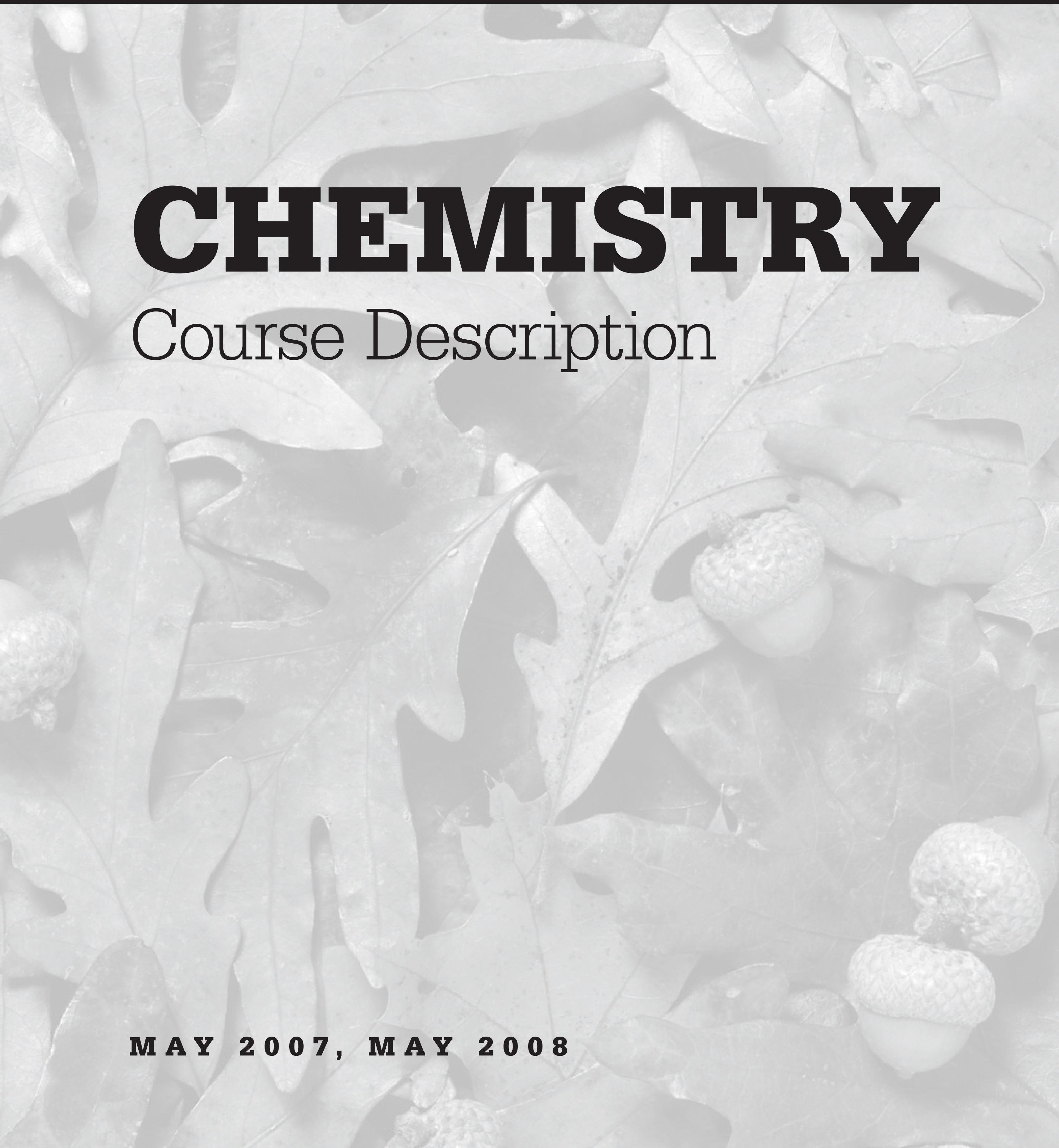

CollegeBoard AP

CHEMISTRY

Course Description

MAY 2007, MAY 2008

The College Board: Connecting Students to College Success

The College Board is a not-for-profit membership association whose mission is to connect students to college success and opportunity. Founded in 1900, the association is composed of more than 5,000 schools, colleges, universities, and other educational organizations. Each year, the College Board serves seven million students and their parents, 23,000 high schools, and 3,500 colleges through major programs and services in college admissions, guidance, assessment, financial aid, enrollment, and teaching and learning. Among its best-known programs are the SAT®, the PSAT/NMSQT®, and the Advanced Placement Program® (AP®). The College Board is committed to the principles of excellence and equity, and that commitment is embodied in all of its programs, services, activities, and concerns.

For further information, visit www.collegeboard.com.

The College Board and the Advanced Placement Program encourage teachers, AP Coordinators, and school administrators to make equitable access a guiding principle for their AP programs. The College Board is committed to the principle that all students deserve an opportunity to participate in rigorous and academically challenging courses and programs. All students who are willing to accept the challenge of a rigorous academic curriculum should be considered for admission to AP courses. The Board encourages the elimination of barriers that restrict access to AP courses for students from ethnic, racial, and socioeconomic groups that have been traditionally underrepresented in the AP Program. Schools should make every effort to ensure that their AP classes reflect the diversity of their student population.

Dear Colleagues:

In 2005, more than 15,000 schools offered high school students the opportunity to take AP® courses, and over 1.2 million students then took the challenging AP Exams. These students felt the power of learning come alive in the classroom, and many earned college credit and placement while still in high school. Behind these students were talented, hardworking teachers who are the heart and soul of the Advanced Placement Program®.

This AP Course Description summarizes the variety of approaches and curricula used in college courses corresponding to the AP course. Teachers have the flexibility to develop their own syllabi and lesson plans, and to bring their individual creativity to the AP classroom. In fact, AP Exams are designed around this flexibility and allow students whose courses vary significantly equal opportunities to demonstrate college-level achievement. Finally, this curricular flexibility is reflected in the AP Course Audit, which identifies elements considered by higher education as essential to a college-level course, providing a consistent standard for disparate AP classes across the world, while not setting forth a mandated AP curriculum.

The College Board is committed to supporting the work of AP teachers. AP workshops and Summer Institutes, held around the globe, provide stimulating professional development for tens of thousands of teachers each year. The College Board Fellows stipends provide funds to support many teachers' attendance at these Institutes. Teachers and administrators can also visit AP Central, the College Board's online home for AP professionals, at apcentral.collegeboard.com. Here, teachers have access to a growing set of resources, information, and tools, from textbook reviews and lesson plans to electronic discussion groups (EDGs) and the most up-to-date exam information. I invite all teachers, particularly those who are new to the AP Program, to take advantage of these resources.

As we look to the future, the College Board's goal is to broaden access to AP classes while maintaining high academic standards. Reaching this goal will require a lot of hard work. We encourage you to connect students to college and opportunity not only by providing them with the challenges and rewards of rigorous academic programs like AP but also by preparing them in the years leading up to AP courses.

Sincerely,

Gaston Caperton
President
The College Board

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Welcome to the AP® Program

The Advanced Placement Program (AP) is a collaborative effort between motivated students; dedicated teachers; and committed high schools, colleges, and universities. Since its inception in 1955, the Program has enabled millions of students to take college-level courses and exams, and to earn college credit or placement, while still in high school.

Most colleges and universities in the United States, as well as colleges and universities in more than 30 other countries, have an AP policy granting incoming students credit, placement, or both on the basis of their AP Exam grades. Many of these institutions grant up to a full year of college credit (sophomore standing) to students who earn a sufficient number of qualifying AP grades.

Each year, an increasing number of parents, students, teachers, high schools, and colleges and universities turn to the AP Program as a model of educational excellence.

More information about the AP Program is available at the back of this Course Description and at AP Central, the College Board's online home for AP professionals (apcentral.collegeboard.com). Students can find more information at the AP student site (www.collegeboard.com/apstudents).

AP Courses

Thirty-eight AP courses in a wide variety of subject areas are available now or are under development. A committee of college faculty and master AP teachers designs each AP course to cover the information, skills, and assignments found in the corresponding college course. See page 2 for a complete list of AP courses and exams.

AP Exams

Each AP course has a corresponding exam that participating schools worldwide administer in May (except for AP Studio Art, which is a portfolio assessment). AP Exams contain multiple-choice questions and a free-response section (either essay or problem solving).

AP Exams are a culminating assessment in all AP courses and are thus an integral part of the Program. As a result, many schools foster the expectation that students who enroll in an AP course will take the corresponding AP Exam. Because the College Board is committed to providing access to AP Exams for homeschooled students and students whose schools do not offer AP courses, it does not require students to take an AP course prior to taking an AP Exam.

AP Courses and Exams

Art
Art History
Studio Art: 2-D Design
Studio Art: 3-D Design
Studio Art: Drawing

Biology

Calculus
Calculus AB
Calculus BC

Chemistry

Chinese Language and Culture (First offered 2006-07)

Computer Science
Computer Science A
Computer Science AB

Economics
Macroeconomics
Microeconomics

English
English Language and Composition
English Literature and Composition

Environmental Science

French
French Language
French Literature

German Language

Government and Politics
Comparative Government and Politics
United States Government and Politics

History
European History
United States History
World History

Human Geography

Italian Language and Culture

Japanese Language and Culture (First offered 2006-07)

Latin
Latin Literature
Latin: Vergil

Music Theory

Physics
Physics B
Physics C: Electricity and Magnetism
Physics C: Mechanics

Psychology

Russian Language and Culture (First offered: date to be determined)

Spanish
Spanish Language
Spanish Literature

Statistics

AP Chemistry

> **Important Changes to This Course Description**
> - Changes to the exam starting in May 2007, pages 8–9
> - New sample free-response questions, pages 20–28

THE COURSE

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, in their first year, 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 college 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 students. Quantitative differences appear in the number of topics treated, the time spent on the course by students, and the nature and the 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.*

Prerequisites

The AP Chemistry course is designed to be taken only after the successful completion of a first course in high school chemistry. Surveys of students who take the AP Chemistry Exam indicate that the probability of achieving a grade of 3 or higher 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. In addition, the recommended mathematics prerequisite for an AP Chemistry class is the successful completion of a second-year algebra course.*

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.

Time Allocations

Developing the requisite intellectual and laboratory skills required of an AP Chemistry student demands that adequate classroom and laboratory time be scheduled. Surveys of students taking the AP Chemistry Exam indicate that performance improved as both total instructional time and time devoted to laboratory work increased.

At least six class periods or the equivalent per week should be scheduled for an AP Chemistry course. Of the total allocated time, a minimum of one double period per week or the equivalent, preferably in a single session, should be spent engaged in laboratory work. Time devoted to class and laboratory demonstrations should not be counted as part of the laboratory period.

Students in an AP Chemistry course should spend at least five hours a week in individual study outside of the classroom.

Textbooks

Current college textbooks are probably the best indicators of the level of the college general chemistry course that AP Chemistry is designed to represent. A contemporary college chemistry text that stresses principles and concepts and their relation to the descriptive chemistry on which they are based should be selected. Even the more advanced secondary school texts cannot serve adequately as texts for an AP course that aims to achieve its objectives. A list of example textbooks appropriate for use in this course is available on the AP Chemistry Course Home Page at AP Central (apcentral.collegeboard.com/chemistry).

The Teachers' Resources section of AP Central (apcentral.collegeboard.com) has a searchable database of chemistry resources. Many of these resources have been reviewed and rated by experienced AP Chemistry teachers.

Topic Outline

The importance of the theoretical aspects of chemistry has brought about an increasing emphasis on these aspects of the content of general chemistry courses. Topics such as the structure of matter, kinetic theory of gases, chemical equilibria, chemical kinetics, and the basic concepts of thermodynamics are now being presented in considerable depth.

If the objectives of a college-level general chemistry course are to be achieved, instruction 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. Teachers with such training are best able to present a course with adequate breadth and depth and to develop students' abilities to use the fundamental facts of the science in their reasoning. Because of the nature of the AP course, the teacher needs time for extra preparation for both class and laboratory and should have a teaching load that is adjusted accordingly.

Chemistry is broad enough to permit flexibility in its teaching, and college teachers exercise considerable freedom in methods and arrangements of topics in the effort to reach the objectives of their courses. The AP Chemistry Development Committee has no desire to impose greater uniformity on secondary schools than now exists in colleges.

The following list of topics for an AP course is intended to be a *guide* to the level and breadth of treatment expected rather than to be a syllabus. The percentage after each major topic indicates the approximate proportion of multiple-choice questions on the exam that pertain to the topic.

I. Structure of Matter (20%)

A. Atomic theory and atomic structure
   1. Evidence for the atomic theory
   2. Atomic masses; determination by chemical and physical means
   3. Atomic number and mass number; isotopes
   4. Electron energy levels: atomic spectra, quantum numbers, atomic orbitals
   5. Periodic relationships including, for example, atomic radii, ionization energies, electron affinities, oxidation states

B. Chemical bonding
   1. Binding forces
      a. Types: ionic, covalent, metallic, hydrogen bonding, van der Waals (including London dispersion forces)
      b. Relationships to states, structure, and properties of matter
      c. Polarity of bonds, electronegativities
   2. Molecular models
      a. Lewis structures
      b. Valence bond: hybridization of orbitals, resonance, sigma and pi bonds
      c. VSEPR
   3. Geometry of molecules and ions, structural isomerism of simple organic molecules and coordination complexes; dipole moments of molecules; relation of properties to structure

C. Nuclear chemistry: nuclear equations, half-lives, and radioactivity; chemical applications

II. States of Matter (20%)

A. Gases
   1. Laws of ideal gases
      a. Equation of state for an ideal gas
      b. Partial pressures
   2. Kinetic molecular theory
      a. Interpretation of ideal gas laws on the basis of this theory
      b. Avogadro's hypothesis and the mole concept
      c. Dependence of kinetic energy of molecules on temperature
      d. Deviations from ideal gas laws

B. Liquids and solids
   1. Liquids and solids from the kinetic-molecular viewpoint
   2. Phase diagrams of one-component systems
   3. Changes of state, including critical points and triple points
   4. Structure of solids; lattice energies

C. Solutions
   1. Types of solutions and factors affecting solubility
   2. Methods of expressing concentration (use of normalities is not tested)

3. Raoult's law and colligative properties (nonvolatile solutes); osmosis
4. Nonideal behavior (qualitative aspects)

III. Reactions (35–40%)

A. Reaction types
   1. Acid-base reactions; concepts of Arrhenius, Brønsted-Lowry, and Lewis; coordination complexes; amphoterism
   2. Precipitation reactions
   3. Oxidation-reduction reactions
      a. Oxidation number
      b. The role of the electron in oxidation-reduction
      c. Electrochemistry: electrolytic and galvanic cells; Faraday's laws; standard half-cell potentials; Nernst equation; prediction of the direction of redox reactions

B. Stoichiometry
   1. Ionic and molecular species present in chemical systems: net ionic equations
   2. Balancing of equations including those for redox reactions
   3. Mass and volume relations with emphasis on the mole concept, including empirical formulas and limiting reactants

C. Equilibrium
   1. Concept of dynamic equilibrium, physical and chemical; Le Chatelier's principle; equilibrium constants
   2. Quantitative treatment
      a. Equilibrium constants for gaseous reactions: K_p, K_c
      b. Equilibrium constants for reactions in solution
         (1) Constants for acids and bases; pK; pH
         (2) Solubility product constants and their application to precipitation and the dissolution of slightly soluble compounds
         (3) Common ion effect; buffers; hydrolysis

D. Kinetics
   1. Concept of rate of reaction
   2. Use of experimental data and graphical analysis to determine reactant order, rate constants, and reaction rate laws
   3. Effect of temperature change on rates
   4. Energy of activation; the role of catalysts
   5. The relationship between the rate-determining step and a mechanism

E. Thermodynamics
   1. State functions
   2. First law: change in enthalpy; heat of formation; heat of reaction; Hess's law; heats of vaporization and fusion; calorimetry
   3. Second law: entropy; free energy of formation; free energy of reaction; dependence of change in free energy on enthalpy and entropy changes
   4. Relationship of change in free energy to equilibrium constants and electrode potentials

IV. Descriptive Chemistry (10–15%)

Knowledge of specific facts of chemistry is essential for an understanding of principles and concepts. These descriptive facts, including the chemistry involved in environmental and societal issues, should not be isolated from the principles being studied but should be taught throughout the course to illustrate and illuminate the principles. The following areas should be covered:

1. Chemical reactivity and products of chemical reactions
2. Relationships in the periodic table: horizontal, vertical, and diagonal with examples from alkali metals, alkaline earth metals, halogens, and the first series of transition elements
3. Introduction to organic chemistry: hydrocarbons and functional groups (structure, nomenclature, chemical properties)

V. Laboratory (5–10%)

The differences between college chemistry and the usual secondary school chemistry course are especially evident in the laboratory work. The AP Chemistry Exam includes some questions based on experiences and skills students acquire in the laboratory:

- making observations of chemical reactions and substances
- recording data
- calculating and interpreting results based on the quantitative data obtained
- communicating effectively the results of experimental work

For information on the requirements for an AP Chemistry laboratory program, the *Guide for the Recommended Laboratory Program* is included on pages 29–39 of this book. The guide describes the general requirements for an AP Chemistry laboratory program and contains a list of recommended experiments. Also included in the guide are resources that AP Chemistry teachers should find helpful in developing a successful laboratory program.

Colleges have reported that some AP students, while doing well on the exam, have been at a serious disadvantage because of inadequate laboratory experience. Meaningful laboratory work is important in fulfilling the requirements of a college-level course of a laboratory science and in preparing a student for sophomore-level chemistry courses in college.

Because chemistry professors at some institutions ask to see a record of the laboratory work done by an AP student before making a decision about granting credit, placement, or both, in the chemistry program, students should keep a laboratory notebook that includes reports of their laboratory work in such a fashion that the reports can be readily reviewed.

Chemical Calculations

The following list summarizes types of problems either explicitly or implicitly included in the preceding material. Attention should be given to significant figures, precision of measured values, and the use of logarithmic and exponential relationships. Critical analysis of the reasonableness of results is to be encouraged.

1. Percentage composition
2. Empirical and molecular formulas from experimental data
3. Molar masses from gas density, freezing-point, and boiling-point measurements
4. Gas laws, including the ideal gas law, Dalton's law, and Graham's law
5. Stoichiometric relations using the concept of the mole; titration calculations
6. Mole fractions; molar and molal solutions
7. Faraday's laws of electrolysis
8. Equilibrium constants and their applications, including their use for simultaneous equilibria
9. Standard electrode potentials and their use; Nernst equation
10. Thermodynamic and thermochemical calculations
11. Kinetics calculations

THE EXAM

Starting in May 2007, the AP Chemistry Exam will have a new format. The two main parts of the exam, Section I and Section II, will contribute equally (50 percent each) toward the final grade. Section I (90 minutes) will still consist of 75 multiple-choice questions with broad coverage of topics.

Teachers should not try to prepare students to answer every question in Section I of the exam. To be broad enough in scope to give every student who has covered an adequate amount of material an opportunity to make a good showing, the exam must be so comprehensive that no student should be expected to make a perfect or near-perfect score.

There will be several changes in Section II of the exam starting in May 2007. The first change is that students will no longer choose between alternative questions. All students will answer the same six free-response questions. A second change relates to Question 4 of the exam, in which students are asked to write chemical equations for five reactions chosen from eight given sets of reactants. In the new Question 4 format, all students will write balanced chemical equations for several different sets of reactants. In addition, students will answer a short question about each reaction.

A third change in Section II relates to the timing of Part A (calculators permitted) and Part B (no calculators permitted). In Part A students will have 55 minutes to answer three problems—one problem involving chemical equilibrium and two other problems, one of which may involve quantitative analysis of data in a laboratory-based problem. In Part B students will have 40 minutes to answer a reactions question (Question 4, described above) and two essay questions, one of which will be based on laboratory in the case that no laboratory-based problem appears in Part A.

Calculators

The policy regarding the use of calculators on the AP Chemistry Exam was developed to address the rapid expansion of the capabilities of scientific calculators, which include not only programming and graphing functions but also the availability of stored equations and other data. For the section of the exam in which calculators are permitted, students should be allowed to use the calculators to which they are accustomed, except as noted below.* On the other hand, they should not have access to information in their calculators that is not available to other students, if that information is needed to answer the questions.

Therefore, calculators are not permitted on the *multiple-choice section* of the AP Chemistry Exam. The purpose of the multiple-choice section is to assess the breadth of students' knowledge and understanding of the basic concepts of chemistry. The multiple-choice questions emphasize conceptual understanding as well as qualitative and simple quantitative applications of principles. Many chemical and physical principles and relationships are quantitative by nature and can be expressed as equations. Knowledge of the underlying basic definitions and principles, expressed as equations, is a part of the content of chemistry that should be learned by chemistry students and will continue to be assessed in the multiple-choice section. However, any numeric calculations that require use of these equations in the multiple-choice section will be limited to simple arithmetic so that they can be done quickly, either mentally or with paper and pencil. Also, in some questions the answer choices differ by several orders of magnitude so that the questions can be answered by estimation. Refer to sample questions on pages 14–16 (#6, 8, 11, 12, 16, and 17), which can be answered using simple arithmetic or by estimation. Students should be encouraged to develop their skills not only in estimating answers but also in recognizing answers that are physically unreasonable or unlikely.

Calculators (with the exceptions previously noted) will be allowed only during the first 55 minutes (Part A) of the free-response section of the exam. During this time, students will work on three problems. **Any programmable or graphing calculator may be used, and students will NOT be required to erase their calculator memories before or after the exam.** Students will not be allowed to move on to the last portion of the free-response section until time is called and all calculators are put away. For the last 40 minutes (Part B) of the exam, students will work without calculators on the remaining portion of the free-response section.

Equation Tables

Tables containing equations commonly used in chemistry are printed both in the free-response (Section II) exam booklet and in the inserts provided with each exam for students to use when taking the free-response section. The equation tables are NOT permitted for use with the multiple-choice section. In general, the equations for each

*__Exceptions to calculator use.__ Calculators that are not permitted are PowerBooks and portable/handheld computers; electronic writing pads or pen-input/stylus-driven devices (e.g., Palm, PDAs, Casio ClassPad 300); pocket organizers; models with QWERTY (i.e., typewriter) keypads (e.g., TI-92 Plus, Voyage 200); models with paper tapes; models that make noise or "talk"; models that require an electrical outlet; cell phone calculators. Students may not share calculators.

year's exam are printed and distributed with the Course Description at least a year in advance so that students can become accustomed to using them throughout the year. However, because the equation tables will be provided with the exam, students will NOT be allowed to bring their own copies to the exam room. The latest version of the equation tables is shown on pages 11–12 of this booklet.

One of the purposes of providing the tables of commonly used equations for use with the free-response section is to address the issue of equity for those students who do not have access to equations stored in their calculators. The availability of these equations to all students means that in the scoring of the free-response sections, little or no credit will be awarded for simply writing down equations or for answers unsupported by explanations or logical development.

The equations in the tables express relationships that are encountered most frequently in an AP Chemistry course and exam. However, they do not include all equations that might possibly be used. For example, they do not include many equations that can be derived by combining others in the tables. Nor do they include equations that are simply special cases of any that are in the tables. Students are responsible for understanding the physical principles that underlie each equation and for knowing the conditions for which each equation is applicable.

The equations are grouped in tables according to major content category. Within each table, the symbols used for the variables in that table are defined. However, in some cases the same symbol is used to represent different quantities in different tables. It should be noted that there is no uniform convention among textbooks for the symbols used in writing equations. The equation tables follow many common conventions, but in some cases consistency was sacrificed for the sake of clarity.

In summary, the purpose of minimizing numerical calculations in both sections of the exam and providing equations with the free-response section is to place greater emphasis on the understanding and application of fundamental chemical principles and concepts. For solving problems and writing essays, a sophisticated programmable or graphing calculator, or the availability of stored equations, is no substitute for a thorough grasp of the chemistry involved.

ADVANCED PLACEMENT CHEMISTRY EQUATIONS AND CONSTANTS

ATOMIC STRUCTURE

$E = h\nu \qquad c = \lambda\nu$

$\lambda = \dfrac{h}{m\upsilon} \qquad p = m\upsilon$

$E_n = \dfrac{-2.178 \times 10^{-18}}{n^2}$ joule

EQUILIBRIUM

$K_a = \dfrac{[H^+][A^-]}{[HA]}$

$K_b = \dfrac{[OH^-][HB^+]}{[B]}$

$K_w = [OH^-][H^+] = 1.0 \times 10^{-14}$ @ 25°C

$= K_a \times K_b$

$pH = -\log[H^+], \; pOH = -\log[OH^-]$

$14 = pH + pOH$

$pH = pK_a + \log\dfrac{[A^-]}{[HA]}$

$pOH = pK_b + \log\dfrac{[HB^+]}{[B]}$

$pK_a = -\log K_a, \; pK_b = -\log K_b$

$K_p = K_c(RT)^{\Delta n}$,

where Δn = moles product gas − moles reactant gas

THERMOCHEMISTRY/KINETICS

$\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$

$\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$

$\Delta G^\circ = \sum \Delta G_f^\circ \text{ products} - \sum \Delta G_f^\circ \text{ reactants}$

$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$

$= -RT \ln K = -2.303\, RT \log K$

$= -n \mathcal{F} E^\circ$

$\Delta G = \Delta G^\circ + RT \ln Q = \Delta G^\circ + 2.303\, RT \log Q$

$q = mc\Delta T$

$C_p = \dfrac{\Delta H}{\Delta T}$

$\ln[A]_t - \ln[A]_0 = -kt$

$\dfrac{1}{[A]_t} - \dfrac{1}{[A]_0} = kt$

$\ln k = \dfrac{-E_a}{R}\left(\dfrac{1}{T}\right) + \ln A$

E = energy
ν = frequency
λ = wavelength
p = momentum
υ = velocity
n = principal quantum number
m = mass

Speed of light, $c = 3.0 \times 10^8$ m s^{-1}

Planck's constant, $h = 6.63 \times 10^{-34}$ J s

Boltzmann's constant, $k = 1.38 \times 10^{-23}$ J K^{-1}

Avogadro's number $= 6.022 \times 10^{23}$ mol^{-1}

Electron charge, $e = -1.602 \times 10^{-19}$ coulomb

1 electron volt per atom = 96.5 kJ mol^{-1}

Equilibrium Constants

K_a (weak acid)
K_b (weak base)
K_w (water)
K_p (gas pressure)
K_c (molar concentrations)

S° = standard entropy
H° = standard enthalpy
G° = standard free energy
E° = standard reduction potential
T = temperature
n = moles
m = mass
q = heat
c = specific heat capacity
C_p = molar heat capacity at constant pressure
E_a = activation energy
k = rate constant
A = frequency factor

Faraday's constant, $\mathcal{F}$ = 96,500 coulombs per mole of electrons

Gas constant, $R = 8.31$ J mol^{-1} K^{-1}

$= 0.0821$ L atm mol^{-1} K^{-1}

$= 8.31$ volt coulomb mol^{-1} K^{-1}

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

$$\left(P + \frac{n^2a}{V^2}\right)(V - nb) = nRT$$

$$P_A = P_{total} \times X_A\text{, where } X_A = \frac{\text{moles A}}{\text{total moles}}$$

$$P_{total} = P_A + P_B + P_C + \ldots$$

$$n = \frac{m}{\boldsymbol{M}}$$

$$\text{K} = {}^\circ\text{C} + 273$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$D = \frac{m}{V}$$

$$u_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{\boldsymbol{M}}}$$

$$KE \text{ per molecule} = \frac{1}{2}mv^2$$

$$KE \text{ per mole} = \frac{3}{2}RT$$

$$\frac{r_1}{r_2} = \sqrt{\frac{\boldsymbol{M}_2}{\boldsymbol{M}_1}}$$

molarity, M = moles solute per liter solution

molality = moles solute per kilogram solvent

$$\Delta T_f = iK_f \times \text{molality}$$

$$\Delta T_b = iK_b \times \text{molality}$$

$$\pi = iMRT$$

$$A = abc$$

P = pressure
V = volume
T = temperature
n = number of moles
D = density
m = mass
v = velocity

u_{rms} = root-mean-square speed
KE = kinetic energy
r = rate of effusion
$\boldsymbol{M}$ = molar mass
π = osmotic pressure
i = van't Hoff factor
K_f = molal freezing-point depression constant
K_b = molal boiling-point elevation constant
A = absorbance
a = molar absorptivity
b = path length
c = concentration
Q = reaction quotient
I = current (amperes)
q = charge (coulombs)
t = time (seconds)
E° = standard reduction potential
K = equilibrium constant

OXIDATION-REDUCTION; ELECTROCHEMISTRY

$$Q = \frac{[\text{C}]^c\,[\text{D}]^d}{[\text{A}]^a\,[\text{B}]^b}\text{, where } a\text{ A} + b\text{ B} \rightarrow c\text{ C} + d\text{ D}$$

$$I = \frac{q}{t}$$

$$E_{\text{cell}} = E^\circ_{\text{cell}} - \frac{RT}{n\mathcal{F}}\ln Q = E^\circ_{\text{cell}} - \frac{0.0592}{n}\log Q \text{ @ } 25^\circ\text{C}$$

$$\log K = \frac{nE^\circ}{0.0592}$$

Gas constant, R = 8.31 J $\text{mol}^{-1}\ \text{K}^{-1}$
= 0.0821 L atm $\text{mol}^{-1}\ \text{K}^{-1}$
= 8.31 volt coulomb $\text{mol}^{-1}\ \text{K}^{-1}$
Boltzmann's constant, k = 1.38×10^{-23} J K^{-1}
K_f for H_2O = 1.86 K kg mol^{-1}
K_b for H_2O = 0.512 K kg mol^{-1}
1 atm = 760 mm Hg
= 760 torr
STP = 0.000°C and 1.000 atm
Faraday's constant, $\mathcal{F}$ = 96,500 coulombs per mole of electrons

Sample Multiple-Choice Questions

The following multiple-choice questions provide a representative subset of those used in previous AP Chemistry Exams. There are two types of multiple-choice questions. The first type consists of five lettered headings followed by a list of numbered phrases. For each numbered phrase, the student is instructed to select the one heading that is most closely related to it. Each heading may be used once, more than once, or not at all in each group.

Questions 1-3 refer to atoms of the following elements.

(A) Lithium
(B) Carbon
(C) Nitrogen
(D) Oxygen
(E) Fluorine

1. In the ground state, have only 1 electron in each of the three *p* orbitals

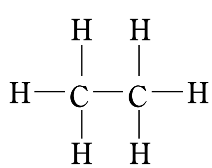
2. Have the smallest atomic radius

3. Have the smallest value for first ionization energy

The majority of the multiple-choice questions consist of questions or incomplete statements followed by five suggested answers or completions. The student is instructed to select the one that is best in each case.

4. Which of the following species is NOT planar?

   (A) CO_3^{2-}
   (B) NO_3^-
   (C) ClF_3
   (D) BF_3
   (E) PCl_3



5. The hybridization of the carbon atoms in the molecule represented above can be described as

   (A) *sp*
   (B) sp^2
   (C) sp^3
   (D) dsp^2
   (E) d^2sp

6. The half-life of ^{55}Cr is about 2.0 hours. The delivery of a sample of this isotope from the reactor to a certain laboratory requires 12 hours. About what mass of such material should be shipped in order that 1.0 mg of ^{55}Cr is delivered to the laboratory?

   (A) 130 mg
   (B) 64 mg
   (C) 32 mg
   (D) 11 mg
   (E) 1.0 mg

7. At constant temperature, the behavior of a sample of a real gas more closely approximates that of an ideal gas as its volume is increased because the

   (A) collisions with the walls of the container become less frequent
   (B) average molecular speed decreases
   (C) molecules have expanded
   (D) average distance between molecules becomes greater
   (E) average molecular kinetic energy decreases

8. A sealed vessel contains 0.200 mol of oxygen gas, 0.100 mol of nitrogen gas, and 0.200 mol of argon gas. The total pressure of the gas mixture is 5.00 atm. The partial pressure of the argon is

   (A) 0.200 atm
   (B) 0.500 atm
   (C) 1.00 atm
   (D) 2.00 atm
   (E) 5.00 atm

9. Which of the following accounts for the fact that liquid CO_2 is <u>not</u> observed when a piece of solid CO_2 (dry ice) is placed on a lab bench?

   (A) The phase diagram for CO_2 has no triple point.
   (B) The normal boiling point of CO_2 is lower than its normal freezing point.
   (C) $CO_2(s)$ is a molecular solid.
   (D) The critical pressure for CO_2 is approximately 1 atm.
   (E) The triple point for CO_2 is above 1 atm.

10. If ΔG for a certain reaction has a negative value at 298 K, which of the following must be true?

    I. The reaction is exothermic.
    II. The reaction occurs spontaneously at 298 K.
    III. The rate of the reaction is fast at 298 K.

    (A) I only
    (B) II only
    (C) I and II only
    (D) II and III only
    (E) I, II, and III

$$2\ SO_2(g) + O_2(g) \rightarrow 2\ SO_3(g)$$

11. A mixture of gases containing 0.20 mol of SO_2 and 0.20 mol of O_2 in a 4.0 L flask reacts to form SO_3. If the temperature is 25°C, what is the pressure in the flask after reaction is complete?

    (A) $\frac{0.4(0.082)(298)}{4}$ atm

    (B) $\frac{0.3(0.082)(298)}{4}$ atm

    (C) $\frac{0.2(0.082)(298)}{4}$ atm

    (D) $\frac{0.2(0.082)(25)}{4}$ atm

    (E) $\frac{0.3(0.082)(25)}{4}$ atm

12. A solution prepared by mixing 10 mL of 1 *M* HCl and 10 mL of 1.2 *M* NaOH has a pH of

    (A) 0 (B) 1 (C) 7 (D) 13 (E) 14

13. All of the following reactions can be defined as Lewis acid-base reactions EXCEPT

    (A) $Al(OH)_3(s) + OH^-(aq) \rightarrow Al(OH)_4^-(aq)$
    (B) $Cl_2(g) + H_2O(l) \rightarrow HOCl(aq) + H^+(aq) + Cl^-(aq)$
    (C) $SnCl_4(s) + 2\ Cl^-(aq) \rightarrow SnCl_6^{2-}(aq)$
    (D) $NH_4^+(g) + NH_2^-(g) \rightarrow 2\ NH_3(g)$
    (E) $H^+(aq) + NH_3(aq) \rightarrow NH_4^+(aq)$

14. Which of the following represents a process in which a species is reduced?

    (A) $Ca(s) \rightarrow Ca^{2+}(aq)$
    (B) $Hg(l) \rightarrow Hg_2^{2+}(aq)$
    (C) $Fe^{2+}(aq) \rightarrow Fe^{3+}(aq)$
    (D) $NO_3^-(aq) \rightarrow NO(g)$
    (E) $SO_3^{2-}(aq) \rightarrow SO_4^{2-}(aq)$

$$Cd^{2+}(aq) + 2\ e^- \rightleftarrows Cd(s) \quad E^\circ = -0.41\ V$$
$$Cu^+(aq) + e^- \rightleftarrows Cu(s) \quad E^\circ = +0.52\ V$$
$$Ag^+(aq) + e^- \rightleftarrows Ag(s) \quad E^\circ = +0.80\ V$$

15. Based on the standard electrode potentials given above, which of the following is the strongest reducing agent?

    (A) $Cd(s)$ (B) $Cd^{2+}(aq)$ (C) $Cu(s)$ (D) $Ag(s)$ (E) $Ag^+(aq)$

16. A sample of $CaCO_3$ (molar mass 100. g) was reported as being 30. percent Ca. Assuming no calcium was present in any impurities, the percent of $CaCO_3$ in the sample is

(A) 30% (B) 40% (C) 70% (D) 75% (E) 100%

$$2\ Al(s) + 6\ HCl(aq) \rightarrow 2\ AlCl_3(aq) + 3\ H_2(g)$$

17. According to the reaction represented above, about how many grams of aluminum (atomic mass 27 g) are necessary to produce 0.50 mol of hydrogen gas at 25°C and 1.00 atm?

(A) 1.0 g
(B) 9.0 g
(C) 14 g
(D) 27 g
(E) 56 g

$$\ldots Cr_2O_7^{2-}(aq) + \ldots HNO_2(aq) + \ldots H^+(aq) \rightarrow \ldots Cr^{3+}(aq) + \ldots NO_3^-(aq) + \ldots H_2O(l)$$

18. When the equation for the redox reaction represented above is balanced and all coefficients are reduced to lowest whole-number terms, the coefficient for $H_2O(l)$ is

(A) 3 (B) 4 (C) 5 (D) 6 (E) 8

19. Which of the following equations represents the net reaction that occurs when gaseous hydrofluoric acid reacts with solid silicon dioxide?

(A) $2\ H^+(aq) + 2\ F^-(aq) + SiO_2(s) \rightarrow SiOF_2(s) + H_2O(l)$
(B) $4\ F^-(aq) + SiO_2(s) \rightarrow SiF_4(g) + 2\ O^{2-}(aq)$
(C) $4\ HF(g) + SiO_2(s) \rightarrow SiF_4(g) + 2\ H_2O(l)$
(D) $4\ HF(g) + SiO_2(s) \rightarrow Si(s) + 2\ F_2(g) + 2\ H_2O(l)$
(E) $2\ H_2F(g) + Si_2O_2(s) \rightarrow 2\ SiF(g) + 2\ H_2O(l)$

20. The ionization constant for acetic acid is 1.8×10^{-5}; that for hydrocyanic acid is 4×10^{-10}. In 0.1 *M* solutions of sodium acetate and sodium cyanide, it is true that

(A) $[H^+]$ equals $[OH^-]$ in each solution
(B) $[H^+]$ exceeds $[OH^-]$ in each solution
(C) $[H^+]$ of the sodium acetate solution is less than that of the sodium cyanide solution
(D) $[OH^-]$ of the sodium acetate solution is less than that of the sodium cyanide solution
(E) $[OH^-]$ for the two solutions is the same

$$HCl > HC_2H_3O_2 > HCN > H_2O > NH_3$$

21. Five acids are listed above in the order of decreasing acid strength. Which of the following reactions must have an equilibrium constant with a value less than 1?

(A) $HCl(aq) + CN^-(aq) \rightleftarrows HCN(aq) + Cl^-(aq)$
(B) $HCl(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + Cl^-(aq)$
(C) $HC_2H_3O_2(aq) + OH^-(aq) \rightleftarrows C_2H_3O_2^-(aq) + H_2O(l)$
(D) $H_2O(aq) + NH_2^-(aq) \rightleftarrows NH_3(aq) + OH^-(aq)$
(E) $HCN(aq) + C_2H_3O_2^-(aq) \rightleftarrows HC_2H_3O_2(aq) + CN^-(aq)$

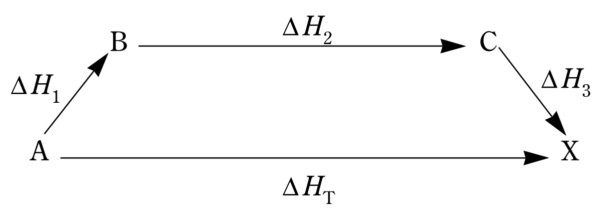
Experiment	*Initial* [X] *(mol L⁻¹)*	*Initial* [Y] *(mol L⁻¹)*	*Initial Rate of Formulation of* Z *(mol L⁻¹ min⁻¹)*
1	0.10	0.30	4.0×10^{-4}
2	0.20	0.60	1.6×10^{-3}
3	0.20	0.30	4.0×10^{-4}

22. The data in the table above were obtained for the reaction X + Y → Z. Which of the following is the rate law for the reaction?

(A) Rate = $k[X]^2$
(B) Rate = $k[Y]^2$
(C) Rate = $k[X][Y]$
(D) Rate = $k[X]^2[Y]$
(E) Rate = $k[X][Y]^2$

$$A \rightarrow X$$

23. The enthalpy change for the reaction represented above is ΔH_T. This reaction can be broken down into a series of steps as shown in the diagram:



A relationship that must exist among the various enthalpy changes is

(A) $\Delta H_T - \Delta H_1 - \Delta H_2 - \Delta H_3 = 0$
(B) $\Delta H_T + \Delta H_1 + \Delta H_2 + \Delta H_3 = 0$
(C) $\Delta H_3 - (\Delta H_1 + \Delta H_2) = \Delta H_T$
(D) $\Delta H_2 - (\Delta H_3 + \Delta H_1) = \Delta H_T$
(E) $\Delta H_T + \Delta H_2 = \Delta H_1 + \Delta H_3$

24. What formula would be expected for a binary compound of barium and nitrogen?

(A) Ba_3N_2 (B) Ba_2N_3 (C) Ba_2N (D) BaN_2 (E) BaN

25. All of the following statements about the nitrogen family of elements are true EXCEPT:

(A) It contains both metals and nonmetals.
(B) The electronic configuration of the valence shell of the atom is ns^2np^3.
(C) The only oxidation states exhibited by members of this family are –3, 0, +3, +5.
(D) The atomic radii increase with increasing atomic number.
(E) The boiling points increase with increasing atomic number.

26. Of the following organic compounds, which is LEAST soluble in water at 298 K?

(A) CH_3OH, methanol
(B) $CH_3CH_2CH_2OH$, l-propanol
(C) C_6H_{14}, hexane
(D) $C_6H_{12}O_6$, glucose
(E) CH_3COOH, ethanoic (acetic) acid

27. Which of the following salts forms a basic solution when dissolved in water?

(A) $NaCl$
(B) $(NH_4)_2SO_4$
(C) $CuSO_4$
(D) K_2CO_3
(E) NH_4NO_3

28. The molecular mass of a substance can be determined by measuring which of the following?

I. Osmotic pressure of a solution of the substance
II. Freezing point depression of a solution of the substance
III. Density of the gas (vapor) phase of the substance

(A) I only
(B) III only
(C) I and II only
(D) II and III only
(E) I, II, and III

29. The table below summarizes the reactions of a certain unknown solution when treated with bases.

		Results	
Sample	*Reagent*	*Limited Amount of Reagent*	*Excess Reagent*
I	NaOH (*aq*)	White precipitate	Precipitate dissolves
II	NH_3(*aq*)	White precipitate	White precipitate

Which of the following metallic ions could be present in the unknown solution?

(A) Ca^{2+} (*aq*)
(B) Zn^{2+} (*aq*)
(C) Ni^{2+} (*aq*)
(D) Al^{3+} (*aq*)
(E) Ag^{+} (*aq*)

Answers to Multiple-Choice Questions

1 – C	7 – D	13 – B	19 – C	25 – C
2 – E	8 – D	14 – D	20 – D	26 – C
3 – A	9 – E	15 – A	21 – E	27 – D
4 – E	10 – B	16 – D	22 – B	28 – E
5 – C	11 – B	17 – B	23 – A	29 – D
6 – B	12 – D	18 – B	24 – A	

Sample Free-Response Questions

IMPORTANT—Please note that starting in May 2007, Section II of the AP Chemistry Exam will have a DIFFERENT FORMAT than that of the May 2005 exam, which appears below. However, with the exception of Question 4, the questions in the 2005 exam are representative of the content and level of depth of the questions that will appear on the May 2007 exam.

For Section II of the exam, students are provided with a periodic table, a table of standard reduction potentials, and a table containing various equations and constants. Additional free-response questions (and scoring guidelines) are available at AP Central.

Part A

Time—40 minutes
YOU MAY USE YOUR CALCULATOR FOR PART A.

CLEARLY SHOW THE METHOD USED AND THE STEPS INVOLVED IN ARRIVING AT YOUR ANSWERS. It is to your advantage to do this, since you may obtain partial credit if you do and you will receive little or no credit if you do not. Attention should be paid to significant figures.

Be sure to write all your answers to the questions on the lined pages following each question in the booklet with the pink cover. Do NOT write your answers on the green insert.

Answer Question 1 below. The Section II score weighting for this question is 20 percent.

$$HC_3H_5O_2(aq) \rightleftarrows C_3H_5O_2^-(aq) + H^+(aq) \qquad K_a = 1.34 \times 10^{-5}$$

1. Propanoic acid, $HC_3H_5O_2$, ionizes in water according to the equation above.

   (a) Write the equilibrium-constant expression for the reaction.

   (b) Calculate the pH of a 0.265 M solution of propanoic acid.

   (c) A 0.496 g sample of sodium propanoate, $NaC_3H_5O_2$, is added to a 50.0 mL sample of a 0.265 M solution of propanoic acid. Assuming that no change in the volume of the solution occurs, calculate each of the following.
   (i) The concentration of the propanoate ion, $C_3H_5O_2^-(aq)$, in the solution
   (ii) The concentration of the $H^+(aq)$ ion in the solution

   The methanoate ion, $HCO_2^-(aq)$, reacts with water to form methanoic acid and hydroxide ion, as shown in the following equation.

$$HCO_2^-(aq) + H_2O(l) \rightleftarrows HCO_2H(aq) + OH^-(aq)$$

   (d) Given that $[OH^-]$ is 4.18×10^{-6} M in a 0.309 M solution of sodium methanoate, calculate each of the following.
   (i) The value of K_b for the methanoate ion, $HCO_2^-(aq)$
   (ii) The value of K_a for methanoic acid, HCO_2H

   (e) Which acid is stronger, propanoic acid or methanoic acid? Justify your answer.

Answer EITHER Question 2 below OR Question 3 printed on pages 22-23. Only one of these two questions will be scored. If you start both questions, be sure to cross out the question you do not want scored. The Section II score weighting for the question you choose is 20 percent.

2. Answer the following questions about a pure compound that contains only carbon, hydrogen, and oxygen.

   (a) A 0.7549 g sample of the compound burns in $O_2(g)$ to produce 1.9061 g of $CO_2(g)$ and 0.3370 g of $H_2O(g)$.
   (i) Calculate the individual masses of C, H, and O in the 0.7549 g sample.
   (ii) Determine the empirical formula for the compound.

   (b) A 0.5246 g sample of the compound was dissolved in 10.0012 g of lauric acid, and it was determined that the freezing point of the lauric acid was lowered by 1.68°C. The value of K_f of lauric acid is 3.90°C m^{-1}. Assume that the compound does not dissociate in lauric acid.
   (i) Calculate the molality of the compound dissolved in the lauric acid.
   (ii) Calculate the molar mass of the compound from the information provided.

   (c) Without doing any calculations, explain how to determine the molecular formula of the compound based on the answers to parts (a)(ii) and (b)(ii).

   (d) Further tests indicate that a 0.10 *M* aqueous solution of the compound has a pH of 2.6. Identify the organic functional group that accounts for this pH.

3. Answer the following questions related to the kinetics of chemical reactions.

$$I^-(aq) + ClO^-(aq) \xrightarrow{OH^-} IO^-(aq) + Cl^-(aq)$$

Iodide ion, I^-, is oxidized to hypoiodite ion, IO^-, by hypochlorite, ClO^-, in basic solution according to the equation above. Three initial-rate experiments were conducted; the results are shown in the following table.

Experiment	$[I^-]$ (mol L^{-1})	$[ClO^-]$ (mol L^{-1})	Initial Rate of Formation of IO^- (mol L^{-1} s^{-1})
1	0.017	0.015	0.156
2	0.052	0.015	0.476
3	0.016	0.061	0.596

(a) Determine the order of the reaction with respect to each reactant listed below. Show your work.
   (i) $I^-(aq)$
   (ii) $ClO^-(aq)$

(b) For the reaction,
   (i) write the rate law that is consistent with the calculations in part (a);
   (ii) calculate the value of the specific rate constant, *k*, and specify units.

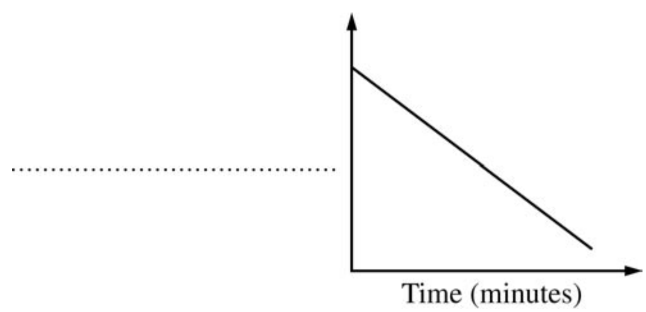
The catalyzed decomposition of hydrogen peroxide, $H_2O_2(aq)$, is represented by the following equation.

$$2\ H_2O_2(aq) \xrightarrow{\text{catalyst}} 2\ H_2O(l) + O_2(g)$$

The kinetics of the decomposition reaction were studied and the analysis of the results show that it is a first-order reaction. Some of the experimental data are shown in the table below.

$[H_2O_2]$ (mol L^{-1})	Time (minutes)
1.00	0.0
0.78	5.0
0.61	10.0

(c) During the analysis of the data, the graph below was produced.



(i) Label the vertical axis of the graph.
(ii) What are the units of the rate constant, *k*, for the decomposition of $H_2O_2(aq)$?
(iii) On the graph, draw the line that represents the plot of the uncatalyzed first-order decomposition of 1.00 M $H_2O_2(aq)$.

Part B

Time—50 minutes
NO CALCULATORS MAY BE USED FOR PART B.

Answer Question 4 below. The Section II score weighting for this question is 15 percent.

4. Write the formulas to show the reactants and the 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) A strip of zinc is placed in a solution of nickel(II) nitrate.

   (b) Solid aluminum hydroxide is added to a concentrated solution of potassium hydroxide.

   (c) Ethyne (acetylene) is burned in air.

   (d) Solid calcium carbonate is added to a solution of ethanoic (acetic) acid.

   (e) Lithium metal is strongly heated in nitrogen gas.

   (f) Boron trifluoride gas is added to ammonia gas.

   (g) Sulfur trioxide gas is bubbled into a solution of sodium hydroxide.

   (h) Equal volumes of 0.1 *M* solutions of lead(II) nitrate and magnesium iodide are combined.

Your responses to the rest of the questions in this part of the exam will be scored on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Examples and equations may be included in your responses where appropriate. Specific answers are preferable to broad, diffuse responses.

Answer BOTH Question 5 below AND Question 6 printed on page 26. Both of these questions will be scored. The Section II score weighting for these questions is 30 percent (15 percent each).

5. Answer the following questions that relate to laboratory observations and procedures.

   (a) An unknown gas is one of three possible gases: nitrogen, hydrogen, or oxygen. For each of the three possibilities, describe the result expected when the gas is tested using a glowing splint (a wooden stick with one end that has been ignited and extinguished, but still contains hot, glowing, partially burned wood).

   (b) The following three mixtures have been prepared: CaO plus water, SiO_2 plus water, and CO_2 plus water. For each mixture, predict whether the pH is less than 7, equal to 7, or greater than 7. Justify your answers.

   (c) Each of three beakers contains a 0.1 *M* solution of one of the following solutes: potassium chloride, silver nitrate, or sodium sulfide. The three beakers are labeled randomly as solution 1, solution 2, and solution 3. Shown below is a partially completed table of observations made of the results of combining small amounts of different pairs of the solutions.

	Solution 1	Solution 2	Solution 3
Solution 1		black precipitate	
Solution 2			no reaction
Solution 3			

   (i) Write the chemical formula of the black precipitate.
   (ii) Describe the expected results of mixing solution 1 with solution 3.
   (iii) Identify each of the solutions 1, 2, and 3.

6. Answer the following questions that relate to chemical bonding.

(a) In the boxes provided, draw the complete Lewis structure (electron-dot diagram) for each of the three molecules represented below.

CF_4	PF_5	SF_4

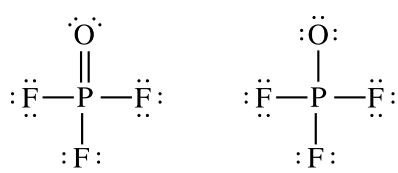
(b) On the basis of the Lewis structures drawn above, answer the following questions about the particular molecule indicated.

(i) What is the F–C–F bond angle in CF_4 ?

(ii) What is the hybridization of the valence orbitals of P in PF_5 ?

(iii) What is the geometric shape formed by the atoms in SF_4 ?

(c) Two Lewis structures can be drawn for the OPF_3 molecule, as shown below.



Structure 1 Structure 2

(i) How many sigma bonds and how many pi bonds are in structure 1 ?

(ii) Which one of the two structures best represents a molecule of OPF_3? Justify your answer in terms of formal charge.

Answer EITHER Question 7 below OR Question 8 printed on page 28. Only one of these two questions will be scored. If you start both questions, be sure to cross out the question you do not want scored. The Section II score weighting for the question you choose is 15 percent.

7. Use principles of atomic structure, bonding, and/or intermolecular forces to respond to each of the following. Your responses must include specific information about all substances referred to in each question.

   (a) At a pressure of 1 atm, the boiling point of $NH_3(l)$ is 240 K, whereas the boiling point of $NF_3(l)$ is 144 K.
      (i) Identify the intermolecular force(s) in each substance.
      (ii) Account for the difference in the boiling points of the substances.

   (b) The melting point of KCl(*s*) is 776°C, whereas the melting point of NaCl(*s*) is 801°C.
      (i) Identify the type of bonding in each substance.
      (ii) Account for the difference in the melting points of the substances.

   (c) As shown in the table below, the first ionization energies of Si, P, and Cl show a trend.

Element	**First Ionization Energy ($kJ\ mol^{-1}$)**
Si	786
P	1,012
Cl	1,251

      (i) For each of the three elements, identify the quantum level (e.g., $n = 1$, $n = 2$, etc.) of the valence electrons in the atom.
      (ii) Explain the reasons for the trend in first ionization energies.

   (d) A certain element has two stable isotopes. The mass of one of the isotopes is 62.93 amu and the mass of the other isotope is 64.93 amu.
      (i) Identify the element. Justify your answer.
      (ii) Which isotope is more abundant? Justify your answer.

$$AgNO_3(s) \rightarrow Ag^+(aq) + NO_3^-(aq)$$

8. The dissolving of $AgNO_3(s)$ in pure water is represented by the equation above.
   (a) Is ΔG for the dissolving of $AgNO_3(s)$ positive, negative, or zero? Justify your answer.
   (b) Is ΔS for the dissolving of $AgNO_3(s)$ positive, negative, or zero? Justify your answer.
   (c) The solubility of $AgNO_3(s)$ increases with increasing temperature.
      (i) What is the sign of ΔH for the dissolving process? Justify your answer.
      (ii) Is the answer you gave in part (a) consistent with your answers to parts (b) and (c) (i) ? Explain.

The compound NaI dissolves in pure water according to the equation $NaI(s) \rightarrow Na^+(aq) + I^-(aq)$. Some of the information in the table of standard reduction potentials given below may be useful in answering the questions that follow.

Half-reaction	***E*° (V)**
$O_2(g) + 4\,H^+ + 4\,e^- \rightarrow 2\,H_2O(l)$	1.23
$I_2(s) + 2\,e^- \rightarrow 2\,I^-$	0.53
$2\,H_2O(l) + 2\,e^- \rightarrow H_2(g) + 2\,OH^-$	–0.83
$Na^+ + e^- \rightarrow Na(s)$	–2.71

   (d) An electric current is applied to a 1.0 M NaI solution.
      (i) Write the balanced oxidation half-reaction for the reaction that takes place.
      (ii) Write the balanced reduction half-reaction for the reaction that takes place.
      (iii) Which reaction takes place at the anode, the oxidation reaction or the reduction reaction?
      (iv) All electrolysis reactions have the same sign for $\Delta G°$. Is the sign positive or negative? Justify your answer.

GUIDE FOR THE RECOMMENDED LABORATORY PROGRAM

The authors of this laboratory guide are the following former members of the AP Chemistry Development Committee.

Peter Demmin, Amherst Central High School, New York
Paula Herron, Whitney M. Young Magnet School, Chicago, Illinois
George Miller, University of California, Irvine
Jerry Mullins, Plano Senior High School, Texas
Arden Zipp, State University College at Cortland, New York

The College Board gratefully acknowledges their contribution.

Introduction

To qualify for accreditation by the American Chemical Society, college chemistry departments typically schedule a weekly laboratory period of three hours. Therefore, it is critical that laboratory work be an important part of an AP Chemistry course so that the course is comparable to a college general chemistry course. Analysis of data from AP Chemistry examinees regarding the length of time they spent per week in the laboratory shows that increased laboratory time is correlated with higher AP grades. The AP Chemistry Development Committee has produced this guide to help teachers and administrators understand the role that laboratory work should play in every AP Chemistry course. This information supplements the guidance provided by the topic outline, which should also be consulted for the most up-to-date information on expectations.

This document does not attempt to provide detailed instructions for experiments, as committee members believe that these are readily available in a number of standard laboratory manuals. Furthermore, it is important that the AP Chemistry laboratory program be adapted to local conditions, even while it aims to offer the students a well-rounded experience with experimental chemistry.

Models showing how several instructors in widely different circumstances have tackled the problems inherent in establishing a high-quality program in AP Chemistry, including laboratory work, are described in considerable detail in the *AP Chemistry Teacher's Guide,* published by the College Board (go to AP Central or see pages 46–47 for ordering information).

General Requirements

The school faculty and administration must make an appropriate commitment for successful implementation of an AP Chemistry course that is designed to be the equivalent of the first-year college course in laboratory chemistry. There are a number of facets to this commitment that must be present for a quality program, including facilities, teacher preparation and training, scheduling, and supplies. A brief review of these items is included in this section. Teachers and administrators must work together to achieve these goals.

School Resources

1. A separate operating and capital budget should be established with the understanding that the per pupil expenditures for this course will be substantially higher than those for regular high school laboratory science courses. Adequate laboratory facilities should be provided so that each student has a work space where equipment and materials can be left overnight if necessary. Sufficient laboratory glassware for the anticipated enrollment and appropriate instruments (sensitive balances, spectrophotometers, and pH meters) should be provided.
2. Students in AP Chemistry should have access to computers with software appropriate for processing laboratory data and writing reports.
3. A laboratory assistant should be provided in the form of a paid or unpaid aide. Parent volunteers, if well organized, may be able to help fill such a role.
4. Flexible or modular scheduling must be implemented in order to meet the time requirements identified in the course outline. Some schools are able to assign daily double periods so that laboratory and quantitative problem-solving skills may be fully developed. At the very least, a weekly extended laboratory period is needed. *It is not possible to complete high-quality AP laboratory work within standard 45- to 50-minute periods.*

Teacher Preparation Time

Because of the nature of the AP Chemistry course, the teacher needs extra time to prepare for laboratory work. Therefore, adequate time must be allotted during the academic year for teacher planning and testing of laboratory experiments.

In the first year of starting an AP Chemistry course, one month of summer time and one additional period each week are also necessary for course preparation work. In subsequent years, an AP Chemistry teacher routinely requires one extra period each week to devote to course preparation.

Teacher Professional Development

AP Chemistry teachers need to stay abreast of current developments in teaching college chemistry. This is done through contacts with college faculty and with high school teacher colleagues. Schools should offer stipends and travel support to enable their teachers to attend workshops and conferences. An adequate budget should be established at the school to support professional development of the AP Chemistry teacher. The following are examples of such opportunities.

1. One- or two-week AP Summer Institutes (supported by the College Board) are offered in several locations.
2. One-day AP conferences are sponsored by College Board regional offices. At these, presentations are made by experienced AP or college-level teachers, many of whom have been AP Exam Readers or members of the Development Committee.
3. AP institutes covering several disciplines are offered as two- or three-day sessions during the school year. These are also organized by College Board regional offices and are held at hotels or universities.

4. Additional opportunities are often provided by local colleges or universities, or by local sections of the American Chemical Society. These can be in the form of one-day workshops, weekend retreats, or summer courses. All offer excellent networking possibilities for AP Chemistry teachers, who can exchange ideas with their colleagues and build long-term support relationships.

Skills and Procedures

When a fact appears opposed to a long train of deductions it invariably proves to be capable of bearing some other interpretation.

—Sherlock Holmes in *A Study in Scarlet*

Laboratory Program Goals

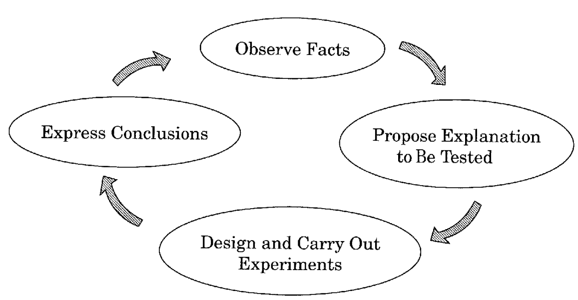
The chemistry laboratory is the place where students learn about the behavior of matter by firsthand observation—to see what actually happens when the "stuff" that makes up the world is "prodded" and "poked." The observations students make may be in marked contrast to preconceived notions of what "should happen" according to textbooks or simplistic theoretical models. The laboratory is the place to learn the difference between observations/recorded data (i.e., facts) and the ideas, inferences, explanations, models (i.e., theories) that may be used to interpret them but are often incomplete or never actually observed.

Chemistry is an experimental science that is most effectively learned through direct experience. Therefore, while computer simulations may be useful to extend or reinforce chemical concepts, they are not adequate substitutes for direct "hands-on" laboratory experience.

The laboratory program that is adopted should challenge every student's ability to:

- think analytically and to reduce problems to identifiable, answerable questions;
- understand problems expressed as experimental questions;
- design and carry out experiments that answer questions;
- manipulate data acquired during an experiment—perhaps even to guide progress;
- make conclusions and evaluate the quality and validity of such conclusions;
- propose further questions for study; and
- communicate accurately and meaningfully about observations and conclusions.

The program of laboratory investigations should be seen as a cyclic continuum of inquiry rather than a linear sequence of steps with a beginning and an end.



Toward this goal, the ideal program should not only allow students to gain experience with traditional laboratory exercises (such as those suggested later) but also provide opportunities for students to carry out novel investigations.

Laboratory Performance Skills

> *To play a violin, one needs to know how to handle it properly. To do a meaningful experiment, one must mix and measure just as properly.*
>
> —Sienko, Plane, and Marcus, 1984

Physical Manipulations

Students must learn the skills necessary to use ordinary equipment such as:

- beakers, flasks, test tubes, crucibles, evaporating dishes, watch glasses, burners, plastic and glass tubing, stoppers, valves, spot plates, funnels, reagent bottles, wash bottles, and droppers;

and measuring equipment, including:

- balances (single pan, double pan, triple beam), thermometers (°C), barometers, graduated cylinders, burets, volumetric pipets, graduated pipets, volumetric flasks, ammeters and voltmeters, pH meters, and spectrophotometers.

Processes and Procedures

Familiarity (more than a single day's experience) with such general types of chemical laboratory work as the following is important:

- synthesis of compounds (solid and gas)
- separations (precipitation and filtration, dehydration, centrifugation, distillation, chromatography)
- observing and recording phase changes (solid—liquid—gas)
- titration using indicators and meters
- spectrophotometry/colorimetry
- devising and utilizing a scheme for qualitative analysis of ions in solution
- gravimetric analysis

Some colleges have laboratory practical exams in which students must perform certain operations accurately within time constraints. Even though this is not part of the AP Chemistry Exam, such exercises are useful in providing students with goals for the development and practice of their laboratory skills.

Observations and Data Manipulation

Students must practice the art of making careful observations and of recording accurately what they observe. Too frequently students confuse *what they see* with *what they think they are supposed to see.* They should be encouraged to be accurate reporters even when this seems to conflict with what the textbook or laboratory procedure has led them to expect. Several great discoveries were made this way (e.g., penicillin and Teflon).

Interpretation of proper observations is also important. Students should be familiar with finding evidence of chemical change (color change, precipitate formation, temperature change, gas evolution, etc.) and its absence (for example, in the identification of spectator ions).

Students should know how to make and interpret quantitative measurements correctly. This includes knowing which piece of apparatus is appropriate. For example, a student should be able to select the correct glassware to dispense *about* 50 mL and the best glassware to dispense *precisely* 10.00 mL of a solution.

Students need a great deal of practice in recording and reporting both qualitative and quantitative information. They should be encouraged to do this properly and at the time that the information is obtained. Often this means anticipating the need to prepare a table in which to record the information to be gathered or a graph on which to plot it. For example, when graphs are prepared during the experiment rather than at some later time, discordant data can often be detected immediately and measurements repeated with little lost time. This is preferable to finding out later that most of the time spent on the experiment was wasted because of an error or misreading.

Students should be given ample opportunity to evaluate their own data, to do their own calculations, and to puzzle over their own errors. They should learn to distinguish between mistakes (blunders) and scientific (experimental) errors. In the latter case, they should also be able to distinguish between systematic and random errors and know how to evaluate their final conclusions in the context of experimental reliability. Even when time does not permit repetition of experiments, students should be asked to comment on how they could have improved their measurements in order to arrive at a more precise conclusion. If extensive computational assistance is available (e.g., a spreadsheet computer program), students should be using it, but they should have full understanding of the operations involved and not just blindly enter numbers to get a "magic" result.

Communication, Group Collaboration, and the Laboratory Record

Laboratory work is an excellent way to help students develop and practice communication skills. Success in subsequent work in chemistry depends heavily on an ability to communicate about chemical observations, ideas, and conclusions. Students must learn to recognize that claiming a knowledge and understanding of chemistry is relatively useless unless they can communicate this knowledge effectively to others.

By working together in a truly collaborative manner to plan and carry out experiments, students learn appropriate oral communication skills as well as how to build social team relationships important to their future scientific work. They must be encouraged to take full individual responsibility for the success of the collaboration and not be a sleeping partner ready to blame the rest of the team for failure. Properly operating teams can assist the instructor greatly by taking over much of the responsibility for preparation and selection of materials, for ensuring safe manipulations, and for cleaning up the laboratory. Effective teams can accomplish more in a given time by working in parallel.

Students must learn how to keep proper records of their experimental work. Even when teams perform experiments, each student should be responsible for making his or her own record of the data obtained. In group work, this ideally leads to double or triple checking of all actions and results, which helps to avoid mistakes and reinforces the idea that the entire team is responsible for the overall experiment. Student laboratory records should form part of the ongoing assessment and evaluation for the course.

If students are required to keep proper records of all experimental work done in the course, they will end the year with a document that is a source of pride and that demonstrates the growth of their skills. *This record is an important document that may be requested by the Chemistry Department at a college or university when a decision is needed regarding credit and/or placement in more advanced chemistry courses.*

Laboratory Safety

The conditions under which AP Chemistry courses are offered vary widely as to facilities and equipment. This is also true for colleges and universities offering general chemistry courses. However, it is important that certain concerns regarding laboratory safety be addressed in all programs. This is important not only for student and instructor safety at the time but also so that students who enter more advanced courses in chemistry have a considerable and expected familiarity with safe laboratory practices.

1. All facilities should conform to federal, state, and local laws and guidelines as they pertain to the safety of students and instructors.
2. Teachers with a limited background in chemistry should receive additional training specifically related to laboratory safety for chemistry laboratories before beginning an assignment in an AP Chemistry course.
3. Laboratory experiments and demonstrations should not be carried out by AP Chemistry students if they could expose the students to risks or hazards that are inappropriate for learning in the instructional sequence (e.g., explosion experiments that do not have any learning objective).
4. Students should be fully informed of potential laboratory hazards relating to chemicals and apparatus before performing specific experiments. If possible, students themselves should research needed safety information in advance online or at a library or local college.
5. Storage and disposal of hazardous chemicals must always be done in accordance with local regulations and policies. As far as possible, the students as well as the instructor should know what these regulations are.

Basic laboratory safety instruction for students should be an integral part of each laboratory experience. Topics that should be covered include:

- simple first aid for cuts and thermal and chemical burns;
- use of safety goggles, eye washes, body showers, fire blankets, and fire extinguishers;

- safe handling of glassware, hot plates, burners and other heating devices, and electrical equipment;
- proper interpretation of Material Safety Data Sheets (MSDS) and hazard warning labels; and
- proper use and reuse practices (including proper labeling of interim containers) for reagent bottles.

A successful AP Chemistry laboratory program will instill in each student a true, lifelong "safety sense" that will ensure his or her safe transition into more advanced laboratory work in college or university laboratories or into the industrial workplace environment.

Recommended Experiments

Because there is a required laboratory-based question on the free-response section of the AP Chemistry Exam, the inclusion of appropriate experiments in each AP Chemistry course is important for student success. Data show that student scores on the AP Chemistry Exam improve with increased time spent in the laboratory.

It is unlikely that every student will complete all of the 22 laboratory experiments below while enrolled in an AP Chemistry course. Some of these experiments, in whole or in part, may be performed during a student's first course in chemistry before the student takes the AP Chemistry course. Also, when planning a laboratory program, it may be useful to consider the experiments in various ways. For example, they might be grouped according to the skills and techniques that the experiments require; e.g., experiments 6, 7, 8, 11, and 19 are all related to titrations. Alternatively, they might be divided on the basis of the chemical concepts that they explore and reinforce; e.g., experiments 8, 20, and 21 all relate to oxidation-reduction and electrochemistry. The major consideration when selecting experiments should be to provide students with the broadest laboratory experience possible.

1. Determination of the formula of a compound

   Teacher preparation time: 2 hours
   Student completion time: 1.5 hours
   Equipment: crucible and cover, tongs, analytical balance, support stand, triangle crucible support, burner

2. Determination of the percentage of water in a hydrate

   Teacher preparation time: 2 hours
   Student completion time: 1 hour
   Equipment: crucible and cover, tongs, test tube, analytical balance, support stand, triangle crucible support, wire gauze, burner

3. Determination of molar mass by vapor density

   Teacher preparation time: 2 hours
   Student completion time: 1.5 hours
   Equipment: barometer, beaker, Erlenmeyer flask, graduated cylinder, clamp, analytical balance, support stand

4. Determination of molar mass by freezing-point depression

   Teacher preparation time: 1 hour
   Student completion time: 2 hours
   Equipment: test tube, thermometer, pipet, beaker, stirrer, stop-watch, ice

5. Determination of the molar volume of a gas

   Teacher preparation time: 1.5 hours
   Student completion time: 2 hours
   Equipment: barometer, beaker, Erlenmeyer flask, test tubes, graduated cylinder, clamp, analytical balance, thermometer, rubber tubing

6. Standardization of a solution using a primary standard

   Teacher preparation time: 1 hour
   Student completion time: 2 hours
   Equipment: pipet, buret, Erlenmeyer flasks, volumetric flask, wash bottle, analytical balance, drying oven, desiccator, support stand, pH meter

7. Determination of concentration by acid-base titration, including a weak acid or weak base

   Teacher preparation time: 1.5 hours
   Student completion time: 2 hours
   Equipment: pipet, buret, Erlenmeyer flasks, wash bottle, analytical balance, drying oven, desiccator, support stand and clamp, pH meter

8. Determination of concentration by oxidation-reduction titration

   Teacher preparation time: 1.5 hours
   Student completion time: 2 hours
   Equipment: pipet, buret, Erlenmeyer flasks, wash bottle, analytical balance, drying oven, desiccator, support stand and clamp, pH meter as millivoltmeter

9. Determination of mass and mole relationship in a chemical reaction

   Teacher preparation time: 1 hour
   Student completion time: 2 hours
   Equipment: beaker, Erlenmeyer flask, graduated cylinder, hot plate, desiccator, analytical balance

10. Determination of the equilibrium constant for a chemical reaction

    Teacher preparation time: 1.5 hours
    Student completion time: 2 hours
    Equipment: pipet, test tubes and/or cuvettes, volumetric flask, analytical balance, spectrophotometer (Spec 20 or 21)

11. Determination of appropriate indicators for various acid-base titrations; pH determination

    Teacher preparation time: 2 hours
    Student completion time: 2 hours

Equipment: pipet, Erlenmeyer flasks, graduated cylinder, volumetric flask, analytical balance, pH meter

12. Determination of the rate of a reaction and its order

    Teacher preparation time: 2 hours
    Student completion time: 2 hours
    Equipment: pipet, buret, Erlenmeyer flasks, graduated cylinder or gas measuring tubes, stopwatch, thermometer, analytical balance, support stand and clamp

13. Determination of enthalpy change associated with a reaction

    Teacher preparation time: 0.5 hours
    Student completion time: 2 hours
    Equipment: calorimeter (can be polystyrene cup), graduated cylinder, thermometer, analytical balance

14. Separation and qualitative analysis of cations and anions

    Teacher preparation time: 2–4 hours
    Student completion time: 3+ hours
    Equipment: test tubes, beaker, evaporating dish, funnel, watch glass, mortar and pestle, centrifuge, Pt or Ni test wire

15. Synthesis of a coordination compound and its chemical analysis

    Teacher preparation time: 2 hours
    Student completion time: 2+ hours
    Equipment: beaker, Erlenmeyer flask, evaporating dish, volumetric flask, pipet, analytical balance, test tubes/cuvettes, spectrophotometer

16. Analytical gravimetric determination

    Teacher preparation time: 1 hour
    Student completion time: 1.5 hours
    Equipment: beakers, crucible and cover, funnel, desiccator, drying oven, Meker burner, analytical balance, support stand, and crucible support triangle

17. Colorimetric or spectrophotometric analysis

    Teacher preparation time: 1 hour
    Student completion time: 2 hours
    Equipment: pipet, buret, test tubes and/or cuvettes, spectrophotometer, buret support stand

18. Separation by chromatography

    Teacher preparation time: 1 hour
    Student completion time: 2 hours
    Equipment: test tubes, pipet, beaker, capillary tubes or open tubes or burets, ion exchange resin or silica gel (or filter paper strips, with heat lamp or blow dryer)

19. Preparation and properties of buffer solutions
    Teacher preparation time: 1 hour
    Student completion time: 1.5 hours
    Equipment: pipet, beaker, volumetric flask, pH meter

20. Determination of electrochemical series
    Teacher preparation time: 1 hour
    Student completion time: 1 hour
    Equipment: test tubes and holder rack, beakers, graduated cylinder, forceps

21. Measurements using electrochemical cells and electroplating
    Teacher preparation time: 1.5 hours
    Student completion time: 1.5 hours
    Equipment: test tubes, beaker, filter flasks, filter crucibles and adapters, electrodes, voltmeter, power supply (battery)

22. Synthesis, purification, and analysis of an organic compound
    Teacher preparation time: 0.5 hours
    Student completion time: 2+ hours
    Equipment: Erlenmeyer flask, water bath, thermometer, burner, filter flasks, evaporating dish (drying oven), analytical balance, burets, support stand, capillary tubes

Microscale Experiments

One important change in chemistry laboratory instruction in recent years has been the introduction of microscale experiments. While the initial goal in this development may have been to improve safety by reducing the amounts of hazardous materials handled, several other benefits have been realized. These include:

- decreased cost of chemicals acquisition and disposal;
- reduced storage space requirements and safer storage;
- less need for elaborate laboratory facilities in schools;
- greater care needed by students to obtain and observe results;
- shorter experiment times as well as easier and faster cleanup; and
- ability to carry out some experiments that were once restricted to demonstrations because of their hazards in macroscale.

Some of these benefits are of particular interest to the AP Chemistry teacher because less time, poorer facilities, and fewer resources for laboratory work are available in high schools than in colleges and universities. Though not all laboratory experiments lend themselves to microscale or CBL™, many do. The time and resources saved by using microscale can be used for more trials or for additional experiments, thus enabling students to complete a more meaningful laboratory program than might be possible with only macroscale techniques.

The techniques employed and the supplies needed for microscale experiments are described in several of the laboratory manuals listed in the resources section of the *AP Chemistry Teacher's Guide* (read more about the guide below), or on AP Central. Typically, these experiments are carried out using plastic pipets and well trays, available at low cost from most laboratory supply houses. Some materials can be adapted from or replaced by items available at commercial restaurant supply and discount warehouses.

AP Chemistry teachers are encouraged to exchange information regarding effective microscale and macroscale laboratory experiments. This can readily be done through local AP workshops. Teachers should contact their College Board regional office to find out about such workshops. Also, it is strongly suggested that teachers contact local college or university Chemistry Departments and ask about their laboratory programs and their use of microscale techniques in general chemistry courses. The topic of "microscale laboratories" would make an ideal subject for a conference of chemistry instructors that could be organized by a local division of the American Chemical Society or other chemistry or science teacher's association. A regular feature on "The Microscale Laboratory" is included in the *Journal of Chemical Education.*

Many of the recommended experiments described in the previous section are suitable for AP Chemistry in a microscale version.

Resources

You will find it a very good practice to always verify your references, sir!

—Routh (1755–1854)

An excellent primary resource for tips and advice on how to begin or enhance an AP Chemistry laboratory program is the *AP Chemistry Teacher's Guide*. The guide includes syllabi from AP Chemistry teachers and college professors who teach general chemistry, as well as descriptions of laboratory programs and experiments. Go to AP Central or see pages 46–47 for ordering information.

Publishers of general chemistry textbooks typically market an associated laboratory manual. Most laboratory manuals have instructor's guides or instructor's versions that provide invaluable help in preparing equipment and solutions. Many contain prelaboratory exercises for each experiment and special sections on safety, general techniques for using equipment, and instructions for writing laboratory reports. Another important resource for laboratory reports is the *ACS Style Guide* (2nd edition, 1997), which is available from the American Chemical Society (www.chemistry.org).

Teachers who are beginning or adapting laboratory programs will find other helpful resources at AP Central. The Teachers' Resources section of the Web site offers reviews of textbooks, articles, Web sites, and other teaching resources. At AP Central, teachers can also subscribe to a moderated electronic discussion group (EDG) and request advice or opinions regarding all issues relating to the teaching of AP Chemistry, including the laboratory.

AP® Program Essentials

The AP Reading

Each year in June, the free-response section of the exams, as well as the AP Studio Art portfolios, are scored by college faculty and secondary school AP teachers at the AP Reading. Thousands of Readers participate, under the direction of a Chief Reader (a college professor) in each AP subject. The experience offers both significant professional development and the opportunity to network with like-minded educators.

If you are an AP teacher or a college faculty member and would like to serve as a Reader, you can apply online at apcentral.collegeboard.com/reader. Alternatively, you can send an e-mail to apreader@ets.org or call Performance Assessment Scoring Services at 609 406-5384.

AP Grades

The Readers' scores on the essay and problem-solving questions are combined with the results of the computer-scored multiple-choice questions, and the total raw scores are converted to a composite score on AP's 5-point scale:

AP GRADE	QUALIFICATION
5	Extremely well qualified
4	Well qualified
3	Qualified
2	Possibly qualified
1	No recommendation

Grade Distributions

Many teachers want to compare their students' grades with national percentiles. Grade distribution charts are available at AP Central, as is information on how the grade boundaries for each AP grade are established. Grade distribution charts are also available on the AP student site at www.collegeboard.com/apstudents.

Why Colleges Grant Credit, Placement, or Both for AP Grades

Colleges know that the AP grades of incoming students represent a level of achievement equivalent to that of students who take the same course in the colleges' own classrooms. That equivalency is ensured through several AP Program processes:

- College faculty serve on the committees that develop the Course Descriptions and exams in each AP course.
- College faculty are responsible for standard setting and are involved in the evaluation of student responses at the AP Reading.
- AP courses and exams are reviewed and updated regularly based on the results of curriculum surveys at up to 200 colleges and universities, collaborations among the College Board and key educational and disciplinary organizations, and the interactions of committee members with professional organizations in their discipline.

- Periodic college comparability studies are undertaken in which the performance of college students on AP Exams is compared with that of AP students to confirm that the AP grade scale of 1 to 5 is properly aligned with current college standards.

In addition, the College Board has commissioned studies that use a "bottom-line" approach to validating AP Exam grades by comparing the achievement of AP students with non-AP students in higher level college courses. For example, in the 1998 Morgan and Ramist "21-College" study, AP students who were exempted from introductory courses and who completed a higher level course in college compared favorably, on the basis of their college grades, with students who completed the prerequisite first course in college, then took the second, higher level course in the subject area. Such studies answer the question of greatest concern to colleges: Are AP students who are exempted from introductory courses as well prepared to continue in a subject area as students who took their first course in college? To see the results of several college validity studies, visit apcentral.collegeboard.com/colleges/research. (The complete Morgan and Ramist study can be downloaded from the site.)

Guidelines on Setting Credit and Placement Policies for AP Grades

The College Board has created two useful resources for admissions administrators and academic faculty who need guidance on setting an AP policy for their college or university. The printed guide *AP and Higher Education* provides guidance for colleges and universities in setting AP credit and placement policies. The booklet details how to set an AP policy, summarizes AP research studies, and describes in detail course and exam development and the exam scoring process. AP Central has a section geared toward colleges and universities that provides similar information and additional resources, including links to all AP research studies, Released Exam questions, and sample student responses at varying levels of achievement for each AP Exam. Visit apcentral.collegeboard.com/highered.

The *Advanced Placement Policy Guide* for each AP subject is designed for college faculty responsible for setting their department's AP policy. These folios provide content specific to each AP Exam, including validity research studies and a description of the AP course curriculum. Ordering information for these and other publications can be found in the AP Publications and Other Resources section of this Course Description.

College and University AP Credit and Placement Policies

Each college and university sets its own AP credit and placement policies. The AP Program has created an online search tool, AP Credit Policy Info, that provides links to credit and placement policies at hundreds of colleges and universities. The tool helps students find the credit hours and advanced placement they can receive for qualifying exam scores within each AP subject. AP Credit Policy Info is available at www.collegeboard.com/ap/creditpolicy.

AP Scholar Awards

The AP Program offers a number of AP Scholar Awards to recognize high school students who have demonstrated college-level achievement through consistently high performance on AP Exams. Although there is no monetary award, students receive an award certificate, and the achievement is acknowledged on grade reports sent to colleges following the announcement of the awards. For detailed information about AP Scholar Awards (including qualification criteria), visit AP Central or contact the College Board's national office. Students can find this information at www.collegeboard.com/apstudents.

AP Calendar

The *AP Program Guide* for education professionals and the *Bulletin for AP Students and Parents* provide important Program information and details on the key events in the AP calendar. Information on ordering or downloading these publications can be found at the back of this book.

Exam Security

All parts of every AP Exam must be kept secure at all times. Forty-eight hours after the exam has been administered, the inserts containing the free-response questions (Section II) can be made available for teacher and student review.* **However, the multiple-choice section (Section I) must remain secure both before and after the exam administration.** No one other than students taking the exam can ever have access to or see the questions contained in Section I—this includes AP Coordinators and all teachers. The multiple-choice section must never be shared, copied in any manner, or reconstructed by teachers and students after the exam. **Schools that knowingly or unknowingly violate these policies will not be permitted to administer AP Exams in the future and may be held responsible for any damages or losses the College Board and/or ETS incur in the event of a security breach.**

Selected multiple-choice questions are reused from year to year to provide an essential method of establishing high exam reliability, controlled levels of difficulty, and comparability with earlier exams. These goals can be attained only when the multiple-choice questions remain secure. This is why teachers cannot view the questions, and students cannot share information about these questions with anyone following the exam administration.

To ensure that all students have an equal opportunity to demonstrate their abilities on the exam, AP Exams must be administered in a uniform manner. **It is extremely important to follow the administration schedule and all procedures outlined in detail in the most recent *AP Coordinator's Manual*.** Please note that AP Studio Art portfolios and their contents are not considered secure testing materials; see the *AP Coordinator's Manual* and the appropriate *AP Examination Instructions* book for further information. The *Manual* also includes directions on how to handle misconduct and other security problems. All schools participating in AP automatically

*The free-response section of the alternate form (used for late-testing administration) is NOT released.

receive printed copies of the *Manual*. It is also available in PDF format at apcentral.collegeboard.com/coordinators. Any breach of security should be reported to the Office of Testing Integrity immediately (call 800 353-8570 or 609 406-5427, fax 609 406-9709, or e-mail tsreturns@ets.org).

Teacher Support

AP Central® (apcentral.collegeboard.com)

You can find the following Web resources at AP Central (free registration required):

- AP Course Descriptions, AP Exam questions and scoring guidelines, sample syllabi, research reports, and feature articles.
- A searchable Institutes and Workshops database, providing information about professional development events. AP Central offers online events that participants can access from their home or school computers.
- The Course Home Pages (apcentral.collegeboard.com/coursehomepages), which contain insightful articles, teaching tips, activities, lab ideas, and other course-specific content contributed by colleagues in the AP community.
- In-depth FAQs, including brief responses to frequently asked questions about AP courses and exams, the AP Program, and other topics of interest.
- Links to AP publications and products (some available for immediate download) that can be purchased online at the College Board Store (store.collegeboard.com).
- Moderated electronic discussion groups (EDGs) for each AP course to facilitate the exchange of ideas and practices.
- Teachers' Resources database—click on the "Teachers' Resources" tab to search for reviews of textbooks, reference books, documents, Web sites, software, videos, and more. College and high school faculty write the reviews with specific reference to the value of the resources in teaching AP courses.

Online Workshops and Events

College Board online events and workshops are designed to help support and expand the high level of professional development currently offered to teachers in Pre-AP and AP workshops and AP Summer Institutes. Because of budgetary, geographical, and time constraints, not all teachers and administrators are able to take advantage of live, face-to-face workshops. The College Board develops and offers both standard and customized online events and workshops for schools, districts, and states in both live and recorded formats. Online events and workshops are developed and presented by experienced College Board consultants and college faculty. Full-day online workshops are equivalent to one-day, face-to-face workshops and participants can earn CEU credits. For more information, visit apcentral.collegeboard.com/onlineevents.

Pre-AP®

Pre-AP® is a suite of K–12 professional development resources and services designed to help equip middle school and high school teachers with the strategies and tools they need to engage their students in high-level learning, thereby ensuring that every middle school and high school student has the opportunity to acquire a deep understanding of the skills, habits of mind, and concepts they need to succeed in college.

Pre-AP is based on the following premises. The first is the expectation that all students can perform at rigorous academic levels. This expectation should be reflected in the curriculum and instruction throughout the school so that all students are consistently being challenged to bring their knowledge and skills to the next level.

The second important premise of Pre-AP is the belief that educators can prepare every student for higher intellectual engagement by starting the development of skills and the acquisition of knowledge as early as possible. When addressed effectively, the middle school and high school years can provide a powerful opportunity to help all students acquire the knowledge, concepts, and skills needed to engage in a higher level of learning.

Pre-AP teacher professional development explicitly supports the goal of college as an option for every student. It is important to have a recognized standard for college-level academic work. The AP Program provides these standards for Pre-AP. Pre-AP professional development resources reflect the topics, concepts, and skills taught in AP courses and assessed in AP Exams.

The College Board does not design, develop, or assess courses or examinations labeled "Pre-AP." The College Board discourages the labeling of courses as "Pre-AP." Typically, such courses create a track, thereby limiting access to AP classes. The College Board supports the assertion that all students should have access to preparation for AP and other challenging courses. Courses labeled "Pre-AP" can inappropriately restrict access to AP and other college-level work and, as such, are inconsistent with the fundamental purpose of the College Board's Pre-AP initiatives.

Pre-AP Professional Development

Pre-AP professional development is available through workshops and conferences coordinated by the College Board's regional offices. Pre-AP professional development is divided into three categories:

1. **Vertical Teaming—**Articulation of content and pedagogy across the middle school and high school years. The emphasis is on aligning curricula and improving teacher communication. The intended outcome is a coordinated program of teaching skills and concepts over several years.
2. **Classroom Strategies—**Content-specific classroom strategies for middle school and high school teachers. Various approaches, techniques, and ideas are emphasized.

3. **Instructional Leadership—**Administrators and other instructional leaders examine how to use Pre-AP professional development—especially AP Vertical Teams®—to create a system that challenges all students to perform at rigorous academic levels.

For a complete list of Pre-AP professional development offerings, please contact your regional office or visit apcentral.collegeboard.com/pre-ap.

AP Publications and Other Resources

A number of AP resources are available to help students, parents, AP Coordinators, and high school and college faculty learn more about the AP Program and its courses and exams. To identify resources that may be of particular use to you, refer to the following key.

AP Coordinators and Administrators .... **A**
College Faculty .... **C**
Students and Parents .... **SP**
Teachers .... **T**

Free Resources

Copies of the following items can be ordered free of charge at apcentral.collegeboard.com/freepubs. Items marked with a computer mouse icon can be downloaded for free from AP Central.

The Value of AP Courses and Exams **A, SP, T**

This brochure, available in English and Spanish, can be used by school counselors and administrators to provide parents and students with information about the many benefits of participation in AP courses and exams.

AP Tools for Schools Resource Kit **A**

This complimentary resource assists schools in building their AP programs. The kit includes the video *Experience College Success*, the brochure *The Value of AP Courses and Exams*, and brief descriptions of the AP Credit Policy Info search tool and the Parent's Night *PowerPoint* presentation.

Experience College Success is a six-minute video that provides a short overview of the AP Program, with commentary from admissions officers, college students, and high school faculty about the benefits of participation in AP courses. Each videotape includes both an English and Spanish version.

Bulletin for AP Students and Parents **SP**

This bulletin provides a general description of the AP Program, including information on the policies and procedures related to taking the exams. It describes each AP Exam, lists the advantages of taking the exams, describes the grade reporting process, and includes the upcoming exam schedule. The *Bulletin* is available in both English and Spanish.

Get with the Program **SP**

All students, especially those from underserved backgrounds, should understand the value of a high-quality education. Written especially for students and their families, this bilingual (Spanish/English) brochure highlights the benefits of participation in the AP Program. (The brochure can be ordered in large quantities for students in grades 8–12.)

AP Program Guide **A**

This guide takes the AP Coordinator through the school year step-by-step—organizing an AP program, ordering and administering the AP Exams, AP Exam payment, and grade reporting. It also includes information on teacher professional development, AP resources, and exam schedules.

AP and Higher Education **A, C, T**

This publication is intended to inform and help educational professionals at the secondary and postsecondary levels understand the benefits of having a coherent, equitable AP credit and placement policy. Topics included are development of AP courses and exams, grading of AP Exams, exam validation, research studies comparing the performance of AP students with non-AP students, uses of AP Exams by students in college, and how faculty can get involved in the AP Program.

Advanced Placement Policy Guides **A, C, T**

These policy guides are designed for college faculty responsible for setting their department's AP policy, and provide, in a subject-specific context, information about AP validity studies, college faculty involvement, and AP course curricular content. There are separate guides for each AP subject field.

Priced Publications

The following items can be ordered through the College Board Store at store.collegeboard.com. Alternatively, you can download an AP Order Form from AP Central at apcentral.collegeboard.com/documentlibrary.

Course Descriptions **A, C, SP, T**

Course Descriptions are available for each AP subject. They provide an outline of each AP course's content, explain the kinds of skills students are expected to demonstrate in the corresponding introductory college-level course, and describe the AP Exam. Sample multiple-choice questions with an answer key and sample free-response questions are included.

Note: PDF versions of current AP Course Descriptions for each AP subject may be downloaded free of charge from AP Central and the College Board's Web site for students. Follow the above instructions to purchase printed copies. (The Course Description for AP Computer Science is available in electronic format only.)

Released Exams **C, T**

Periodically the AP Program releases a complete copy of each exam. In addition to providing the multiple-choice questions and answers, the publication describes the process of scoring the free-response questions and includes examples of students' actual responses, the scoring standards, and commentary that explains why the responses received the scores they did.

Teacher's Guides **T**

For those about to teach an AP course for the first time, or for experienced AP teachers who would like to get some fresh ideas for the classroom, the *Teacher's Guide* is an excellent resource. Each *Teacher's Guide* contains syllabi developed by high school teachers currently teaching the AP course and college faculty who teach the equivalent course at colleges and universities. Along with detailed course outlines and innovative teaching tips, you'll also find extensive lists of suggested teaching resources.

AP Vertical Team Guides **A, T**

AP Vertical Teams (APVT) are made up of teachers from different grade levels who work together to develop and implement a sequential curriculum in a given discipline. Teams help students acquire the skills necessary for success in AP courses. To assist teachers and administrators who are interested in establishing an APVT at their school, the College Board has published these guides: *AP Vertical Teams Guide for English; AP Vertical Teams Guide for Mathematics; AP Vertical Teams Guide for Science; AP Vertical Teams Guide for Social Studies; AP Vertical Teams Guide for World Languages and Cultures; AP Vertical Teams Guide for Fine Arts, Vol. 1: Studio Art; AP Vertical Teams Guide for Fine Arts, Vol. 2: Music Theory;* and *AP Vertical Teams Guide for Fine Arts, Vols. 1 and 2* (set).

Multimedia

APCD® (home version), (multinetwork site license) **SP, T**

These CD-ROMs are available for AP Calculus AB, AP English Literature, AP European History, and AP U.S. History. They each include actual AP Exams, interactive tutorials, exam descriptions, answers to frequently asked questions, and test-taking strategies. Also included are a listing of resources for further study and a planner to help students schedule and organize their study time.

The teacher version of each CD, which can be licensed for up to 50 workstations, enables you to monitor student progress and provide individual feedback. Included is a Teacher's Manual that gives full explanations along with suggestions for utilizing the APCD in the classroom.

Electronic Publications

Additional supplemental publications are available in electronic format to be purchased and downloaded from the College Board Store. These include a collection of 13 AP World History Teaching Units, AP Calculus free-response questions and solutions from 1969 to 1997, the *Physics Lab Guide*, and a collection of Java syllabi for AP Computer Science.

Announcements of new electronic publications can be found on the AP Course Home Pages on AP Central (apcentral.collegeboard.com/coursehomepages).

Contact Us

National Office
Advanced Placement Program
45 Columbus Avenue
New York, NY 10023-6992
212 713-8066
E-mail: ap@collegeboard.org

AP Services
P.O. Box 6671
Princeton, NJ 08541-6671
609 771-7300
877 274-6474 (toll free in the U.S. and Canada)
E-mail: apexams@info.collegeboard.org

AP Canada Office
2950 Douglas Street, Suite 550
Victoria, BC, Canada V8T 4N4
250 472-8561
800 667-4548 (toll free in Canada only)
E-mail: gewonus@ap.ca

AP International Office
Serving all countries outside the U.S. and Canada
45 Columbus Avenue
New York, NY 10023-6992
212 373-8738
E-mail: apintl@collegeboard.org

Middle States Regional Office
Serving Delaware, District of Columbia, Maryland, New Jersey, New York, Pennsylvania, Puerto Rico, and the U.S. Virgin Islands
Two Bala Plaza, Suite 900
Bala Cynwyd, PA 19004-1501
866 392-3019
E-mail: msro@collegeboard.org

Midwestern Regional Office
Serving Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, West Virginia, and Wisconsin
6111 N. River Road, Suite 550
Rosemont, IL 60018-5158
866 392-4086
E-mail: mro@collegeboard.org

New England Regional Office
Serving Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont
470 Totten Pond Road
Waltham, MA 02451-1982
866 392-4089
E-mail: nero@collegeboard.org

Southern Regional Office
Serving Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia
3700 Crestwood Parkway NW, Suite 700
Duluth, GA 30096-7155
866 392-4088
E-mail: sro@collegeboard.org

Southwestern Regional Office
Serving Arkansas, New Mexico, Oklahoma, and Texas
4330 South MoPac Expressway, Suite 200
Austin, TX 78735-6735
866 392-3017
E-mail: swro@collegeboard.org

Western Regional Office
Serving Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, Washington, and Wyoming
2099 Gateway Place, Suite 550
San Jose, CA 95110-1051
866 392-4078
E-mail: wro@collegeboard.org

apcentral.collegeboard.com

I.N. 050081741