i) For the reaction, indicate whether the standard entropy change, ΔS^o_{298}, is positive, or negative, or zero. Justify your answer.

(ii) Which factor, the change in enthalpy, ΔH^o_{298}, or the change in entropy, ΔS^o_{298}, provides the principal driving force for the reaction at 298 K? Explain.

(iii) For the reaction, how is the value of the standard free energy, ΔG^o, affected by an increase in temperature? Explain.

(b) Some reactions that are predicted by their sign of ΔG^o to be spontaneous at room temperature do not proceed at a measurable rate at room temperature.
   (i) Account for this apparent contradiction.
   (ii) A suitable catalyst increases the rate of such a reaction. What effect does the catalyst have on ΔG^o for the reaction? Explain.

(SOURCE: CEEB, 1999b, p. 47)

Suggested Modification

The panel suggests that Section II, Part B, Question 6 of the AP exam, which deals with thermodynamic principles and KMT concepts, could be directed to higher levels of thinking in part (a) by relating a simple system, such as an ice cube melting, to enthalpy, entropy, and free energy. The student could be asked to explain the process using the above terms and appropriate equations. Part (b) could be similar but related to something common, such as the possible oxidation of sucrose, which has a large negative free energy. The student could discuss why the sugar does not spontaneously combust on the kitchen table since the free energy is favorable. Included in the explanation would be descriptions of the differences between thermodynamic and kinetic stability.

AP CHEMISTRY 1999, SECTION II, PART B, QUESTION 7

Original Question

Answer the following questions, which refer to the 100 mL samples of aqueous solutions at 25°C in the stoppered flasks shown above (four partially full flasks are shown, each containing an equal volume of 0.10 *M* solutions of NaF, $MgCl_2$, C_2H_5OH, and CH_3COOH, respectively).

(a) Which solution has the lowest electrical conductivity? Explain.
(b) Which solution has the lowest freezing point? Explain.
(c) Above which solution is the pressure of water vapor greatest? Explain.
(d) Which solution has the highest pH? Explain.

(SOURCE: CEEB, 1999b, p. 48)
(NOTE: On the exam, students were asked to answer *either* this question *or* the next question concerning principles of chemical bonding and molecular structure, but not both.)

Suggested Modification

The panel suggest the following modified question:

Modification 1. Do not have all solutions be 0.10 M. Instead use 0.010 M NaF, 0.050 M $MgCl_2$, 0.10 M C_2H_5OH, and 0.20 M CH_3COOH. This change requires a student to think more critically about the nature of these solutions to answer the subsequent questions correctly. More discrimination is required to differentiate acetic acid from NaF and from $MgCl_2$ solution behavior.

Modification 2. If the stoppers were removed from the flasks, from which flask would the solute escape most readily? Explain the answer.

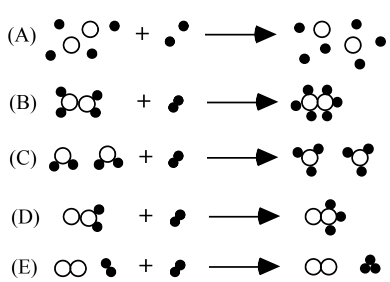
Modification 3. The contents of which flask(s) could be used as reactant(s) in an esterification reaction? Explain.

This would become a more challenging question if varying concentrations of the compounds in water were used. This change would make the question quantitative and more difficult. The quantitative nature of Question 7 would make it less appropriate as a companion for question 8. These two questions should be of like nature and degree of difficulty. To avoid the quantitative aspect of concentration calculation, it would be appropriate to ask the student to identify the type of substance for each question and to write a dissociation, ionization, hydration equation (as necessary) for these substances in water and discuss their relative activity.

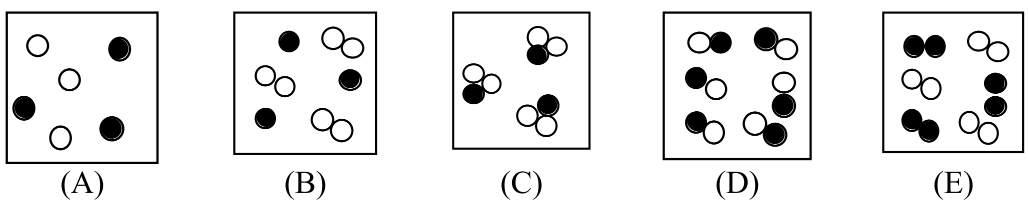
These three items are examples of particulate representations linked to symbolic representations or macroscopic phenomena. Such questions are not part of the AP or IB examinations.

1. Which particulate representation corresponds to the equation?

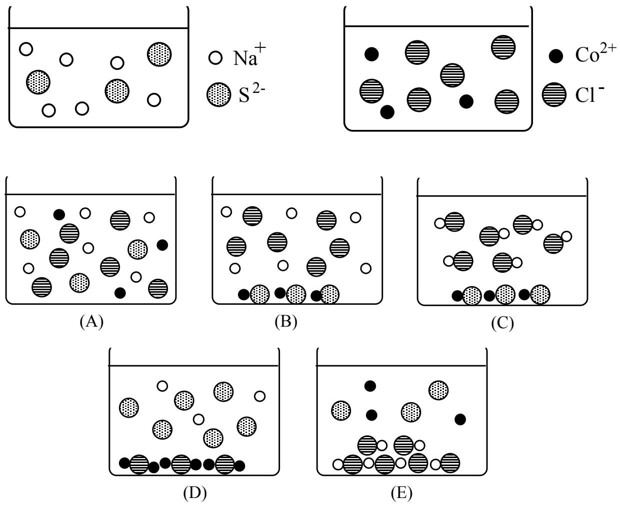
$$2\,SO_2 + O_2 \rightarrow 2\,SO_3$$



2. Which would best represent a mixture of the gases helium and chlorine?



3. If the contents of these two beakers are poured into a third beaker, what will the resulting mixture look like?



This is an example of an error analysis–type item.

4. A student titrated 10.00 mL of fruit juice with 12.84 mL of 9.580×10^{-2} M NaOH. Which step is NOT correct in this calculation of mass of citric acid in 1.00 mL of juice?

$$C_3H_5O(COOH)_3 + 3\ NaOH \rightarrow Na_3(C_3H_5O(COO)_3 + 3\ H_2O$$

(a) Moles NaOH = (12.84 mL) (9.580×10^{-2} mol/L).
(b) Moles citric acid = (1.230 mol NaOH) (1 mol citric acid / 3 mol NaOH).
(c) Mass citric acid in sample = (0.4100 mol citric acid) (192.12 g/mol citric acid).
(d) Mass citric acid in 1 mL fruit juice = (78.77 g citric acid) / (10.00 mL fruit juice).
(e) All the steps are correct.

This is an example of a laboratory-related item.

5. Consider a laboratory exercise in which you prepare approximately 200 mL of a pH = 4.35 buffer. The chemicals available for your use are: 1M solutions of acetic acid, ammonium acetate, ammonium chloride, aqueous ammonia, hydrochloric acid, sodium acetate, and sodium hydroxide (acetic acid $K_a = 1.8 \times 10^{-5}$ and ammonia $K_b = 1.8 \times 10^{-5}$).

    (a) Which chemicals will you use to make your buffer? Explain your choice; use chemical equations where appropriate.
    (b) How much of each chemical will you need? Show calculations to support your answer.
    (c) Outline the procedure you will follow to make your buffer. Include specific equipment and glassware you will use.
    (d) How will you prove that you successfully prepared the buffer?

ADDITIONAL SUGGESTIONS FOR SECTION II, PART B

The following are some other suggestions for Section II, Part B that are not specifically tied to the 1999 version of the examination.

(1) A 0.2 M sulfuric acid is added to a 0.2 M solution of barium nitrate. Describe what happens and write an equation representing the reaction.
(2) A small piece of solid potassium is added to 500 mL of water in a beaker. The potassium fizzes, dances about, and bursts into flame.
    (a) Write an equation representing the reaction.
    (b) A drop of phenolphthalein solution is added to the resulting solution. What would you observe?. Explain.

The panel also suggests that a useful addition would require students to identify reactions as examples of one or more of the following types of reactions: acid/base, oxidation/reduction, decomposition, combination, precipitation, gas evolution, double displacement, electron transfer, and proton transfer. (This list could be expanded or reduced.)

Appendix E
Research Agenda for Advanced Studies in High School Chemistry

The chemistry panel identified a number of topics on which research is needed with respect to advanced studies in high school chemistry:

1. How do students who take advanced courses in high school chemistry move through their college studies (e.g., choice of major, continued interest and enrollment in chemistry), and how well do they succeed compared with students who do not take these programs? Longitudinal data are needed to address these questions.
2. What are the actual costs for implementing, sustaining, updating, and upgrading advanced courses in the experimental sciences? Surveys of teachers are needed to determine actual costs.
3. Is there a difference in the academic success of students whose school districts spend more money on these programs (e.g., for staff development, materials, and modern equipment and facilities) compared with districts that spend less?
4. How much is information technology being integrated into advanced study courses, and what are the requirements for achieving such integration?
5. To what extent do the AP and IB courses reflect current approaches to teaching and learning in introductory college courses?
6. How much variation exists in the granting of college credit and placement in courses to students who take advanced courses in high school?
7. What are the effects of the current ordering of prerequisite and advanced courses in science?
8. Do advanced programs favor some kinds of students over others?
9. What backgrounds, credentials, and professional experience characterize teachers who are involved with these programs? Do these differences translate into how well students learn and achieve in the courses?
10. What percentage of students who take AP Chemistry take it as their first course in chemistry? How well do these students fare in the course and subsequently in college chemistry courses?
11. What proportion of students who take AP or IB Chemistry do not take the examinations? What effect does the resulting lack of information about student learning have on the quality and quality control of the AP program in individual schools and on the AP program overall?
12. Are there advantages to having schools offer clusters of advanced study courses as opposed to isolated courses? What is the impact of not doing so (for example, in small high schools that can support only one or two advanced study courses that may not be connected with each other)?

13. Are there "critical masses" in the number of teachers in a school who teach advanced study courses? In other words, do differences in opportunities for isolated teachers to communicate with colleagues translate into differences in learning and achievement of their students?
14. Are there "critical masses" in the number of students who enroll in advanced study courses? Are students who enroll in such courses either individually (e.g., through distance learning courses) or in small numbers at an advantage or disadvantage relative to students who are enrolled in very large classes?
15. What percentage of schools have prerequisites or other screening procedures for entry into advanced study courses? Do more stringent requirements for entry into such courses translate into differences in scores on the respective assessments?
16. What kinds of physical facilities, equipment and instrumentation, and support for laboratories are available to teachers and students in advanced study programs in the experimental sciences? Do differences in the level and availability of such resources have an impact on student learning and performance?
17. Are there differences in student performance on advanced study examinations in districts or states that provide incentives to students to do well as compared with students in districts or states that do not offer these kinds of incentives?