The College Board

AP® ADVANCED PLACEMENT PROGRAM®

Course Description

CHEMISTRY

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The College Board is a national nonprofit membership association dedicated to preparing, inspiring, and connecting students to college and opportunity. Founded in 1900, the association is composed of more than 3,900 schools, colleges, universities, and other educational organizations. Each year, the College Board serves over three million students and their parents, 22,000 high schools, and 3,500 colleges, through major programs and services in college admission, guidance, assessment, financial aid, enrollment, and teaching and learning. Among its best-known programs are the SAT®, the PSAT/NMSQT™, the Advanced Placement Program® (AP®), and Pacesetter®. The College Board is committed to the principles of equity and excellence, and that commitment is embodied in all of its programs, services, activities, and concerns.

Visit College Board on the Web: **www.collegeboard.com/ap.**

Dear Colleagues:

Last year more than three quarters of a million high school students benefited from the opportunity of studying in AP courses and then taking the challenging AP Exams. These students experienced the power of learning as it comes alive in the classroom, as well as the practical benefits of earning college credit and placement while still in high school. Behind each of these students was a talented, hardworking teacher. Teachers are the secret to the success of AP. They are the heart and soul of the Program.

The College Board is committed to supporting the work of AP teachers in as many ways as possible. AP workshops and Summer Institutes held around the globe provide stimulating professional development for 60,000 teachers each year. The College Board Fellows stipends provide funds to support many teachers' attendance at these institutes, and in 2001, stipends were offered for the first time to teams of Pre-AP™ teachers as well.

Perhaps most exciting, the College Board continues to expand an interactive Web site designed specifically to support AP teachers. At this Internet site, teachers have access to a growing array of classroom resources, from textbook reviews to lesson plans, from opinion polls to cutting-edge exam information. I invite all AP teachers, particularly those who are new to the Program, to take advantage of these resources.

This AP Course Description provides an outline of content and description of course goals, while still allowing teachers the flexibility to develop their own lesson plans and syllabi, and to bring their individual creativity to the AP classroom. Additional resources, including sample syllabi, can be found in the AP Teacher's Guide that is available for each AP subject.

As we look to the future, the College Board's goal is to provide access to AP courses in every high school. Reaching this goal will require a lot of hard work. We encourage you to help us build bridges to college and opportunity by finding ways to prepare students in your school to benefit from participation in AP.

Sincerely,

Gaston Caperton
President
The College Board

Contents

Welcome to the AP Program

The Advanced Placement Program is sponsored by the College Board, a non-profit membership association. AP offers 35 college-level courses and exams in 19 subject areas for highly motivated students in secondary schools. Its reputation for excellence results from the close cooperation among secondary schools, colleges, and the College Board. More than 2,900 universities and colleges worldwide grant credit, advanced placement, or both to students who have performed satisfactorily on the exams, and 1,400 institutions grant sophomore standing to students who meet their requirements. Approximately 13,000 high schools throughout the world participate in the AP Program; in May 2000, they administered more than 1.3 million AP Exams.

You will find more information about the AP Program at the back of this Course Description, and at www.collegeboard.com/ap. This Web site is maintained for the AP Program by collegeboard.com, a destination Web site for students and parents.

AP Courses

AP courses are available in the subject areas listed on the next page. (Unless noted, an AP course is equivalent to a full-year college course.) Each course is developed by a committee composed of college faculty and AP teachers. Members of these Development Committees are appointed by the College Board and serve for overlapping terms of up to four years.

AP Exams

For each AP course, an AP Exam is administered at participating schools and multischool centers worldwide. Schools register to participate by completing the AP Participation Form and agreeing to its conditions. For more details, see *A Guide to the Advanced Placement Program*; information about ordering and downloading this publication can be found at the back of this booklet.

Except for Studio Art — which consists of a portfolio assessment — all exams contain a free-response section (either essay or problem-solving) and another section consisting of multiple-choice questions. The modern language exams also contain a speaking component, and the Music Theory exam includes a sight-singing task.

AP Subject Areas	**AP Courses and Exams**
Art	Art History; Studio Art: Drawing Portfolio; Studio Art: 2-D Portfolio; Studio Art: 3-D Portfolio
Biology	Biology
Calculus	AB; BC
Chemistry	Chemistry
Computer Science	A*; AB
Economics	Macroeconomics*; Microeconomics*
English	Language and Composition; Literature and Composition; International English Language (APIEL™)
Environmental Science	Environmental Science*
French	Language; Literature
German	Language
Geography	Human Geography*
Government and Politics	Comparative*; United States*
History	European; United States; World
Latin	Literature; Vergil
Music	Music Theory
Physics	B; C: Electricity and Magnetism*; C: Mechanics*
Psychology	Psychology*
Spanish	Language; Literature
Statistics	Statistics*

* This subject is the equivalent of a half-year college course.

Equity and Access

The College Board and the Advanced Placement Program encourage teachers, AP Coordinators, and school administrators to make equity and access guiding principles 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. The Board encourages the elimination of barriers that restrict access to AP courses for students from ethnic and racial groups that have been traditionally underrepresented in the AP Program.

For more information about equity and access in principle and practice, contact the National Office in New York.

Introduction to AP Chemistry

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, as freshmen, second-year work in the chemistry sequence at their institution or to register in courses in other fields where general chemistry is a prerequisite. For other students, the AP Chemistry course fulfills the laboratory science requirement and frees time for other courses.

AP Chemistry should meet the objectives of a good general chemistry course. Students in such a course should attain a depth of understanding of fundamentals and a reasonable competence in dealing with chemical problems. The course should contribute to the development of the students' abilities to think clearly and to express their ideas, orally and in writing, with clarity and logic. The college course in general chemistry differs qualitatively from the usual first secondary school course in chemistry with respect to the kind of textbook used, the topics covered, the emphasis on chemical calculations and the mathematical formulation of principles, and the kind of laboratory work done by 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. A survey of students who took the 1986 AP Chemistry Examination indicates that the probability of achieving a grade of 3 or higher on the AP Chemistry Examination is significantly greater for students who successfully complete a first course in high school chemistry prior to undertaking the AP course. Thus it is strongly recommended that credit in a first-year high school chemistry course be a prerequisite for enrollment in an AP Chemistry class. *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 candidate demands that adequate classroom and laboratory time be scheduled. Data obtained from a 1986 survey of students taking the AP Chemistry Examination indicate that performance improved as both total instructional time and time devoted to laboratory work increased.

Thus it is expected that a minimum of 290 minutes per week should be allotted for an AP Chemistry course. Of the total allocated time, a minimum of 90 minutes per week, preferably in one 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.

It is assumed that the student will spend at least five hours a week in unsupervised individual study.

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 relations 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 is to achieve its objectives.

Among the many available high-quality college textbooks appropriate for AP Chemistry courses are the following (inclusion of a text in this list does not constitute endorsement by the College Board, ETS, or the AP Chemistry Development Committee):

Atkins, P. W., and L. Jones. *Chemical Principles*, New York: Freeman, 1999.

Brown, T. L., H. E. LeMay, Jr., and B. E. Bursten. *Chemistry: The Central Science and Media Companion*, 8th ed. Upper Saddle River, N.J.: Prentice-Hall, 2000.

Chang, R. *Chemistry (with E-Text CD-ROM, Solutions Manual, and Student Study Guide)* Boston: McGraw Hill, 2000.

Ebbing, D., and S. D. Gammon. *General Chemistry*, 6th ed. Boston: Houghton Mifflin, 1999.

Hill, J. W., and R. H. Petrucci. *General Chemistry: An Integrated Approach*, 2nd ed. Upper Saddle River, NJ: Prentice Hall, 1999.
Kotz, J. C., and P. Treichel. *Chemistry and Chemical Reactivity*, 4th ed. Fort Worth: Saunders, 1999.
Oxtoby, D. W., H. P. Gillis, and N. H. Nachtrieb. *Principles of Modern Chemistry*, 4th ed. Fort Worth: Saunders, 1999.
Whitten, K. W., R. E. Davis, and M. P. Peck. *General Chemistry*, 6th ed. Fort Worth: Saunders, 2000.
Zumdahl, S. S. *Chemistry*, 5th ed. Boston: Houghton Mifflin, 2000.

Supplemental textbooks that can serve as resources for teachers include the following:

Robinson, R. W., J. D. Odom, and H. F. Holtzclaw. *General Chemistry with Qualitative Analysis*, 10th ed. Boston: Houghton Mifflin, 1997.
Silberberg, M. *Chemistry: The Molecular Nature of Matter and Change*, 2nd ed. St. Louis: Mosby, 2000.

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, the teaching should be done by a teacher who has completed an undergraduate major program in chemistry including at least a year's work in physical chemistry. Teachers with such training are best able to present a course with adequate breadth and depth and to develop the 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. There is no desire to impose greater uniformity on the secondary schools than now exists in the 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 examination 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 (The use of normalities is not tested.)
   3. Raoult's law and colligative properties (nonvolatile solutes); osmosis
   4. Non-ideal 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 Examination 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 36-51 of this booklet. The Guide describes the general requirements for an AP Chemistry laboratory program and contains a list of recommended experiments. Also included in the Guide is a list of resources that AP Chemistry teachers should find helpful in developing a successful laboratory program.

Colleges have reported that some AP candidates, while doing well on the examination, 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 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 Examination

The AP Chemistry Examination is a 180-minute examination, divided into two parts. The first part (90 minutes) constitutes 45 percent of the final grade and consists of 75 multiple-choice questions with broad coverage of topics. Teachers should not try to prepare students to answer every question on a test of this kind. 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 test must be so comprehensive that no student should be expected to make a perfect or near-perfect score. Thought-provoking problems and questions based on fundamental ideas from chemistry are included.

The second part of the examination, which constitutes 55 percent of the final grade, is 90 minutes. For the first 40 minutes of this part, students will be permitted to use a calculator as they work on several comprehensive problems. Time will be called at 40 minutes, after which calculators must be put away for the remaining 50 minutes. During these last 50 minutes, students will answer a question requiring the determination of products of chemical reactions and several essay questions.

The student is allowed considerable choice among the questions included in the second part of the examination. The problems allow the student to demonstrate reasoning abilities by the application of chemical principles to problem solving. The question pertaining to descriptive chemistry in this section of the examination asks students to write ionic and molecular formulas for reactants and products of chemical reactions. The essays give the candidate an opportunity to demonstrate the ability to think clearly and to present ideas in a logical and coherent fashion.

Calculators

The policy regarding the use of calculators on the AP Chemistry Examination 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 taking the section of the examination 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 Examination. 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 18-21 (#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.

***Exceptions to calculator use.** Although most calculators are permitted on the free-response section, it should be noted that they may not be shared with other students. Some specific calculators that are not permitted include minicomputers, electronic writing pads or pen-input devices (Newton, Palm), pocket organizers, models with QWERTY (i.e., typewriter) keyboards (TI-92 and HP-95), models with paper tapes, models that make noise or "talk," and models that require an electrical outlet.

Calculators (with exceptions noted below) will be allowed only during the first 40 minutes of the free-response section of the examination. During this time, students will work on two problems, one that is required and one chosen from a set of two other problems. **Any programmable or graphing calculator may be used, and students will NOT be required to erase their calculator memories before or after the examination.** 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 50 minutes of the examination, 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 on the green inserts provided with each examination for students to use when taking the free-response section. The equation tables are NOT permitted for use with the multiple-choice section of the examination. The equation tables are reprinted on pages 15-16 of this booklet. In general, the equations for each year's examination will be 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, since the equation tables will be provided with the examination, students will NOT be allowed to bring their own copies to the examination room.

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 grading 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 examination. 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 examination 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.

ATOMIC STRUCTURE

$$\Delta E = h\nu$$
$$c = \lambda\nu$$
$$\lambda = \frac{h}{mv}$$
$$p = mv$$
$$E_n = \frac{-2.178 \times 10^{-18}}{n^2} \text{ joule}$$

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

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

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

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

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

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

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

EQUILIBRIUM

$$K_a = \frac{[H^+][A^-]}{[HA]}$$
$$K_b = \frac{[OH^-][HB^+]}{[B]}$$
$$K_w = [OH^-][H^+] = 1.0 \times 10^{-14} \text{ @ } 25^\circ\text{C}$$
$$= K_a \times K_b$$
$$\text{pH} = -\log[H^+],\ \text{pOH} = -\log[OH^-]$$
$$14 = \text{pH} + \text{pOH}$$
$$\text{pH} = \text{p}K_a + \log\frac{[A^-]}{[HA]}$$
$$\text{pOH} = \text{p}K_b + \log\frac{[HB^+]}{[B]}$$
$$\text{p}K_a = -\log K_a,\ \text{p}K_b = -\log K_b$$
$$K_p = K_c(RT)^{\Delta n},$$
where Δn = moles product gas − moles reactant gas

Equilibrium Constants

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

THERMOCHEMISTRY

$$\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$$
$$\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$$
$$\Delta G^\circ = \sum \Delta G_f^\circ \text{ products} - \sum \Delta G_f^\circ \text{ reactants}$$
$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$
$$= -RT \ln K = -2.303\, RT \log K$$
$$= -n \mathcal{F} E^\circ$$
$$\Delta G = \Delta G^\circ + RT \ln Q = \Delta G^\circ + 2.303\, RT \log Q$$
$$q = mc\Delta T$$
$$C_p = \frac{\Delta H}{\Delta T}$$

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
1 faraday $\mathcal{F}$ = 96,500 coulombs

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

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

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

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

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

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

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

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

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

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

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

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

molarity, M = moles solute per liter solution

molality = moles solute per kilogram solvent

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

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

$$\pi = \frac{nRT}{V}i$$

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
$\mathbf{M}$ = molar mass
π = osmotic pressure
i = van't Hoff factor
K_f = molal freezing-point depression constant
K_b = molal boiling-point elevation constant
Q = reaction quotient
I = current (amperes)
q = charge (coulombs)
t = time (seconds)
E° = standard reduction potential
K = equilibrium constant

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

OXIDATION-REDUCTION; ELECTROCHEMISTRY

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

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

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

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

Sample Multiple-Choice Questions

The following multiple-choice questions provide a representative subset of those used in previous AP Examinations in Chemistry. There are two types of multiple-choice questions on the examination. The first type of question 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.

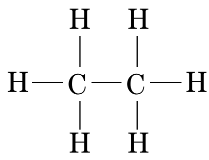
(A) Lithium
(B) Carbon
(C) Nitrogen
(D) Oxygen
(E) Fluorine

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) $\dfrac{0.4(0.082)(298)}{4}$ atm

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

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

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

    (E) $\dfrac{0.3(0.082)(25)}{4}$ 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) $SO_3^{2-}(aq) \rightarrow SO_4^{2-}(aq)$

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

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) $HCN(aq) + C_2H_3O_2^-(aq) \rightleftarrows HC_2H_3O_2(aq) + CN^-(aq)$

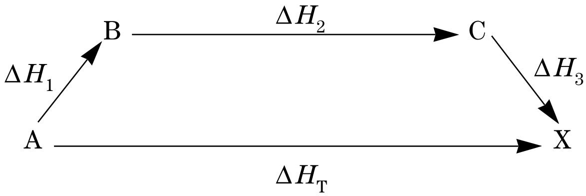
Experiment	*Initial* [X] *(mol L^{-1})*	*Initial* [Y] *(mol L^{-1})*	*Initial Rate of Formulation of* Z *(mol L^{-1} min^{-1})*
1	0.10	0.30	4.0×10^{-4}
2	0.20	0.60	1.6×10^{-3}
3	0.20	0.30	4.0×10^{-4}

22. The data in the table above were obtained for the reaction $X + Y \rightarrow Z$. 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

Section II of the 2000 AP Chemistry Examination is reproduced here. Students are provided with a periodic table, a table of standard reduction potentials, and a table containing various equations and constants. Additional sample questions are available in the AP section of the College Board Web site

Part A

Time—40 minutes

YOU MAY USE YOUR CALCULATOR FOR PART A.

CLEARLY SHOW THE METHOD USED AND STEPS INVOLVED IN ARRIVING AT YOUR ANSWERS. It is to your advantage to do this, because you may earn 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 this booklet.

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

$$2\ H_2S(g) \rightleftarrows 2\ H_2(g) + S_2(g)$$

1. When heated, hydrogen sulfide gas decomposes according to the equation above. A 3.40 g sample of $H_2S(g)$ is introduced into an evacuated rigid 1.25 L container. The sealed container is heated to 483 K, and 3.72×10^{-2} mol of $S_2(g)$ is present at equilibrium.

   (a) Write the expression for the equilibrium constant, K_c, for the decomposition reaction represented above.

   (b) Calculate the equilibrium concentration, in mol L^{-1}, of the following gases in the container at 483 K.
   (i) $H_2(g)$
   (ii) $H_2S(g)$

(c) Calculate the value of the equilibrium constant, K_c, for the decomposition reaction at 483 K.

(d) Calculate the partial pressure of $S_2(g)$ in the container at equilibrium at 483 K.

(e) For the reaction $H_2(g) + \frac{1}{2} S_2(g) \rightleftarrows H_2S(g)$ at 483 K, calculate the value of the equilibrium constant, K_c.

Answer EITHER Question 2 below OR Question 3 printed on page 29. Only one of these two questions will be graded. If you start both questions, be sure to cross out the question you do not want graded. The Section II score weighting for the question you choose is 20 percent.

2. Answer the following questions that relate to electrochemical reactions.

   (a) Under standard conditions at 25°C, Zn(*s*) reacts with $Co^{2+}(aq)$ to produce Co(*s*).

      (i) Write the balanced equation for the oxidation half reaction.

      (ii) Write the balanced net-ionic equation for the overall reaction.

      (iii) Calculate the standard potential, $E°$, for the overall reaction at 25°C.

   (b) At 25°C, H_2O_2 decomposes according to the following equation.

$$2\ H_2O_2(aq) \rightarrow 2\ H_2O(l) + O_2(g) \qquad E° = 0.55\ V$$

      (i) Determine the value of the standard free energy change, $\Delta G°$, for the reaction at 25°C.

      (ii) Determine the value of the equilibrium constant, K_{eq}, for the reaction at 25°C.

      (iii) The standard reduction potential, $E°$, for the half reaction $O_2(g) + 4\ H^+(aq) + 4\ e^- \rightarrow 2\ H_2O(l)$ has a value of 1.23 V. Using this information in addition to the information given above, determine the value of the standard reduction potential, $E°$, for the half reaction below.

$$O_2(g) + 2\ H^+(aq) + 2\ e^- \rightarrow H_2O_2(aq)$$

   (c) In an electrolytic cell, Cu(*s*) is produced by the electrolysis of $CuSO_4(aq)$. Calculate the maximum mass of Cu(*s*) that can be deposited by a direct current of 100. amperes passed through 5.00 L of 2.00 *M* $CuSO_4(aq)$ for a period of 1.00 hour.

3. Answer the following questions about $BeC_2O_4(s)$ and its hydrate.

(a) Calculate the mass percent of carbon in the hydrated form of the solid that has the formula $BeC_2O_4 \cdot 3\ H_2O$

(b) When heated to 220.°C, $BeC_2O_4 \cdot 3\ H_2O(s)$ dehydrates completely as represented below.

$$BeC_2O_4 \cdot 3\ H_2O(s) \rightarrow BeC_2O_4(s) + 3\ H_2O(g)$$

If 3.21 g of $BeC_2O_4 \cdot 3\ H_2O(s)$ is heated to 220.°C, calculate

(i) the mass of $BeC_2O_4(s)$ formed, and,

(ii) the volume of the $H_2O(g)$ released, measured at 220.°C and 735 mm Hg.

(c) A 0.345 g sample of anhydrous BeC_2O_4, which contains an inert impurity, was dissolved in sufficient water to produce 100. mL of solution. A 20.0 mL portion of the solution was titrated with $KMnO_4(aq)$. The balanced equation for the reaction that occurred is as follows.

$$16\ H^+(aq) + 2\ MnO_4^-(aq) + 5\ C_2O_4^{2-}(aq) \rightarrow 2\ Mn^{2+}(aq) + 10\ CO_2(g) + 8\ H_2O(l).$$

The volume of 0.0150 M $KMnO_4(aq)$ required to reach the equivalence point was 17.80 mL.

(i) Identify the reducing agent in the titration reaction.

(ii) For the titration at the equivalence point, calculate the number of moles of each of the following that reacted.

- $MnO_4^-(aq)$
- $C_2O_4^{2-}(aq)$

(iii) Calculate the total number of moles of $C_2O_4^{2-}(aq)$ that were present in the 100. mL of prepared solution.

(iv) Calculate the mass percent of $BeC_2O_4(s)$ in the impure 0.345 g sample.

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 small piece of calcium metal is added to hot distilled water.

   (b) Butanol is burned in air.

   (c) Excess concentrated ammonia solution is added to a solution of nickel(II) sulfate.

   (d) A solution of copper(II) chloride is added to a solution of sodium sulfide.

   (e) A solution of tin(II) nitrate is added to a solution of silver nitrate.

   (f) Excess hydrobromic acid solution is added to a solution of potassium hydrogen carbonate.

   (g) Powdered strontium oxide is added to distilled water.

   (h) Carbon monoxide gas is passed over hot iron(III) oxide.

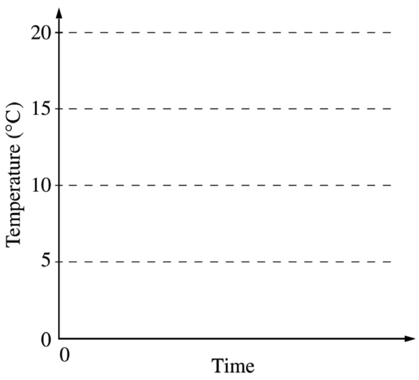
Answer BOTH Question 5 below AND Question 6 printed on page 32. Both of these questions will be graded. The Section II score weighting for these questions is 30 percent (15 percent each).

5. The molar mass of an unknown solid, which is nonvolatile and a nonelectrolyte, is to be determined by the freezing-point depression method. The pure solvent used in the experiment freezes at 10°C and has a known molal freezing-point depression constant, K_f. Assume that the following materials are also available.

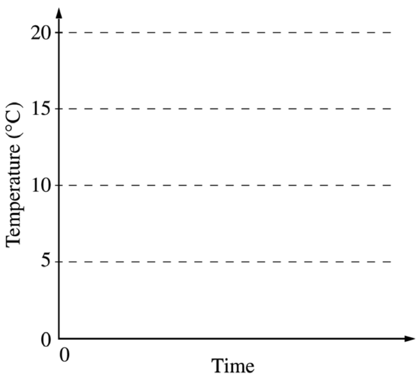
- test tube
- beaker
- stirrer
- stop watch
- pipet
- graph paper
- thermometer
- hot-water bath
- balance
- ice

(a) Using the two sets of axes provided below, sketch cooling curves for (i) the pure solvent and for (ii) the solution as each is cooled from 20°C to 0.0°C.

Pure Solvent



Solution



(b) Information from these graphs may be used to determine the molar mass of the unknown solid.

(i) Describe the measurements that must be made to determine the molar mass of the unknown solid by this method.

(ii) Show the setup(s) for the calculation(s) that must be performed to determine the molar mass of the unknown solid from the experimental data.

(iii) Explain how the difference(s) between the two graphs in part (a) can be used to obtain information needed to calculate the molar mass of the unknown solid.

(c) Suppose that during the experiment a significant but unknown amount of solvent evaporates from the test tube. What effect would this have on the calculated value of the molar mass of the solid (i.e., too large, too small, or no effect)? Justify your answer.

(d) Show the setup for the calculation of the percentage error in a student's result if the student obtains a value of 126 g mol^{-1} for the molar mass of the solid when the actual value is 120. g mol^{-1}.

$$O_3(g) + NO(g) \rightarrow O_2(g) + NO_2(g)$$

6. Consider the reaction represented above.

(a) Referring to the data in the table below, calculate the standard enthalpy change, $\Delta H°$, for the reaction at 25°C. Be sure to show your work.

	$O_3(g)$	$NO(g)$	$NO_2(g)$
Standard enthalpy of formation, ΔH_f°, at 25°C ($kJ\ mol^{-1}$)	143	90.	33

(b) Make a qualitative prediction about the magnitude of the standard entropy change, $\Delta S°$, for the reaction at 25°C. Justify your answer.

(c) On the basis of your answers to parts (a) and (b), predict the sign of the standard free-energy change, $\Delta G°$, for the reaction at 25°C. Explain your reasoning.

(d) Use the information in the table below to write the rate-law expression for the reaction, and explain how you obtained your answer.

Experiment Number	Initial $[O_3]$ (mol L^{-1})	Initial [NO] (mol L^{-1})	Initial Rate of Formation of NO_2 (mol L^{-1} s^{-1})
1	0.0010	0.0010	x
2	0.0010	0.0020	$2x$
3	0.0020	0.0010	$2x$
4	0.0020	0.0020	$4x$

(e) The following three-step mechanism is proposed for the reaction. Identify the step that must be the slowest in order for this mechanism to be consistent with the rate-law expression derived in part (d). Explain.

Step I: $O_3 + NO \rightarrow O + NO_3$

Step II: $O + O_3 \rightarrow 2\ O_2$

Step III: $NO_3 + NO \rightarrow 2\ NO_2$

Answer EITHER Question 7 below OR Question 8 printed on page 35. Only one of these two questions will be graded. If you start both questions, be sure to cross out the question you do not want graded. The Section II score weighting for the question you choose is 15 percent.

7. Answer the following questions about the element selenium, Se (atomic number 34).

   (a) Samples of natural selenium contain six stable isotopes. In terms of atomic structure, explain what these isotopes have in common, and how they differ.

   (b) Write the complete electron configuration (e.g., $1s^2\ 2s^2 \ldots$ etc.) for a selenium atom in the ground state. Indicate the number of unpaired electrons in the ground-state atom, and explain your reasoning.

   (c) In terms of atomic structure, explain why the first ionization energy of selenium is

      (i) less than that of bromine (atomic number 35), and

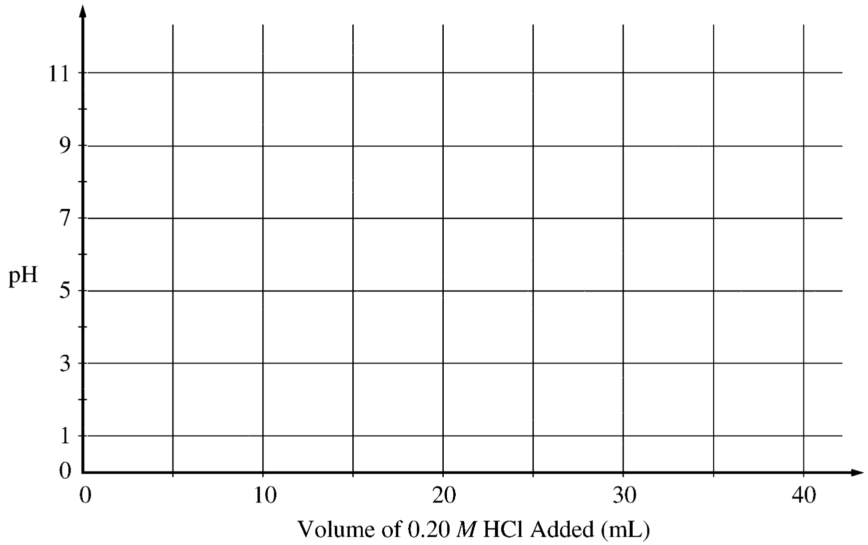
      (ii) greater than that of tellurium (atomic number 52).

   (d) Selenium reacts with fluorine to form SeF_4. Draw the complete Lewis electron-dot structure for SeF_4 and sketch the molecular structure. Indicate whether the molecule is polar or nonpolar, and justify your answer.

8. A volume of 30.0 mL of 0.10 M $NH_3(aq)$ is titrated with 0.20 M $HCl(aq)$. The value of the base-dissociation constant, K_b, for NH_3 in water is 1.8×10^{-5} at 25°C.

(a) Write the net-ionic equation for the reaction of $NH_3(aq)$ with $HCl(aq)$.

(b) Using the axes provided below, sketch the titration curve that results when a total of 40.0 mL of 0.20 M $HCl(aq)$ is added dropwise to the 30.0 mL volume of 0.10 M $NH_3(aq)$.



(c) From the table below, select the most appropriate indicator for the titration. Justify your choice.

Indicator	**pK_a**
Methyl Red	5.5
Bromothymol Blue	7.1
Phenolphthalein	8.7

(d) If equal volumes of 0.10 M $NH_3(aq)$ and 0.10 M $NH_4Cl(aq)$ are mixed, is the resulting solution acidic, neutral, or basic? Explain.

Guide for the Recommended Laboratory Program

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

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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 course 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*, which is published by the College Board.

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, including facilities, teacher preparation and training, scheduling, and supplies that must be present for a quality program. 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. Counseling and guidance personnel should be thoroughly briefed as to the nature of the program and the need to have students succeed in the course. Full attention must be given to mechanisms that identify potentially successful candidates and avoid inappropriate placement of students.
5. 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 (some 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 involved as faculty consultants at AP Readings or as 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."

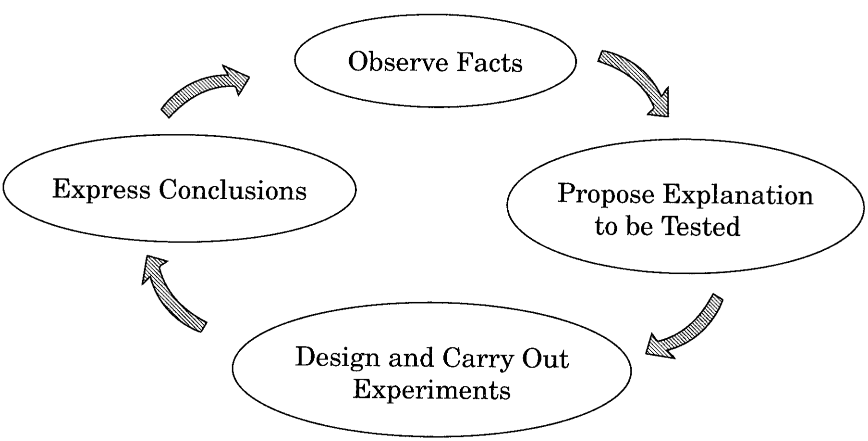
The observations students make may be in marked contrast to preconceived notions of what "should happen" according to textbooks or simplistic theoretical models. The laboratory is the place to learn the difference between observations/recorded data (i.e., facts) and the ideas, inferences, explanations, 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, involving more than a single day's experience, is important with such general types of chemical laboratory work as the following:

- 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 examinations in which students must perform certain operations accurately within time constraints. Even though this is not part of the AP Chemistry Examination, 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 some 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 assuring 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 when there is access to such information in a library or at a 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, 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

With the introduction in 1999 of a required laboratory-based question on the free-response section of the AP Chemistry Exam, the inclusion of appropriate experiments into each AP Chemistry course is increasingly important. Data show that student scores on the AP Chemistry Exam improved with increased time spent in the laboratory. This correlation is expected to be even stronger now that a question concerned with laboratory experiences is included on the examination each year.

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, stopwatch, 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 clean-up; 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 that are listed in the resources section. 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 regional College Board 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)

This listing is not meant to be exhaustive, but it represents suggestions from the authors for items that may be helpful to teachers beginning or adapting laboratory programs for AP Chemistry. Most general chemistry textbook publishers publish a laboratory manual keyed to their textbook. No attempt is made to list these here. *No endorsement of any program or publication is implied by this listing.*

General

Bond, W., ed. *Teacher's Guide — AP Chemistry*. New York: College Board, 2000.

Mullins, J., ed. *Teacher's Guide to Advanced Placement Courses in Chemistry*. New York: College Entrance Examination Board, 1994.

Dodd, J. S., ed. *The ACS Style Guide.* Washington, DC: American Chemical Society, 2nd ed. Sections on word usage and table construction are especially useful.

Laboratory Manuals

Most laboratory manuals have associated instructor's guides or instructor's versions that provide invaluable help in preparing equipment and solutions. Most contain prelaboratory exercises for each experiment and special sections on safety, how to write laboratory reports, and general techniques for using apparatus. Each publisher of a textbook in general chemistry markets an associated laboratory manual. Many are ring bound to lie flat, or punched to be torn apart and inserted into a ring binder.

Abraham, M. R., and M. J. Pavelich. *Inquiries into Chemistry*, 2nd ed. Prospect Heights, IL.: Waveland Press, 1991. Has some open-ended experiments to challenge students and guided inquiry experiments to introduce concepts. Mostly macroscale, but some microscale experiments.

Bishop, C. B. et al. *Experiments for General Chemistry*, 2nd ed. Orlando, FL: Saunders College Pub., 1992. Contains 32 experiments, with qualitative analysis.

Brown, T. L., H. E. LeMay, and B. E. Burstein. *Laboratory Experiments for the 6th Edition of Chemistry, The Central Science.* Englewood

Cliffs, NJ: Prentice-Hall, 1994. Contains 40 experiments with supplementary material on techniques.

Chemical Education Resources, Inc. *Modular Laboratory Program in Chemistry.* 1992 catalog. This program, mostly macroscale, allows instructors to package their own laboratory manuals by selecting individual experiment modules that are indexed to particular portions of the curriculum. Recent additions to the extensive list include new introductory-level experiments and a few microscale versions of experiments.

Ehrenkranz, D., and J. J. Mauch. *Chemistry in Microscale*, 2nd ed. Dubuque, IA: Kendall/Hunt, 1996.

Hall, J. F. *Experimental Chemistry*, 4th ed. Boston: Houghton Mifflin, 1997. A comprehensive manual with extensive introductions and *Choices* for instructor variations or possible extensions to experiments.

Hunt, H. R., and T. F. Block. *Laboratory Experiments for General Chemistry*, 3rd ed. Fort Worth: Saunders, 1997. Contains 42 experiments. An instructor's manual is also available to help in setup.

Milio, F. R., N. W. G. Debye, and C. Metz. *Experiments in Chemistry*, Philadelphia: Saunders, 1991. Contains 44 experiments applying principles in the laboratory. Designed to be a comprehensive program with substantial theory included in introductory sections.

Mills, J. L., and M. D. Hampton. *Microscale and Macroscale Experiments for General Chemistry.* New York: McGraw-Hill, 1991. Contains 25 microscale and 15 macroscale experiments for a full two-semester course.

Mills, J. L., and M. D. Hampton. *Microscale Experiments for General Chemistry.* New York: McGraw-Hill, 1991.

Peck, L., and K. J. Irgolic. *Measurement and Synthesis in the Chemistry Laboratory*, 2nd ed. Upper Saddle River, NJ: Prentice Hall, 1998. Contains 35 experiments in a new style format with complete concept introduction and operations sections.

Roberts, J. L., J. L. Hollenberg, and J. M. Postma. *Chemistry in the Laboratory*, 4th ed. New York: Freeman, 1997. A comprehensive and stand-alone manual coordinated with the McQuarrie and Rock textbook in the classic Frantz/Malm style.

Vonderbrink, S. *Laboratory Experiments for Advanced Placement Chemistry*. Batavia, IL: Flinn Scientific, 1995.

The Microscale Laboratory. *Journal of Chemical Education.* A regular feature.

Safety

Care and Handling of Laboratory Glassware. Corning Glassworks, Corning, NY 14831. (Free)

ChemAlert poster. Fisher Scientific - EMD, 4990 W. LeMoyne St., Chicago, IL 60605. (Free)

Chemical Storage Chart. Fisher Scientific - EMD (see above). (Free)

Design of Safe Chemical Labs. Brochure. American Chemical Society, 1155 16th St., N.W., Washington DC 20036. (Free)

Flinn Scientific Reference Manual and Catalog. Flinn Scientific, Batavia, IL.

Jump Start Instruction. National Society to Prevent Blindness, New York, 1980. (Free)

Laboratory Safety Supply Catalog. Lab Safety Supply Company, Janesville, WI. (Free)

Pocket Emergency Handbook. National Safety Council Ave., 444 N. Michigan Ave., Chicago, IL 60651. ($4.50 for 10)

Safety in the High School Chemunity. American Chemical Society (see above). (Free)

Safety Brochures and Posters. National Safety Council (see above). Many different items.

Safety in Academic Chemistry Laboratories. American Chemical Society, Washington, DC, 1995.

Safety Manual and Catalog. Fisher Scientific (see above). (Free)

Speaking of Safety. Newsletter. Laboratory Safety Workshop, Curry College, Milton, MA 02186. (Free)

Lab Safety Web Sites

Howard Hughes Medical Institute — www.hhmi.org

Flinn Scientific — www.flinnsci.com

Vermont Safety Information Resources, Inc. — www.hazard.com

University of Minnesota, Environmental Health & Safety — www.dehs.umn.edu

University of Nebraska-Lincoln, Department of Chemistry — wwitch.unl.edu/safety/

Material Safety Data Sheets search — www.ilpi.com/msds/index.html

ChemFinder Webserver Project — www. chemfinder.camsoft.com

AP Program Essentials

The AP Reading

In June, the free-response sections of the exams, as well as the portfolios in Studio Art, are scored by college and secondary school teachers at the AP Reading. Thousands of these faculty consultants participate, under the direction of a Chief Faculty Consultant in each field. The experience offers both significant professional development and the opportunity to network with like-minded educators; if you are an AP teacher or a member of a college faculty and would like to serve as a faculty consultant, you can apply online in the AP section of the College Board's Web site. Alternatively, send an e-mail message to apreader@ets.org, or call Performance Scoring Services at 609 406-5383.

AP Grades

The faculty consultants' judgments 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 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 the national percentiles. Grade distribution charts are available in the subject pages of the AP Web site, as is information on how the cut-off points for each AP grade are calculated.

AP and College Credit

Advanced placement and/or credit is awarded by the college or university, not the College Board or the AP Program. The best source of specific and up-to-date information about an individual institution's policy is its catalog or Web site.

Why Colleges Give Credit for AP Grades

Colleges need to know that the AP grades they receive for their 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 assured through several Advanced Placement Program processes:

- College faculty serve on the committees that develop the course descriptions and examinations in each AP subject.
- 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 updated regularly, based on both the results of curriculum surveys at up to 200 colleges and universities and the interactions of committee members with professional organizations in their discipline.
- 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 1–5 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 versus 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 are compared, 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 their 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, go to the AP pages of the College Board's Web site. (The aforementioned Morgan and Ramist study can be downloaded from the site in its entirety.)

Guidelines on Granting Credit for AP Grades

If you are an admission administrator and need guidance on setting a policy for your college, you will find the *College and University Guide to the Advanced Placement Program* useful; see the back of this booklet for ordering information. Alternatively, contact your local College Board Regional Office, as noted on the inside back cover of this booklet.

Finding Colleges That Accept AP Grades

In addition to contacting colleges directly for their AP policies, students and teachers can use College Search, an online resource maintained by the College Board through its Annual Survey of Colleges. College Search can be accessed via the College Board's Web site (www.collegeboard.com). It is worth remembering, though, that policies are subject to change. Contact the college directly to get the most up-to-date information.

AP Scholar Awards and the AP International Diploma

The AP Program offers a number of awards to recognize high school students who have demonstrated college-level achievement through AP courses and exams. In addition, the AP International Diploma (APID) certifies the achievement of successful AP candidates who plan to apply to a university outside the United States.

For detailed information on AP Scholar Awards and the APID, including qualification criteria, visit the AP Web site or contact the College Board's National Office. Students' questions are also answered in the *AP Bulletin for Students and Parents*; information about ordering and downloading the *Bulletin* can be found at the back of this booklet.

AP Calendar

To get an idea of the various events associated with running an AP program and administering the AP Exams, please refer to this year's edition of *A Guide to the Advanced Placement Program*; information about ordering and downloading the *Guide* can be found at the back of this booklet.

Test Security

The entire AP Exam must be kept secure until the scheduled administration date. Except during the actual exam administration, exam materials must be placed in locked storage. Forty-eight hours after the exam has been administered, the green and blue inserts from the free-response section (Section II) are 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 candidates taking

*The alternate (make-up) form of the free-response section is NOT released.

the exam can ever have access to or see the questions contained in this section — this includes AP Coordinators and AP teachers. The multiple-choice section must never be shared or copied in any manner.

Various combinations of 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 only be attained 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 chance to perform 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*.** The manual also includes directions on how to deal with misconduct and other security problems. Any breach of security should be reported immediately through the test security hot line (call 800 353-8570, e-mail tsreturns@ets.org, or fax 609 406-9709).

Teacher Support

Look for these enhanced Web resources at www.collegeboard.com/ap

- Information about AP Exam development, administration, scoring and grading, fees, and scheduling.
- Program news, such as exam format changes, opinion polls (teacher surveys, ad hoc polls), and profiles of successful teachers and AP programs.
- A searchable catalog of teaching resources, including: course topic outlines, sample syllabi and lesson plans, strategies and tips, topic briefs, links, and textbook reviews.
- A searchable catalog of professional development opportunities (e.g., workshops, summer institutes, conferences). New and experienced AP teachers are invited to attend workshops and institutes to learn the fundamentals of teaching an AP course, as well as the latest expectations for each course and exam. Sessions ranging from one day to three weeks in length are held year-round. Dates, locations, topics, and fee information are also available through the College Board's Regional Offices.

- Online forums for exchanging ideas with AP teachers.
- Sample multiple-choice and free-response questions.

To supplement these online resources, there are a number of AP publications, CD-ROMs, and videos that can assist AP teachers. Please see the following pages for an overview and for ordering information.

Pre-AP™

Preparing Students for Challenging Courses; Preparing Teachers for Student Success

Pre-AP has two objectives: (1) to promote access to AP for all students; (2) to provide professional development through content-specific strategies to build a rigorous curriculum. Teachers employ Pre-AP strategies and materials to introduce skills, concepts, and assessment methods that prepare students for success when they take AP and other challenging academic courses. Schools use Pre-AP strategies to strengthen and align the curriculum across grade levels, and to increase the academic challenge for all students.

Pre-AP professional development is available to teachers through Building Success workshops and through AP Vertical Teams™ conferences and workshops.

- **Building Success** is a two-day workshop that assists English and history teachers in designing curricula for grade 7 and above. Teachers learn strategies to help students engage in active questioning, analysis, and constructing arguments. Workshop topics include assessment, interdisciplinary teaching and learning, and vertical planning.
- **AP Vertical Teams** are trained via one-day workshops, two-day conferences, and five-day summer institutes; they enable middle school and high school teachers to prepare Pre-AP students for academic success in AP courses and in college. Topics include organizing effective teams, aligning curricula, and developing content-specific teaching strategies.
- **Setting the Cornerstones: Building the Foundation of AP Vertical Teams** is a two-day workshop designed to provide information about the College Board and the AP Program, and to suggest strategies for establishing coherence, commitment, collegiality, and collaboration among the members of an AP Vertical Team.

For more information about Building Success workshops and for schedules of AP Vertical Teams workshops and conferences, contact your College Board Regional Office. Alternatively, contact Mondy Raibon, Pre-AP Initiatives, AP Program, The College Board, 45 Columbus Avenue, New York, NY 10023-6992; 212 713-8156; mraibon@collegeboard.org.

AP Publications and Other Resources

A number of AP publications, CD-ROMs, and videos 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.

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

Ordering Information

You have several options for ordering publications:

- **Online.** Visit the College Board store to see descriptions and pictures of AP publications and to place your order.
- **By mail.** Send a completed order form with your payment or credit card information to: Advanced Placement Program, Dept. E-06, P.O. Box 6670, Princeton, NJ 08541-6670. If you need a copy of the order form, you can download one from the AP Library (www.collegeboard.com/ap/library).
- **By fax.** Credit card orders can be faxed to AP Order Services at 609 771-7385.
- **By phone.** Call AP Order Services at 609 771-7243, Monday through Friday 8:00 a.m. to 9:00 p.m., and Saturday 9:00 a.m. to 4:45 p.m. ET. Have your American Express, MasterCard, or VISA information ready. This phone number is for credit card orders only.

Payment must accompany all orders not on an institutional purchase order or credit card, and checks should be made payable to the College Board. The College Board pays fourth-class book rate postage (or its equivalent) on all prepaid orders; you should allow two to three weeks for delivery. Postage will be charged on all orders requiring billing and/or requesting a faster method of shipment.

Publications may be returned within 15 days of receipt if postage is prepaid and publications are in resalable condition and still in print. Unless otherwise specified, **orders will be filled with the currently available edition;** prices are subject to change without notice.

Print

Items marked with a computer mouse icon can be downloaded for free from the AP Library (www.collegeboard.com/ap/library).

AP Bulletin for Students and Parents: Free **SP**

This bulletin provides a general description of the AP Program, including policies and procedures for preparing to take the exams, and registering for the AP courses. It describes each AP Exam, lists the advantages of taking the exams, describes the grade reporting and award options available to students, and includes the upcoming exam schedule.

College and University Guide to the AP Program: $10 **C, A**

This guide is intended to help college and university faculty and administrators understand the benefits of having a coherent, equitable AP policy. Topics included are validity of AP grades; developing and maintaining scoring standards; ensuring equivalent achievement; state legislation supporting AP; and quantitative profiles of AP students by each AP subject.

Course Descriptions: $12 **SP, T, A, C**

Course Descriptions provide an outline of the AP course content, explain the kinds of skills students are expected to demonstrate in the corresponding introductory college-level course, and describe the AP Exam. They also provide sample multiple-choice questions with an answer key, as well as sample free-response questions. A complete set of Course Descriptions is available for $100.

A Guide to the Advanced Placement Program: Free **A**

Written for both administrators and AP Coordinators, this guide is divided into two sections. The first section provides general information about AP, such as how to organize an AP program at your high school, the kind of training and support that is available for AP teachers, and a look at the AP Exams and grades. The second section contains more specific details about testing procedures and policies and is intended for AP Coordinators.

Interpreting and Using AP Grades: Free **A, C, T**

A booklet containing information on the development of scoring standards, the AP Reading, grade-setting procedures, and suggestions on how to interpret AP grades.

Pre-AP: Achieving Equity, Emphasizing Excellence: Free **A, T**

An informational brochure describing the Pre-AP concept and outlining the characteristics of a successful Pre-AP program.

Released Exams: $20
($30 for "double" subjects: Calculus, Computer Science, Latin, Physics) **T**

About every four years, on a staggered schedule, 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.

Packets of 10: $30. For each subject with a released exam, you can purchase a packet of 10 copies of that year's exam for use in your classroom (e.g., to simulate an AP Exam administration).

Secondary School Guide to the AP Program: $10 **A, T**

This guide is a comprehensive consideration of the AP Program. It covers topics such as developing or expanding an AP program; gaining faculty, administration, and community support; AP Grade Reports, their use and interpretation; AP Scholar Awards; receiving college credit for AP; AP teacher training resources; descriptions of successful AP programs in nine schools around the country; and "Voices of Experience," a collection of ideas and tips from AP teachers and administrators.

Student Guides
(available for Calculus, English, and U.S. History): $12 **SP**

These are course and exam preparation manuals designed for high school students who are thinking about or taking a specific AP course. Each guide answers questions about the AP course and exam, suggests helpful study resources and test-taking strategies, provides sample questions with answers, and discusses how the free-response questions are scored.

Teacher's Guides: $12 **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 recommended teaching resources.

AP Vertical Team Guides **T, A**

An AP Vertical Team (APVT) is made up of teachers from different grade levels who work together to develop and implement a sequential curriculum in a given discipline. The team's goal is to help students acquire the skills necessary for success in AP. To help teachers and administrators who are interested in establishing an APVT at their school, the College Board has published three guides: *AP Vertical Teams in Science, Social Studies, Foreign Language, Studio Art, and Music Theory: An Introduction* ($12); *A Guide for Advanced Placement English Vertical Teams* ($10); and *Advanced Placement Program Mathematics Vertical Teams Toolkit* ($35). A discussion of the English Vertical Teams guide, and the APVT concept, is also available on a 15-minute VHS videotape ($10).

Multimedia

EssayPrep® **SP, T**

EssayPrep is available through the AP subject pages of the College Board's Web site. Students can select an essay topic, type a response, and get an evaluation from an experienced reader. The service is offered for the free-response portions of the AP Biology, English Language and Composition, English Literature and Composition, and U.S. History Exams. The fee is $15 per response for each evaluation. SAT® II: Writing Subject Test topics are also offered for a fee of $10. Multiple evaluations can be purchased at a 10–20% discount.

APCD®: $49 (home version),
$450 (multi-network site license) SP, T

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

Videoconference Tapes: $15 SP, T, C

AP has conducted live, interactive videoconferences for various subjects, enabling AP teachers and students to talk directly with the Development Committees that design and develop the AP courses and exams. Tapes of these events are available in VHS format and are approximately 90 minutes long.

AP: Pathway to Success
(video — available in English and Spanish): $15 SP, T, A, C

This 25-minute video takes a look at the AP Program through the eyes of people who know AP: students, parents, teachers, and college admission staff. They answer such questions as: “Why do it?” “Who teaches AP courses?” and “Is AP for you?” College students discuss the advantages they gained through taking AP courses, such as academic self-confidence, improved writing skills, and college credit. AP teachers explain what the challenge of teaching AP courses means to them and their school, and admission staff explain how they view students who have stretched themselves by taking AP Exams. There is also a discussion of the impact that an AP program has on an entire school and its community, and a look at resources available to assist AP teachers, such as regional workshops, teacher conferences, and summer institutes.

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