SAT **Subject Tests**™

TEACHER'S GUIDE to
SAT **Subject Tests**™

Science

Biology • Chemistry • Physics

SAT

Dear Educator,

We know connecting your students to college opportunity and success is important to you. One way to help your students along the path to higher education is to share with them the benefits of taking SAT Subject Tests™.

The SAT Subject Tests are hour-long tests based on high school course work offered across five subject areas: Science, Mathematics, English, History and Languages.

Coupled with students' high school grades and SAT scores, Subject Test scores can create a powerful and comprehensive picture of your students' capabilities, helping them stand out to prospective colleges. Colleges also use SAT Subject Tests to put other admission factors into context, place students in certain courses and even offer credit based on Subject Test performance.

To better support you in helping your students do well on these tests, we are pleased to provide you with the *Teacher's Guide to SAT Subject Tests in Science*, a comprehensive resource that will familiarize you with the science tests and the topics they cover. It includes sample questions as well as tips and best practices from other teachers to help you advise and prepare your students to do their best on the SAT Subject Tests.

The best news for science teachers? SAT Subject Tests cover the material you already teach your students. In fact, 82 percent of high school science teachers agree that the knowledge and skills measured by the SAT Subject Tests in Science are part of their existing curriculum. Nearly 90 percent of high school teachers and college professors surveyed indicated that the knowledge and skills tested on the SAT Subject Tests are important for college readiness.

There is no better source than you — teachers in the classroom — when it comes to helping students prepare for the SAT Subject Tests. If you have feedback, tips or ideas you'd like to share with other teachers, please send them to us at SATSubjectTests@collegeboard.org so we can include them in future guides.

The SAT Subject Tests in Science will help your students shine in the college admission process. We appreciate the opportunity to partner with you to help your students showcase the knowledge and skills you have taught them.

The College Board

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What Are the SAT Subject Tests™?

SAT Subject Tests™ are one-hour-long exams that give students the opportunity to enhance their college admission credentials by demonstrating their knowledge in specific subjects.

They are the only national admission tests in which your students choose to take the tests that best showcase their achievements and interests.

Because every student is unique, academic records often don't tell the whole story of his/her capabilities and potential. Encourage your students to consider taking one or more SAT Subject Tests so they can show colleges a more complete picture of their academic background, interests and talents.

What Are the Benefits of Taking the SAT Subject Tests in Science?

The SAT Subject Tests in Science can help students differentiate themselves in a competitive college admission environment by providing additional information about their readiness for college-level study. This is important for all students as it contextualizes other academic credentials, such as grades, SAT scores, etc.

Some schools require SAT Subject Tests in Science for admission into science and engineering programs or majors, while others require these tests from all students. For example, the California Institute of Technology requires all applicants to submit Subject Test scores in both mathematics and science. Many colleges use Subject Test scores to advise students or help with course placement. Other schools allow students to place out of introductory courses or gain credit based on their performance on certain Subject Tests. Students can visit bigfuture.collegeboard.org/college-search to explore colleges and get information about Subject Test requirements.

Tip

Students can use SAT Subject Tests for purposes beyond college admission and placement. For example, students in New York can use them as a substitute for some Regents exams for a New York State Regents high school diploma. Subject Tests can also be used to fulfill subject-based competency requirements for large university systems like the University of California and the University of Arizona.

What Are the Differences Between the SAT® and the SAT Subject Tests?

The SAT® is the most widely used college entrance exam, testing what students learn in classrooms and how well they apply that knowledge. Its reading, math and writing sections are based on the critical thinking and problem-solving skills needed for college success.

SAT Subject Tests cover a wide range of subject areas, including science, history and languages. Each SAT Subject Test focuses on a single subject and indicates a student's readiness to take college-level courses in that subject.

Tip

Encourage your science students who are applying to competitive colleges or programs of study to take an SAT Subject Test in Science to enhance their college applications.

Which Students Should Take SAT Subject Tests?

Many students can benefit from taking SAT Subject Tests to highlight their knowledge of a specific subject or subjects. SAT Subject Tests may be especially beneficial for students who:

- Are applying to colleges that require or recommend Subject Tests for admission and/or specific majors or areas of study.
- Want to show strength in specific subject areas.
- Would like to demonstrate knowledge obtained outside a traditional classroom environment (e.g., summer enrichment, distance learning, weekend study, etc.).
- May be able to place out of certain classes in college.
- Are enrolled in dual-enrollment programs.
- Are home-schooled or taking courses online.

Tip

Encourage your science students who may not be as strong in other academic areas or who are English language learners (ELL) to take the SAT Subject Tests in Science to showcase their science knowledge. ELL students may benefit from taking an SAT Subject Test in Science because it is not as reliant on English language mastery.

Should Students Taking Advanced Placement® Classes Take SAT Subject Tests?

SAT Subject Tests are high school-level tests, reflecting high school curricula. AP® Exams assess a student's college-level knowledge, skills and abilities learned in the corresponding AP courses in high school. Many colleges still require students to submit SAT Subject Test scores, even if they have taken AP Exams. Students taking AP courses may benefit from taking SAT Subject Tests as an additional opportunity to show colleges their knowledge of specific subjects. The tests also can gauge student readiness for AP Exams. As a result, some students take SAT Subject Tests as early as the spring of their freshman or sophomore years.

When Should Students Take SAT Subject Tests?

The best time for students to take the Subject Tests is after they complete the corresponding course or set of courses, when the content is still fresh in their minds. Students who wait until the fall of their senior year to take tests may miss the opportunity to put their best foot forward.

Not every test is offered on every test date, so encourage your students to review the SAT Subject Test calendar early so they can plan accordingly. The test calendar can be found on sat.collegeboard.org/register/sat-subject-test-dates.

Tip

Suggest that your students take the SAT Subject Tests in Science soon after they have completed the corresponding course or set of courses to avoid scrambling during the fall of their senior year.

How Do Colleges Use SAT Subject Test Scores?

Colleges use SAT Subject Test scores to gain a more comprehensive understanding of a student's academic background and achievement in specific areas. They use this information, along with factors like high school grades, extracurricular activities and other test scores, to make admission or placement decisions.

Some colleges require Subject Test scores for general admission or acceptance into certain majors or courses of study.

Other schools recommend Subject Test scores to help them make more informed admission decisions, and nearly all schools will take Subject Test scores into consideration as part of a student's college application.

Many colleges also use Subject Test scores for course placement and advising, and others will allow students to place out of introductory courses or receive credits based on performance on certain Subject Tests.

Most college websites and catalogs include information about admission requirements, including which Subject Tests are needed or recommended for admission. Advise your students to research Subject Test requirements and recommendations for the schools they are interested in attending.

"At Caltech, where the academic emphasis is on STEM fields, it is critical for us to require and evaluate certain SAT Subject Tests in math and science to get a stronger sense of a student's true passion and strength in these areas. We select candidates from a talented pool of applicants, and SAT Subject Tests help us to better understand a student's preparation for our demanding curriculum."

—Jarrid Whitney, Executive Director of Admissions and Financial Aid
California Institute of Technology

What SAT Subject Tests Are Offered?

Twenty tests are offered in five subject areas: Science, Mathematics, English, History and Languages. Three of the tests are in Science: Biology E (Ecological focus) or M (Molecular focus), Chemistry and Physics.

English
  Literature

History
  United States History
  World History

Mathematics
  Mathematics Level 1
  Mathematics Level 2

Science
  Biology E/M
  Chemistry
  Physics

Languages	
Reading Only	**Languages with Listening**
French	Chinese
German	French
Italian	German
Latin	Japanese
Modern Hebrew	Korean
Spanish	Spanish

Which SAT Subject Tests Should Your Students Take?

While advising your science students to take one or more of the SAT Subject Tests in Science, also consider encouraging them to take other SAT Subject Tests in areas in which they excel or have an interest. In addition, students should research to determine if the colleges they are considering require or recommend Subject Tests for admission or other purposes.

Tip

Share information about the SAT Subject Tests with other teachers at your school so they can recommend SAT Subject Tests to students who might benefit from taking these tests.

How Do Students Register for the Tests?

Students can register for the SAT Subject Tests several ways:

- On the College Board's website at collegeboard.org. Most students choose to register for Subject Tests on the College Board's website.

- By telephone (for a fee) if the student has registered previously for the SAT or an SAT Subject Test. Toll free, within the United States: 866-756-7346; from outside the United States: 212-713-7789.

- If students do not have access to the Internet, registration forms are available in *The Paper Registration Guide for the SAT and SAT Subject Tests*. Students can find the booklet in a guidance office at most high schools or by writing to:

  The College Board
  SAT Program
  P.O. Box 025505
  Miami, FL 33102

When students register for the SAT Subject Tests, they will need to indicate the specific Subject Tests they plan to take on the test date they select. Students may take one, two or three tests on any given test date; their testing fee will vary accordingly. Except for the Language with Listening tests, students may change their minds on the day of the test and instead select from any of the other Subject Tests offered that day.

Is There a Fee-Waiver Service?

Eligible students in grades 9–12 may receive fee waivers to take up to three SAT Subject Tests in each of two sittings (up to six tests total). These fee waivers are available in addition to those given for the SAT.

How Can Students Prepare for the SAT Subject Tests?

There are several ways students can prepare for the Subject Tests.

Regular Course Work

The best preparation for students is to learn the material taught in the classroom. The SAT Subject Tests are based on high school curricula. Later in this guide we will discuss ways you can help your students prepare throughout the year while taking your course.

Free Resources on collegeboard.org

Collegeboard.org offers a variety of information to help students prepare for the SAT Subject Tests. The site discusses topics covered on each test, recommended preparation and tips to help students do their best on test day.

Students can also prepare using the free sample practice materials offered by the College Board at collegeboard.org/subjecttests.

Getting Ready for the SAT Subject Tests Practice Booklet

For students who don't have consistent access to the Internet, this downloadable PDF offers test-taking approaches and sample questions with free answer explanations available online. School counselors also have access to copies of this free booklet.

SAT Subject Test Study Guides

Official SAT Subject Test study guides are available for purchase online at sat.collegeboard.org/sat-store or in bookstores. The College Board's study guides are the only source for full-length, previously administered SAT Subject Tests. Encourage students to read the instructions before each practice test to become familiar with them before test day.

Tip

Encourage your students to explore the free practice resources on collegeboard.org/subjecttests.

What Tips I Should Give My Students Before the Test?

Some suggestions include:

- The day before the test, students should do a brief review. Cramming is typically not helpful.
- The night before the test, students should prepare what they need to take, including the admission ticket, a photo ID, two No. 2 pencils with soft erasers (no mechanical pencils), a watch and a snack. It's wise for students to double-check the route to the test center, instructions for finding the entrance and the time of arrival.
- Students should arrive with plenty of time to spare.
- It's recommended that students answer the easy questions first, then move to the more difficult ones.
- Advise your students to skip the questions they cannot answer and mark them with a check in the test booklet so they can find them later.
- Students can make educated guesses on tougher questions by eliminating the answers that they know are wrong. However, if they cannot eliminate any of the answer choices, it is best to skip the question as the test penalizes random guessing.
- If your students opt to purchase a study guide, encourage them to take the practice tests with a timer set for 60 minutes. This will help students learn to pace themselves and get used to taking a one-hour test.
- Students should check their answer sheets regularly to see if the number of the question and the number of the answer match.
- It's important for students to keep track of the time.
- If they don't know every question on the test, students don't need to worry. The SAT Subject Test questions reflect what is commonly taught in high school. Due to differences in high school classes, it's likely that most students will find questions on topics they're not familiar with. Students do not have to get every question correct to receive the highest score (800) for the test. Many students do well despite not having studied every topic covered.

How Are the SAT Subject Tests Scored?

SAT Subject Tests are scored on a 200- to 800-point scale. All questions on the Subject Tests are multiple choice. Each correct answer receives one point. Each incorrect answer is subtracted as follows:

- ¼ point subtracted for each five-choice question
- ⅓ point subtracted for each four-choice question
- ½ point subtracted for each three-choice question
- 0 points subtracted for questions you don't answer

Please note that all questions on the three Subject Tests in Science are considered five-choice questions. Therefore, ¼ point is subtracted for each question a student answers incorrectly. Visit collegeboard.org for additional SAT Subject Test scoring information.

How Will the Students Get Their Scores?

Scores are available for free at collegeboard.org several weeks after each test is given. Students also can get their scores for a fee by telephoning customer service at 866-756-7346 in the United States and 212-713-7789 outside the United States.

Tip

Scores are also sent to high schools if students opt to share their scores with their schools. To help inform curricular planning, you can find out your students' scores by checking with your high school guidance office. Student scores are sent to the high schools approximately four weeks after students take the SAT Subject Tests.

Should a Student Take the SAT Subject Test Again?

To help your students decide whether or not to retest, help them evaluate their scores by comparing the Subject Test score with the average scores at the colleges where they are applying or the minimum scores needed to place them into a higher class or earn college credit. The two of you may decide that, with additional practice, the student could do better by taking the test again.

What Is Score Choice™?

In March 2009, the College Board introduced Score Choice™, a feature that gives students the option to choose the scores they send to colleges by test date for the SAT and by individual test for the SAT Subject Tests — at no additional cost. Designed to reduce test-day stress, Score Choice gives students an opportunity to show colleges the scores that they feel best represent their abilities.

Score Choice is optional: if students don't actively choose to use it, all of their scores will be sent automatically with their score report. Since most colleges only consider students' best scores, students should still feel comfortable reporting scores from all of their tests.

The SAT Subject Tests in Science

The SAT Subject Tests offered in Science are Biology E/M (Ecological/Molecular), Chemistry and Physics.

Each subject has its own test development committee, typically composed of teachers and college professors appointed for the different Subject Tests. The test questions are written and reviewed by each Subject Test Committee under the guidance of professional test developers.

The tests are rigorously developed, highly reliable assessments of knowledge and skills taught in high school classrooms.

SAT Subject Tests assess students' grasp of fundamental concepts in specific subjects and their ability to apply that knowledge. As such, to properly prepare for a Subject Test in Science (i.e., biology, chemistry or physics), students should take a high school–level course in the corresponding subject. In contrast, other national, standardized admission tests in science assess reading comprehension of science topics rather than more in-depth, content knowledge.

Biology E/M (Ecological/Molecular)

The SAT Subject Test in Biology E/M assesses students' understanding of general biology and covers knowledge of fundamental concepts, applications and interpretation skills.

The test measures the knowledge students would be expected to have after successfully completing a college-preparatory course in high school. The test is not connected to a specific textbook or instructional approach. The Biology E/M Test is for students taking a biology course that has placed particular emphasis on either ecological or molecular biology, with the understanding that evolution is inherent in both. Students can choose the test that covers the area in biology (ecological or molecular) that interests them most.

Biology-E specifically focuses on biological communities, populations and energy flow.

Biology-M specifically covers biochemistry, cellular structure and processes, such as respiration and photosynthesis.

Course work preparation includes a one-year preparatory course in biology, a one-year course in algebra and familiarity with simple algebraic concepts such as ratios and direct and inverse proportions. Laboratory experience is also helpful.

How to Help Your Students Choose Biology-E or Biology-M

- Students should choose Biology-E if they feel more comfortable answering questions pertaining to biological communities, populations and energy flow.

- Students should choose Biology-M if they feel more comfortable answering questions pertaining to biochemistry, cellular structure and processes, such as respiration and photosynthesis.

- Students will be required to indicate choice of Biology-E or Biology-M on their answer sheet on test day. Students are not allowed to take both tests on the same test day. They can, however, take them on two different test dates.

- Students can decide whether they want to take Biology-E or Biology-M on the test day by gridding the appropriate code for the test they have chosen on their answer sheet. Only questions pertaining to the test code that is gridded on their answer sheet will be scored.

Test Format

The one-hour Subject Test in Biology E/M with either ecological (Biology-E) or molecular (Biology-M) emphasis has a common core of 60 questions, followed by 20 questions in each specialized section (Biology-E or Biology-M). Each student answers 80 questions.

Understanding Content and Skills Tested

Students should understand the major concepts of biology and apply the principles they have learned to solve specific problems in biology. They should also be able to organize and interpret results obtained by observation and experimentation and to draw conclusions or make inferences from experimental data, including data presented in graphic and/or tabular form.

The content covered in the Subject Test in Biology E/M and descriptions of the topics are shown in the chart below.

Biology E/M Test Topics Covered in Common Core	Approximate Percentage of E Test	Approximate Percentage of M Test
Cellular and Molecular Biology	15%	27%
Cell structure and organization, mitosis, photosynthesis, cellular respiration, enzymes, biosynthesis and biological chemistry		
Ecology	23%	13%
Energy flow, nutrient cycles, populations, communities, ecosystems, biomes, conservation biology, biodiversity and effects of human intervention		
Classical Genetics	15%	20%
Meiosis, Mendelian genetics, inheritance patterns, molecular genetics and population genetics		
Organismal Biology	25%	25%
Structure, function and development of organisms (with emphasis on plants and animals) and animal behavior		
Evolution and Diversity	22%	15%
Origin of life, evidence of evolution, natural selection, speciation, patterns of evolution and classification and diversity of organisms		

Skills assessed on the Biology-E and Biology-M Tests are outlined in the table below.

Biology-E and Biology-M Skills Specifications	Approximate Percentage of Test
Knowledge of Fundamental Concepts:	**30%**
• Demonstrating knowledge of key concepts • Familiarity with terminology	
Application:	**35%**
• Understanding concepts and reformulating information into other formats • Applying knowledge to unfamiliar and/or practical situations • Solving problems using mathematical relationships	
Interpretation:	**35%**
• Inferring and deducing from qualitative and quantitative data • Integrating information to form conclusions • Recognizing unstated assumptions	

Helping Students Prepare for the Biology E/M Test

Classroom Preparation

Before students take the Biology E/M Test, they should have completed a one-year course not only in biology but also in algebra so they can understand simple algebraic concepts (including ratios and direct and inverse proportions) and apply such concepts to solving word problems.

Laboratory experience is a significant factor in developing reasoning and problem-solving skills. Although testing of laboratory skills in a multiple-choice test is necessarily limited, reasonable experience in the laboratory will help students prepare for the test.

Important Skills

Success in high school biology courses typically requires good reasoning and mathematical skills. Students' preparation in biology should have enabled them to develop these and other skills that are important to the study of biology.

Preparation and Practice

Encourage your students to get ready by working on the free sample practice questions on the College Board's website at collegeboard.org/subjecttests. Additional practice materials are available for purchase in bookstores or online at sat.collegeboard.org/sat-store.

Tip

Students will not be allowed to use a calculator during the Biology E/M Test. Numerical calculations are limited to simple arithmetic. The metric system is used in these tests.

Chemistry

The SAT Subject Test in Chemistry covers the major concepts of chemistry and assesses students' ability to apply these concepts in problem-solving scenarios. The test also requires students to organize and interpret results obtained by observation and experimentation.

Course work preparation includes one year of a college preparatory course in chemistry as well as familiarity with simple algebraic relationships and applying these to solving word problems. Students should be familiar with concepts of ratio and direct and inverse proportions, exponents and scientific notation. Laboratory experience is also beneficial.

Like the other SAT Subject Tests, the Subject Test in Chemistry is not connected to a specific textbook or instructional approach.

Test Format

This is a one-hour test with 85 multiple-choice questions.

Understanding Content and Skills Tested

The test covers the topics listed in the chart below. Different aspects of these topics are stressed from year to year. However, because high school courses differ, both in the amount of time devoted to each major topic and in the specific subtopics covered, it is likely that most students will encounter some questions on topics with which they are not familiar. Every edition of the test contains approximately five questions on equation balancing and/or predicting products of chemical reactions; these are distributed among the various content categories.

Topics Covered	Approximate Percentage of Test
I. Structure of Matter	25%
• **Atomic Structure**, including experimental evidence of atomic structure, quantum numbers and energy levels (orbitals), electron configurations and periodic trends • **Molecular Structure**, including Lewis structures, three-dimensional molecular shapes and polarity • **Bonding**, including ionic, covalent and metallic bonds; relationships of bonding to properties and structures; intermolecular forces such as hydrogen-bonding, dipole-dipole forces and dispersion (London) forces	
II. States of Matter	16%
• **Gases**, including the kinetic molecular theory, gas law relationships, molar volumes, density and stoichiometry • **Liquids and Solids**, including intermolecular forces in liquids and solids, types of solids, phase changes and phase diagrams • **Solutions**, including molarity and percent by mass concentrations, solution preparation and stoichiometry, factors affecting solubility of solids, liquids, and gases and qualitative aspects of colligative properties	
III. Reaction Types	14%
• **Acids and Bases**, including Brønsted-Lowry theory, strong and weak acids and bases, pH, titrations and indicators • **Oxidation-Reduction**, including recognition of oxidation-reduction reactions, combustion, oxidation numbers and use of activity series • **Precipitation**, including basic solubility rules	

Topics Covered	Approximate Percentage of Test
IV. Stoichiometry	**14%**
• **Mole Concept**, including molar mass, Avogadro's number and empirical and molecular formulas • **Chemical Equations**, including the balancing of equations, stoichiometric calculations, percent yield and limiting reactants	
V. Equilibrium and Reaction Rates	**5%**
• **Equilibrium Systems**, including factors affecting position of equilibrium (Le Châtelier's principle) in gaseous and aqueous systems, equilibrium constants and equilibrium expressions • **Rates of Reactions**, including factors affecting reaction rates, potential energy diagrams and activation energies	
VI. Thermochemistry	**6%**
• Includes conservation of energy, calorimetry and specific heats, enthalpy (heat) changes associated with phase changes and chemical reactions, heating and cooling curves and randomness (entropy)	
VII. Descriptive Chemistry	**12%**
• Includes common elements, nomenclature of ions and compounds, periodic trends in chemical and physical properties of the elements, reactivity of elements and prediction of products of chemical reactions and examples of simple organic compounds and compounds of environmental concern	
VIII. Laboratory	**8%**
• Includes knowledge of laboratory equipment, measurements, procedures, observations, safety, calculations, data analysis, interpretation of graphical data and drawing conclusions from observations and data	

Skills assessed on the Chemistry Test are outlined in the table below.

Skills Specifications	Approximate Percentage of Test
Fundamental Knowledge	**20%**
• Remembering fundamental concepts and specific information • Demonstrating familiarity with terminology	
Application of Knowledge	**45%**
• Applying a single principle to unfamiliar and/or practical situations to obtain a qualitative result or solve a quantitative problem	
Synthesis of Knowledge	**35%**
• Inferring and deducing from qualitative data and/or quantitative data • Integrating two or more relationships to draw conclusions or solve problems	

Helping Students Prepare for the Chemistry Test

Classroom Preparation

Students taking the Chemistry Test should have taken a one-year introductory chemistry course at the college-preparatory level.

Laboratory experience is a significant factor in developing reasoning and problem-solving skills and should help in test preparation even though laboratory skills can be tested only in a limited way in a multiple-choice test.

Important Skills

Students should also have the ability to:

- Understand the major concepts of chemistry and apply the principles to solve specific problems in chemistry.
- Organize and interpret results obtained by observation and experimentation and to draw conclusions or make inferences from experimental data, including data presented in graphic and/or tabular form.

Preparation and Practice

Encourage your students to get ready by working on the free sample practice questions on the College Board's website at collegeboard.org/subjecttests. Additional practice materials are available for purchase in bookstores or online at sat.collegeboard.org/sat-store.

Tip

A periodic table indicating the atomic numbers and masses of elements is provided for all test administrations. Calculators are not permitted during the test. Problem-solving requires simple numerical calculations. The metric system of units is used.

Physics

The Subject Test in Physics measures the knowledge students would be expected to have after successfully completing a college-preparatory physics course in high school. The test is not connected to a specific textbook or instructional approach but concentrates on the common material found in most texts. Laboratory experience is also helpful.

This test assesses students' understanding of the major concepts of physics and the ability to apply physical principles to solve specific problems. Students should have familiarity with simple algebraic, trigonometric and graphical relationships, as well as the concepts of ratio and proportion and be able to apply these to physics problems. Familiarity with the metric system is also important.

Format

This one-hour test consists of 75 multiple-choice questions. The test emphasizes topics that are covered in most high school courses. Because high school courses differ, both in percentage of time devoted to each major topic and in the specific subtopics covered, most students will find that there are some questions on topics with which they are not familiar.

Understanding Content and Skills Tested

The content covered in the Subject Test in Physics and descriptions of the topics are shown in the chart below.

Topics Covered	Approximate Percentage of Test
I. Mechanics	**36%–42%**
• **Kinematics**, such as velocity, acceleration, motion in one dimension and motion of projectiles • **Dynamics**, such as force, Newton's laws, statics and friction • **Energy and Momentum**, such as potential and kinetic energy, work, power, impulse and conservation laws • **Circular Motion**, such as uniform circular motion and centripetal force • **Simple Harmonic Motion**, such as mass on a spring and the pendulum • **Gravity**, such as the law of gravitation, orbits and Kepler's laws	
II. Electricity and Magnetism	**18%–24%**
• **Electric Fields, Forces and Potentials**, such as Coulomb's law, induced charge, field and potential of groups of point charges and charged particles in electric fields • **Capacitance**, such as parallel-plate capacitors and transients • **Circuit Elements and DC Circuits**, such as resistors, lightbulbs, series and parallel networks, Ohm's law and Joule's law • **Magnetism**, such as permanent magnets, fields caused by currents, particles in magnetic fields, Faraday's law and Lenz's law	

Topics Covered	Approximate Percentage of Test
III. Waves and Optics	**15%–19%**
General Wave Properties, such as wave speed, frequency, wavelength, superposition, standing waves and Doppler effect **Reflection and Refraction**, such as Snell's law, and changes in wavelength and speed **Ray Optics**, such as image formation using pinholes, mirrors and lenses **Physical Optics**, such as single-slit diffraction, double-slit interference, polarization and color	
IV. Heat and Thermodynamics	**6%–11%**
Thermal Properties, such as temperature, heat transfer, specific and latent heats and thermal expansion **Laws of Thermodynamics**, such as first and second laws, internal energy, entropy and heat engine efficiency	
V. Modern Physics	**6%–11%**
Quantum Phenomena, such as photons and photoelectric effect **Atomic**, such as the Rutherford and Bohr models, atomic energy levels and atomic spectra **Nuclear and Particle Physics**, such as radioactivity, nuclear reactions and fundamental particles **Relativity**, such as time dilation, length contraction and mass-energy equivalence	
VI. Miscellaneous	**4%–9%**
General, such as history of physics and general questions that overlap several major topics **Analytical Skills**, such as graphical analysis, measurement and math skills **Contemporary Physics**, such as astrophysics, superconductivity and chaos theory	

SAT **Subject Tests**

Skills assessed on the SAT Subject Test in Physics are in the table below.

Skills Specification	Approximate Percentage of Test
Fundemental Knowledge	**20%–33%**
• Remembering and understanding concepts or information	
Single-Concept Problem	**40%–53%**
• Understanding and using a single physical relationship	
Multiple-Concept Problem	**20%–33%**
• Understanding and integrating two or more physical relationships	
Laboratory Skills	
• Demonstrating laboratory skills in context	

Helping Your Students Prepare for the Physics Test

Classroom Preparation

The test is intended for students who have completed a one-year introductory physics course at the college-preparatory level.

Laboratory experience is a significant factor in developing reasoning and problem-solving skills. This multiple-choice test can measure laboratory skills only in a limited way, such as data analysis.

Important Skills

Students taking the SAT Subject Test in Physics should be able to:

- Understand the major concepts of physics and apply these physical principles to solve specific problems.
- Understand simple algebraic, trigonometric, and graphical relationships and the concepts of ratio and proportion and apply these to physics problems.
- Apply laboratory skills in the context of physics.

Preparation and Practice

Encourage your students to get ready by working on the free sample practice questions found on the College Board's website at collegeboard.org/subjecttests. Additional practice materials are available for purchase at bookstores or online at sat.collegeboard.org/sat-store.

Tip

This test assumes that the direction of any current is the direction of flow of positive charge (conventional current). Calculator use is not permitted during the test. Numerical calculations are not emphasized and are limited to simple arithmetic. This test predominantly uses the metric system.

Biology

Sample Questions and
Answer Explanations

Biology

E/M Core Section (Ecological and Molecular)

Directions: Each set of lettered choices below refers to the numbered questions or statements immediately following it. Select the one lettered choice that best answers each question or best fits each statement and then fill in the corresponding circle on the answer sheet. A choice may be used once, more than once, or not at all in each set.

Questions 1–2 refer to the following parts of the cell cycle.

A) Mitosis

B) Prophase

C) Cytokinesis

D) Interphase

E) Metaphase

1. The point at which chromosomes are replicated to provide a full set of genetic material for both daughter cells

2. The point at which the cytoplasm divides

Answers and Explanations

1. **Correct Answer: D**
   Explanation: Choice (D) is the correct answer. In order to produce two daughter cells, the complete DNA must be replicated. This occurs during the S (synthesis) phase of interphase. During other stages of interphase, protein synthesis takes place and the centrioles replicate. Interphase is not technically part of mitosis.

2. **Correct Answer: C**
   Explanation: Choice (C) is the correct answer. Cytokinesis is the process during which the cell actually divides in two. At this point, the two nuclei of the daughter cells are at opposite poles of the cell, and the cytoplasm separates. In animal cells, a contractile ring of cytoskeleton elements forms; the ring contracts and cleavage occurs to eventually form two daughter cells. In plant cells, a cell plate forms with new cell membranes for each cell. A new cell wall then forms between the two membranes of the cell plate.

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Some questions pertain to a set that refers to a laboratory or experimental situation. For each question, select the one choice that is the best answer to the question and then fill in the corresponding circle on the answer sheet.

Questions 3–4 refer to the following figure.

The figure below represents the percent germination of gourd seeds after being exposed to various treatments.
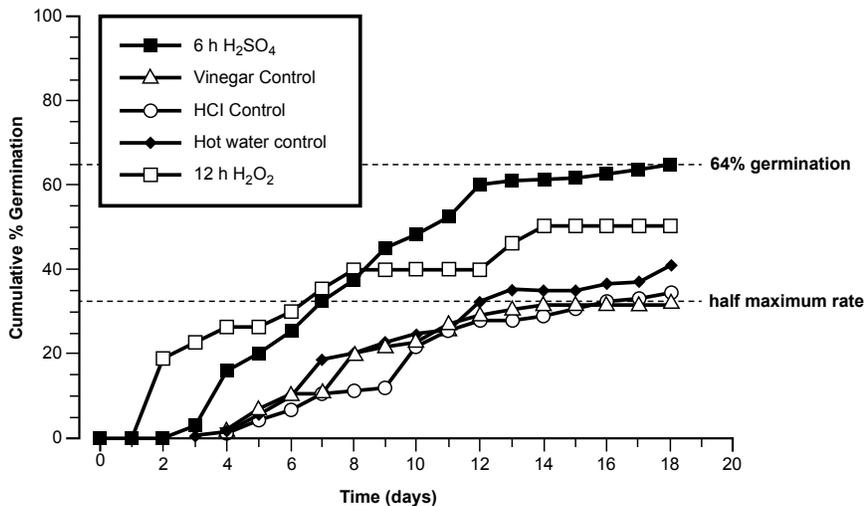
Cumulative germination of gourd seeds following various pregermination treatments.
n = 100 seeds per trial.

3. **Which treatments reach more than a 30% germination rate by day 8?**

   A) 6 h H_2SO_4 only
   B) 6 h H_2SO_4 and 12 h H_2O_2
   C) Hot water control and vinegar control
   D) Vinegar control only
   E) 6 h H_2SO_4, vinegar control and hot water control

4. **Which of the following can be inferred from this data?**

   A) Gourd seeds that are exposed to the hot water control would grow better if they were also exposed to 6 h H_2SO_4.
   B) 64% is the highest possible germination rate for any group of gourd seeds.
   C) Strong acids, like H_2SO_4, have a greater effect on germination than weak acids, like vinegar.
   D) Tomato seeds would have similar responses to the same treatments.
   E) If the experiment continued, the treatment with the highest germination rate would also have the tallest plants.

Answers and Explanations

3. **Correct Answer: B**

    Explanation: Choice (B) is the correct answer. On day 8, the only treatments that have passed the 30% germination rate mark are 6 h H_2SO_4 and 12 h H_2O_2. Choice (A) is incorrect because it only includes the 6 h H_2SO_4 treatment. Choices (C), (D) and (E) are incorrect because they all include treatments that have not passed the 30% germination rate mark by day 8.

4. **Correct Answer: C**

    Explanation: Choice (C) is the correct answer. According to the data, gourd seeds exposed to 6 h H_2SO_4 had the highest germination rate. H_2SO_4 is considered a strong acid, while vinegar is considered a weak acid. It can be inferred from the graph that strong acids could have a greater effect on germination than weak acids. Choice (A) is incorrect because there is no information on the graph about exposing gourd seeds to both hot water and H_2SO_4. Choice (B) is incorrect because the graph only provides information for gourd seeds given specific treatments, not any random group of gourd seeds. Choice (D) is incorrect because tomatoes are a different plant species; the effects of these treatments on tomato seeds could be different than those on gourd seeds. Choice (E) is incorrect because the graph only provides information on germination rates, not on the height of the gourd plants.

5. Meiosis is a type of cell division important in human gametogenesis (spermatogenesis and oogenesis). Which of the following statements about human gamete formation is correct?

    A) The final step of gametogenesis results in the formation of two diploid cells.

    B) The result of oogenesis is the formation of four fully functional ova.

    C) Spermatogenesis and oogenesis are both regulated by a monthly cycle.

    D) Oogenesis occurs throughout the lifetime of a female.

    E) Spermatogenesis results in four fully functional sperm cells.

6. In our current classification system, members that belong to the same order also belong to the same

    A) genus

    B) class

    C) species

    D) family

    E) race

7. The cells of the fruit fly *Drosophila melanogaster* contain 3 pairs of autosomal chromosomes and one pair of sex chromosomes. Upon completion of Meiosis II, how many chromosomes will each fruit fly gamete contain?

    A) 2

    B) 4

    C) 6

    D) 8

    E) 16

8. Huntington's disease is a degenerative disorder of the nervous system that follows an inheritance pattern of autosomal dominance. What is the probability that a child will inherit Huntington's disease if one of the parents has an allele for the disease?

    A) 0%

    B) 25%

    C) 50%

    D) 75%

    E) 100%

5. **Correct Answer: E**
Explanation: Choice (E) is the correct answer. In sperm production, all four products of meiosis become viable gametes. Choice (A) is incorrect because it describes the results of mitotic action, not meiosis, which results in twice as many nuclear products containing half the number of chromosomes (reduction division). Choice (B) is incorrect because oogenesis produces only one functional ova and three smaller polar bodies. Choice (C) is incorrect because spermatogenesis occurs continuously after puberty while ovulation and completion of oogenesis is regulated by a menstrual cycle. Choice (D) is incorrect because the actual production of viable eggs occurs only after puberty and ends after menopause.

6. **Correct Answer: B**
Explanation: Choice (B) is the correct answer. In the Linnaean classification hierarchy, class is above order. Therefore, order members share the same class, phylum, and domain. Order members will not necessarily share the same genus, species name, or family, so choices (A), (C) and (D) are incorrect. Choice (E) is incorrect because race is a subdivision under species; it is defined as "a geographically isolated breeding population that shares certain characteristics in higher frequencies than other populations of that species, but has not become reproductively isolated."

7. **Correct Answer: B**
Explanation: Choice (B) is the correct answer. The process of meiosis is a reduction division that produces cells containing the haploid number of chromosomes. A fruit fly cell contains a total of 8 chromosomes arranged into 4 pairs. Replication will occur prior to meiosis, producing 16 chromosomes to be distributed. Upon completion of Meiosis II, four cells will be produced, and each cell will contain 4 chromosomes (half the original number and one from each of the 4 pairs).

Tip

Remind students that chromosomes of sexually reproducing organisms are arranged in homologous pairs. For example, if a cell contains 12 pairs of chromosomes (24 total), the haploid gamete will contain 12 chromosomes.

8. **Correct Answer: C**
Explanation: Choice (C) is the correct answer. Traits following a pattern of autosomal dominant inheritance do not need to be present in both alleles for expression to occur. If an individual inherits one copy of the Huntington's disease allele, he or she will have the disease. If one parent carries one allele for the disease, there is a 50% chance that the child will inherit the allele and have the disease.

Tip

Drawing a Punnett square could be helpful for working out the probability of inheritance.

	A	a
A	AA	Aa
a	Aa	aa

9. Pattern baldness is a sex-linked recessive trait characterized by hair loss near the hairline and at the crown of the head. If a woman whose father is bald and a man who is bald have a son, what is the probability that the son will inherit the allele for pattern baldness? Assume that the woman's mother does not carry the allele for pattern baldness.

    A) 0%
    B) 25%
    C) 50%
    D) 75%
    E) 100%

10. Which of the following characteristics is present in the taxa Gymnospermae (gymnosperms)?

    I.   The appearance of true leaves
    II. The ability to fertilize eggs in a non-water environment
    III. The process of double fertilization
    IV. The development of seeds
    V.   The development of a vascular system

    A) I, V
    B) I, IV, V
    C) I, II, IV, V
    D) I, III, IV, V
    E) I, II, III, IV, V

11. Which of the following plant hormones elicits seed dormancy, slows plant growth and can regulate stomata during adverse environmental conditions such as drought?

    A) Gibberellin
    B) IAA
    C) Abscisic acid
    D) Ethylene
    E) Phytochrome

9. **Correct Answer: C**

Explanation: Choice (C) is the correct answer. Pattern baldness is a sex-linked recessive trait, which indicates that it is carried on the X chromosome. A female inherits one X chromosome from her father. Because the woman's mother does not carry the allele for pattern baldness, the woman only carries one copy of the allele. If the couple has a son, there is a 50% chance that the son will inherit the X-linked allele for pattern baldness from his mother. The father's baldness is irrelevant; he will pass his unaffected Y chromosome to the son.

Tip

Remind students that it is important to read questions related to sex-linked inheritance carefully. If the question asks about the number of sons or daughters that are affected, the correct answer will be 0%, 50% or 100%. If the question asks about the number of children affected, other percentages could also be correct.

10. **Correct Answer: C**

Explanation: Choice (C) is the correct answer. Gymnosperms have leaves; they have a vascular system; they are the first plants to have produced pollen, which eliminates the need for water to get sperm and egg together; and they are the first plants to have developed seeds (protected young embryo sporophytes packaged with food). Choices (A) and (B) are incorrect because they do not include all of these features. Choice (D) is incorrect because it does not include the ability to fertilize eggs in a non-water environment and because it does include the process of double fertilization, which only occurs in angiosperms. Choice (E) is incorrect because it includes the process of double fertilization.

11. **Correct Answer: C**

Explanation: Choice (C) is the correct answer. Abscisic acid is a plant hormone that has numerous, mainly inhibitory, effects on plants that help plants deal with stress. These effects include keeping seeds dormant until favorable conditions for germination occur, slowing growth in preparation for winter, and closing stomata to prevent dehydration and wilting. Choices (A), (B), (D) and (E) are incorrect. Gibberellins are plant hormones that promote stem elongation and the stimulation of enzyme production in germinating seeds. IAA, or indole-3-acetic acid, also promotes stem elongation and growth. Ethylene promotes fruit ripening. Phytochrome is a light-sensitive protein pigment that absorbs red light; this can stimulate tropism in plants or a directional movement response based on a directional stimulus.

12. Both avian and mammalian hearts are referred to as double-pump structures. Which of the following explains the anatomical and physiological basis for this description?

    A) Blood always enters into an atrium and then is pumped into a ventricle.

    B) Blood pressure alternates between systolic pressure and diastolic pressure.

    C) The atria provide one pump and the ventricles provide a second pump.

    D) The heart sends blood out through arteries and retrieves blood through veins.

    E) The heart pumps blood simultaneously through a pulmonary circuit and a systemic circuit.

13. All of the following would be true of a population in Hardy-Weinberg equilibrium EXCEPT

    A) There is no migration of individuals either into or out of the population.

    B) The population is not influenced by selective pressures.

    C) Mating occurs randomly within the population.

    D) There is no change in the rate of mutation.

    E) The population is relatively small.

14. There is a high degree of homology in the DNA of dogs and wolves. Which of the following statements provides the best explanation for this observation?

    A) Dogs and wolves have the same number of chromosomes.

    B) The morphologies of dogs and wolves are similar.

    C) Dogs and wolves share the same ecological niche.

    D) Dogs and wolves share a very recent common ancestor.

    E) The high degree of homology is the result of convergent evolution.

Biology   Answers and Explanations

12. Correct Answer: E

Explanation: Choice (E) is the correct answer. The first pump sends oxygen-poor blood to the lungs and oxygen-rich blood back to the heart, which is pulmonary circulation. The second pump sends oxygen-rich blood to the rest of the body, which is systemic circulation. Choice (A) is incorrect because one atrium and one ventricle create a single pumping unit. Choice (B) is incorrect because systolic pressure and, together, diastolic pressure are simply measures of the pumping pressure in the systemic circulatory system. Choice (C) is incorrect because atria and ventricles work together to provide pumping pressure. The atria are receiving chambers and are too weak to work alone as pumps. Choice (D) is incorrect because arteries and veins are not pumping structures.

> **Tip**
>
> It may be helpful for students to think of deoxygenated blood entering the heart on the right side, and oxygenated blood leaving the left side of the heart.

13. Correct Answer: E

Explanation: Choice (E) is the correct answer. The Hardy-Weinberg equilibrium is used to determine the shift in allele frequency within a population. The introduction or loss of genes will have a greater effect on a small population than it would on a large population. Choices (A), (B), (C) and (D) are incorrect because they are all requirements for Hardy-Weinberg equilibrium (no occurrence of evolution). The Hardy-Weinberg equilibrium predicts gene flow patterns within a population and assumes alleles will be inherited in similar ratios to those of the parents over several generations. This genetic equilibrium is maintained if few new genes are introduced to the population.

> **Tip**
>
> Remind students that the predictability of inherited gene ratios will be altered if the genetic balance of the population is altered.

14. Correct Answer: D

Explanation: Choice (D) is the correct answer. Homology refers to traits that two different organisms are inherited from a common ancestor. The best explanation for the high degree of homology in the DNA of dogs and wolves is that dogs and wolves share a very recent common ancestor. Choice (A) is incorrect. Although it is true that dogs and wolves both have 78 chromosomes, chromosome number does not necessarily indicate a close relationship (for example, chickens also have 78 chromosomes). Choice (B) refers only to morphology, which describes the form and structure of an organism but does not discuss its inherited traits; two organisms can share certain morphological features but may not be genetically related. Choice (C) describes the relative position of species within a habitat where organisms live, which does not affect DNA. Choice (E) describes convergent evolution, which means that a similar characteristic evolved within two separate lineages independently, usually due to similar environmental challenges. Since dogs and wolves share a high degree of homology in their DNA, their similarities are genetically based, and not independent of one another.

15. **Darwin's ideas concerning natural selection were based on all of the following facts and observations EXCEPT**

    A) Parents pass their successful traits on to their offspring.

    B) Population members exhibit variations in many traits.

    C) All living organisms use the same genetic code.

    D) Environmental pressures can select various traits based on survivability.

    E) Populations that adapt to environmental conditions produce many offspring.

16. **Which of the following is LEAST likely to result in speciation?**

    A) Random mating among members of a large population of a species

    B) Occurrence of hybridization between individuals from two different species

    C) Development of different mating behavior by some members of a species

    D) Emigration to a specialized microenvironment by some members of a species

    E) Formation of a physical barrier that blocks gene flow between members of a species

E Section (Ecological)

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Some questions pertain to a set that refers to a laboratory or experimental situation. For each question, select the one choice that is the best answer to the question and then fill in the corresponding circle on the answer sheet.

17. **Most human population growth is occurring in developing countries, where 80% of the world's population lives. Which of the following is the best factor in determining high population growth rates within specific countries?**

    A) Carrying capacity

    B) Increase in agricultural technology

    C) Declining birth rates in developed countries

    D) Improved nutrition across the globe

    E) Age structure

15. **Correct Answer: C**

Explanation: Choice (C) is the correct answer. The structure of DNA was not discovered until the 1950s; Darwin could not possibly have had knowledge of the genetic code. Choices (A), (B), (D) and (E) are incorrect because they do support Darwin's theory of evolution. Darwin conducted direct observations of various species and he noted that parents with the most favorable traits survive to have offspring who receive those favorable traits; that there is variety in traits; that there is relative success or failure based on environmental conditions; and that species seem to overpopulate.

Tip

Students may confuse the time periods during which these discoveries were initially described.

16. **Correct Answer: A**

Explanation: Choice (A) is the correct answer. Random mating is considered to be one of the factors that maintains gene flow within a species and therefore should show no change with time, or evolution of the species. Choice (B) is incorrect because hybridization can be a factor in speciation, especially in some plant species. Choice (C) is incorrect because differences in mating behavior that prevent successful mating are considered reproductive isolating mechanisms and can lead to speciation. Choices (D) and (E) are incorrect because both emigration and the formation of physical barriers lead to isolation of a subpopulation, which can lead to genetic divergence of the subpopulation from the original population, which can lead to speciation.

17. **Correct Answer: E**

Explanation: Choice (E) is the correct answer. Age structure is the percentage of the population at each age within a country. Often depicted graphically, an age structure diagram can predict a population's growth trends and indicate future social structures. A uniform distribution across age groups indicates stable population size. A population that has a much higher distribution among young people will show rapid population growth. A population with a higher distribution among elderly people will show a decline in population growth. Choice (A) is incorrect because carrying capacity, the maximum population a particular environment can support, cannot be used to predict population growth rates in different countries. Although an increase in agricultural technology could affect a population's ability to grow, choice (B) is incorrect because it is not the best factor to determine population growth rates in specific countries. Choice (C) is incorrect because information about population growth rates in *developed* countries would not help in determining high population growth rates in developing countries. Although improved nutrition across the globe can affect population growth, choice (D) is incorrect because it is not the best factor to determine population growth rates in specific countries.

18. **Which of the following nutrient cycles has its largest reservoir in the atmosphere?**

    A) Carbon cycle

    B) Nitrogen cycle

    C) Potassium cycle

    D) Phosphorus cycle

    E) Water cycle

19. **A shrubland was studied to determine its metabolic rate. The data from the study show that the energy being released by respiration was less than the energy captured during photosynthesis. What phenomenon is taking place in this terrestrial plant community?**

    A) Major plant species are dying.

    B) Biomass of the community is increasing.

    C) Biomass of the community is decreasing.

    D) The rate of plant reproduction is increasing.

    E) A secondary succession of plants is growing in an established community.

20. **A food chain consists of producers, primary consumers, secondary consumers and tertiary consumers. If the producers produce 1000 kcal of energy, how many kcal are theoretically available to the secondary consumers based on normal trophic efficiencies?**

    A) 1000

    B) 100

    C) 10

    D) 1

    E) 0.5

21. **A sample of living tissue of a fish-eating bird species was found to have a specific, heavy metal concentration of 700,000 ppt (parts per trillion). What is the best inferential explanation you could make based on these data?**

    A) Air pollution may have caused this bird species to inhale dangerous amounts of heavy metals while migrating.

    B) The entire population of the bird species, from which this sample was taken, died.

    C) The population of this bird species exploded, causing an ecosystem imbalance.

    D) Pollutants tend to collect in areas of land where this bird species nests.

    E) This bird species is at a high trophic level on the food chain.

Answers and Explanations

18. **Correct Answer: B**
    Explanation: Choice (B) is the correct answer. Nitrogen makes up 80% of the atmosphere. It is incorporated into the biosphere via work by microorganisms that can break the triple covalent bonds of N_2 and fix it into NH_3 and, later, into nitrites and nitrates that are taken up by plants for use in biosyntheses. Choice (A) is incorrect because CO_2 is only 0.04% of the atmosphere; most carbon is reservoired in sediments and rocks. Choices (C) and (D) are incorrect because potassium and phosphorus are rarely in gaseous form. Choice (E) is incorrect because atmospheric water is the smallest source of H_2O, with oceans serving as the major reservoir for water.

19. **Correct Answer: B**
    Explanation: Choice (B) is the correct answer. This question refers to net primary productivity. An ecosystem's net primary production is measured by the amount of light energy converted to chemical energy by autotrophs minus the energy those organisms must use to survive. In other words, it is the amount of new "food" or biomass available to consumers. If more energy were captured during photosynthesis than was released by respiration, the biomass must be increasing. Choice (A) is incorrect because the data describe an increase in primary productivity, so major plant species probably are not dying. Choice (C) is incorrect because a decrease in the biomass of the community would mean that the energy being released by respiration was more than the energy captured during photosynthesis, which is the opposite of what the question is asking. Choice (D) is incorrect because multiplication of producers is irrelevant; it is the efficiency of the producers present that will determine productivity. Choice (E) is incorrect because the question refers to the amount of energy, not the type of plant species present in the community.

20. **Correct Answer: C**
    Explanation: Choice (C) is the correct answer. 10 kcal of energy are available to the secondary consumers. As energy flows through a food chain, it is incorporated by the organisms at each level. Although some energy will be utilized for cellular metabolism, most of it is lost as heat. As a result, approximately 10% is available for transfer to the next trophic level (known as the 10% rule). If the producers produce 1000 kcal of energy, then 100 kcal will be available to the primary consumers, 10 kcal will be available to the secondary consumers, and 1 kcal will be available to the tertiary consumers.

21. **Correct Answer: E**
    Explanation: Choice (E) is the correct answer. This question deals with biomagnification. Organisms at higher trophic levels in a food chain can experience biomagnification, which is the accumulation of environmental toxins (such as heavy metals) in living tissue. Organisms at lower trophic levels accumulate small amounts of toxins through their food. Because organisms at the next highest trophic level eat many of the lower-level organisms, they take in higher amounts of the toxins. At the highest trophic levels, increased concentrations of toxins in organisms' tissues can be dangerous. This bird tissue has a high concentration of a specific heavy metal, so the species must be at a high trophic level. Choice (A) is incorrect because even though there can be heavy metals in air pollution, the major cause of heavy metals in the tissue of fish-eating birds is biomagnification. Choice (B) is incorrect because the high concentration of heavy metal in the tissue of one fish-eating bird does not imply that all birds of that species in the population died. Choice (C) is incorrect because a high concentration of heavy metals is not in any way related to the explosive increase of populations; in fact, it can have the opposite effect. Choice (D) is incorrect because land pollutants would be in the soil. This species eats fish rather than soil organisms or plants, so the heavy metals present in a toxic soil wouldn't make their way into the bird's tissue at such high levels.

SAT **Subject Tests**

M Section (Molecular)

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Some questions pertain to a set that refers to a laboratory or experimental situation. For each question, select the one choice that is the best answer to the question and then fill in the corresponding circle on the answer sheet.

22. **Which of the following statements regarding mitosis is correct?**

    A) Mitosis will result in reduction division.

    B) Sister chromatids will separate during metaphase.

    C) Cytokinesis occurs during the process of prophase.

    D) Mitosis occurs continually in the life cycle of all somatic cells.

    E) The final product of mitosis is the formation of two identical nuclei.

23. **Erythromycin is an antibiotic that can block protein synthesis of bacteria without harming its eukaryotic host because**

    A) prokaryotic cells have membrane-bound organelles.

    B) eukaryotic DNA is linear, while prokaryotic DNA is circular.

    C) in prokaryotes, translation can occur at the same time as transcription.

    D) there is much more space within a eukaryotic cell than within a prokaryotic cell.

    E) prokaryotes have ribosomes that are much smaller and simpler than eukaryotes.

24. **The process of photosynthesis occurs in two steps. One step is referred to as the light-dependent reaction, and the other is the light-independent (or dark) reaction. Which of the following events occurs during the light-independent process?**

    A) The production of oxygen

    B) The splitting of a molecule of water

    C) The production of ATP

    D) The production of glucose

    E) The formation of NADPH

22.   Correct Answer: E

Explanation: Choice (E) is the correct answer. Mitosis is a process that produces two diploid nuclei that are genetically identical to the original. Choice (A) is incorrect because meiosis, not mitosis, reduces the final chromosome number by half. Choice (B) is incorrect because sister chromatids separate during anaphase. Choice (C) is incorrect because cytokinesis occurs at the end of telophase, not during prophase. Choice (D) is incorrect because some somatic cells, such as certain neurons and skeletal muscle cells, do not divide once they are fully differentiated.

Tip

It may be helpful to draw the phases of mitosis as a guide. Students often confuse the term "chromatid" with the term "chromosome." It may help them to think of a replicated chromosome as consisting of two chromatids. When these chromatids separate during anaphase, they will each become part of a separate nucleus. Once this separation occurs, they are again referred to as chromosomes.

23.   Correct Answer: E

Explanation: Choice (E) is the correct answer. Prokaryotes have ribosomes that are smaller and simpler than the more complex ribosomes of eukaryotes. Ribosomes are made out of a special class of RNA molecules (ribosomal RNA, or rRNA) and a specific collection of proteins. Prokaryotic ribosomes have only three types of rRNA and around 50 types of proteins, while eukaryotic ribosomes are made of five kinds of rRNA and around 80 types of proteins. This structural difference allows erythromycin and certain other antibiotics to target bacteria without harming its eukaryotic host. Choice (A) is incorrect because by definition, prokaryotic cells are characterized by a lack of membrane-bound organelles. They contain a nucleoid region in which DNA is present but not enclosed by a nuclear membrane. Choice (B) is incorrect because although eukaryotic DNA is linear and prokaryotic DNA is coiled, this is not the reason that an antibiotic is able to target protein synthesis in bacteria. Choice (C) is incorrect because although translation can occur at the same time as transcription in prokaryotes, this does not explain why an antibiotic would not harm its eukaryotic host. Choice (D) is incorrect because although there is more space in a eukaryotic cell than in a prokaryotic cell, this is not the reason that an antibiotic is able to target protein synthesis in bacteria.

24.   Correct Answer: D

Explanation: Choice (D) is the correct answer. The production of glucose occurs in the stroma of the chloroplast, using light reaction products (ATP and NADPH) to fix carbon in either light or dark conditions. Choices (A), (B), (C) and (E) all occur during the light-dependent reaction and are necessary for the capture and conversion of energy. Only choice (D), the production of glucose, is an event that does not directly require light.

25. **Which of the following process does NOT involve the breakdown of carbon compounds?**

    A) Glycolysis

    B) Calvin cycle

    C) Respiration

    D) Krebs cycle

    E) Fermentation

26. **Changes in temperature and pH often have great effects on the efficiency of enzymes because**

    A) the energy of activation will be raised or lowered.

    B) the three-dimensional protein structure of enzymes is altered.

    C) changes affect substrate surfaces and make them unrecognizable.

    D) all enzymes work best at normal body temperature and a neutral pH.

    E) cofactors are not available under abnormal conditions.

25. **Correct Answer: B**

    Explanation: Choice (B) is the correct answer. The Calvin cycle is a metabolic pathway that occurs in the stroma of chloroplasts. During this cycle, carbon enters in the form of carbon dioxide (CO_2) and is converted—broken down—into sugar($C_6H_{12}O_6$). Choice (A) is incorrect because glucose, a carbon compound ($C_6H_{12}O_6$), is broken down into pyruvate during glycolysis. Choice (C) is incorrect because molecules such as glucose, a carbon compound ($C_6H_{12}O_6$), are broken down during respiration. Glucose is oxidized, and the energy derived from this oxidation reaction is used to form ATP. Choice (D) is incorrect because during the Krebs cycle, which occurs in the mitochondria, pyruvate (CH_3COCO_2H), a carbon compound, is broken down into Acetyl-CoA. Carbon dioxide is a product of this reaction. Choice (E) is incorrect because fermentation is made up of glycolysis in addition to the reduction of pyruvate to either lactate or alcohol and CO_2.

26. **Correct Answer: B**

    Explanation: Choice (B) is the correct answer. Both temperature and pH can alter tertiary protein structure, changing the active site where enzymatic activity occurs. There is a certain optimal temperature at which an enzyme's catalytic activity is greatest. Above this temperature, the enzyme structure denatures because intra- and intermolecular bonds are broken. Each enzyme also works within a specific pH range. Changes in pH can make and break intra- and intermolecular bonds. Choice (A) is incorrect because the energy of activation does not change. Choice (C) is incorrect because it does not address the effect on the enzyme. Choice (D) is incorrect because enzymes have different optimal conditions depending on their location in the body and function. Choice (E) is incorrect because cofactor availability would not normally be affected by physical conditions.

Chemistry

Sample Questions and
Answer Explanations

DO NOT DETACH FROM BOOK.

PERIODIC TABLE OF THE ELEMENTS

1 **H** 1.0079																	2 **He** 4.0026
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.811	6 **C** 12.011	7 **N** 14.007	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.179
11 **Na** 22.99	12 **Mg** 24.30											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.974	16 **S** 32.06	17 **Cl** 35.453	18 **Ar** 39.948
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.938	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.91	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57 ***La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.85	75 **Re** 186.21	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.02	89 **†Ac** 227.03	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (263)	107 **Bh** (262)	108 **Hs** (265)	109 **Mt** (266)	110 **§** (269)	111 **§** (272)	112 **§** (277)						

§Not yet named

*Lanthanide Series

58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 151.97	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97

†Actinide Series

90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** 237.05	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)

Chemistry

Chemistry

Classification Questions

Directions: Each set of lettered choices below refers to the numbered statements or questions immediately following it. Select the one lettered choice that best fits each statement or answers each question and then fill in the corresponding circle on the answer sheet. A choice may be used once, more than once or not at all in each set.

Note: For all questions involving solutions, assume that the solvent is water unless otherwise stated.

Throughout the test the following symbols have the definitions specified unless otherwise noted.

H	=	enthalpy	atm	=	atmosphere(s)
M	=	molar	g	=	gram(s)
n	=	number of moles	J	=	joule(s)
P	=	pressure	kJ	=	kilojoule(s)
R	=	molar gas constant	L	=	liter(s)
S	=	entropy	mL	=	milliliter(s)
T	=	temperature	mm	=	millimeter(s)
V	=	volume	mol	=	mole(s)
			V	=	volt(s)

Questions 1–3 refer to the following topics and relationships concerning states of matter.

A) A general rule for predicting solubility

B) Solid phase changing to the liquid phase

C) A state in which the liquid and gas phases are in equilibrium

D) Relationship between volume and temperature at constant pressure

E) Relationship between absolute temperature and the kinetic energy of particles

Which topic or relationship is best illustrated by the following?

1. Particles in a substance vibrate faster and faster until some are able to break from their fixed positions and move around more freely.

2. Evaporation and condensation rates in a closed container are the same.

3. The spaces between gas particles in air increase as the temperature of the air increases.

1.   Correct Answer: B
Explanation: Choice (B) is the correct answer. In a solid, particles are fixed in position in a lattice structure but are not motionless. When heated, particles in a solid gain energy and freedom of motion as the solid melts and becomes a liquid. Although particles in a liquid have freedom of motion, they are still close together.

2.   Correct Answer: C
Explanation: Choice (C) is the correct answer. When the liquid and gas phases are in equilibrium in a closed container, the number of particles leaving the liquid (evaporation) is equal to the number of particles entering the liquid from the gas phase (condensation).

3.   Correct Answer: D
Explanation: Choice (D) is the correct answer. Charles's Law describes the direct relationship of temperature and volume of a gas. Assuming that pressure does not change, a doubling in absolute temperature of a gas causes a doubling of the volume of that gas. A decrease in absolute temperature is proportional to the decrease in volume.

Chemistry

The equations below represent three different types of chemical reactions.

$$H_2SO_4(aq) + Zn(s) \rightarrow H_2(g) + ZnSO_4(aq)$$
$$AgNO_3(aq) + KI(aq) \rightarrow KNO_3(aq) + AgI(s)$$
$$HF(aq) + H_2O(l) \leftrightarrows F^-(aq) + H_3O^+(aq)$$
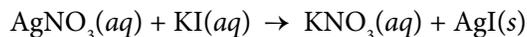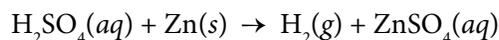
Questions 4–6 refer to the identity of five species involved in these reactions.

    A) $Zn(s)$

    B) $H_2(g)$

    C) $AgI(s)$

    D) $H_2O(l)$

    E) $H_3O^+(aq)$

4.   Which species is classified as an insoluble salt?

5.   Which species is the acid of a conjugate acid-base pair?

6.   Which species is acting as a reducing agent?

Questions 7–9 refer to properties of the following elements.

    A) Al, aluminum

    B) C, carbon

    C) Ca, calcium

    D) F, fluorine

    E) Li, lithium

7.   Which element is the most electronegative of all elements?

8.   Which element reacts with oxygen in a 2 to 3 ratio of element to oxygen, producing X_2O_3?

9.   Which element often forms compounds in which it has four covalent bonds?

4. **Correct Answer: C**

Explanation: Choice (C) is the correct answer. As a solid, this species is formed in the reaction as a precipitate, or insoluble solid. Also, AgI is the only listed species that is a salt, or a neutral compound made of positive and negative ions. The second reaction is a precipitation reaction, showing two salts are switching ion pairs from $Ag^+NO_3^-$ and K^+I^- to $K^+NO_3^-$ and the insoluble salt Ag^+I^-.

Tip
Review reaction notation and precipitation reactions.

5. **Correct Answer: E**

Explanation: Choice (E) is the correct answer. The Brønsted-Lowry acid base theory says that an acid donates a proton to a base, which accepts the proton. After the acid reactant donates a proton to the base reactant, the acid reactant becomes the conjugate base product, and the base reactant becomes the conjugate acid product. The HF is the acid that donates a proton to become the conjugate base, F^-. H_2O is the base that accepts the proton to become the conjugate acid, H_3O^+. The third reaction is the only acid base reaction. Although the first reaction involves a strong acid, it is not an acid base reaction because there is no proton transfer between the reactants.

6. **Correct Answer: A**

Explanation: Choice (A) is the correct answer. The first reaction is the only reduction-oxidation reaction, and the reducing agent loses electrons and increases its oxidation state, or hypothetical charge. In this case, Zn loses two electrons and is oxidized to Zn^{2+}. In the process, it is the agent that reduces H^+ to elemental H^o.

Tip
Have students assign oxidation numbers to each species in a redox reaction. By doing so, students should be able to recognize which species are losing or gaining electrons, which will help them to identify the oxidizing and reducing agents. A reducing agent includes an atom or element that increases in oxidation number during a reaction.

7. **Correct Answer: D**

Explanation: Choice (D) is the correct answer. As you move from left to right across a row in the periodic table, electronegativity increases due to the stronger attraction that atoms obtain as the nuclear charge increases. As you move down a group in the periodic table, electronegativity decreases because the atomic number increases, increasing the distance between the valence electrons and nucleus. The exceptions are the noble or inert gases, because they already have a complete valence shell, and the lanthanides and actinides that do not follow these trends. Fluorine's position in the top right corner of the periodic table corresponds with the fact that it is the most electronegative element.

8. **Correct Answer: A**

Explanation: Choice (A) is the correct answer. Aluminum has an oxidation state of +3 in the majority of Al-containing compounds, and oxygen commonly has an oxidation state of -2. In order for a molecule with 3 oxygen atoms to have a neutral charge, something must balance out the $(3)(-2) = -6$ charge. Here, the 2 Al ions contribute a charge of $(2)(+3) = 6$ to give a neutral compound. The other elements do not have the oxidation states for making a neutral compound if 2 atoms were to react with 3 oxygen atoms.

9. **Correct Answer: B**

Explanation: Choice (B) is the correct answer. Carbon has four valence electrons and often forms four single bonds with other nonmetals. Students should recognize that this is the basis of organic chemistry.

Relationship Analysis Questions

Directions: Each question on pages 43-48 consists of two statements: I in the left-hand column and II in the right-hand column. For each question, determine whether statement I is true or false <u>and</u> whether statement II is true or false and fill in the corresponding T or F circles on your answer sheet. *<u>Fill in circle CE only if statement II is a correct explanation of the true statement I.</u>

On the actual Chemistry Test, the following type of question must be answered on a special section (labeled "Chemistry") at the lower left-hand corner of your answer sheet. These questions will be numbered beginning with 101 and must be answered according to the proceeding directions.

EXAMPLES:

	I		II
EX 1.	H_2SO_4 is a strong acid	BECAUSE	H_2SO_4 contains sulfer.
EX 2.	An atom of oxygen is electrically neutral	BECAUSE	an oxygen atom contains an equal number of protons and electrons.

SAMPLE ANSWERS

	I	II	CE
EX 1.	● Ⓕ	● Ⓕ	○
EX 2.	● Ⓕ	● Ⓕ	●

	I		II
10.	Sodium and chlorine have different chemical properties	BECAUSE	sodium and chlorine have different principal quantum numbers for the highest occupied energy level.
11.	Carbon tetrachloride (CCl_4) is insoluble in water	BECAUSE	water molecules contain polar bonds and have an asymmetric shape.
12.	Water molecules have a bent shape	BECAUSE	water molecules have lone pairs of electrons that repel bonding electrons.

10. Correct Answer: I True, II False, CE No

Explanation: Statement I is true, and statement II is false. Sodium (Na) and chlorine (Cl) have different chemical properties because they have different numbers of valence electrons. Elements in different groups of the periodic table have vastly different chemical properties because they have different numbers of valence electrons in their outer shells. Sodium and chlorine have the *same* principal quantum number for the highest energy electron, because they are in the same period; this is true for any of the elements in the first three rows of the periodic table.

Tip

Have students compare chemical properties for any two elements based on their position on the periodic table. Each element has unique chemical properties, but elements from the same column or group generally have similar chemical characteristics. Students should be familiar with the general chemical characteristics associated with each group. Students should also be able to determine the principal quantum number for the valence electrons of any element on the periodic table. While this is fairly easy to do for elements in the first three rows, it becomes more complicated once the transition metals, lanthanoids and actinoids are considered.

11. Correct Answer: I True, II True, CE Yes

Explanation: Both statements I and II are true, and statement I is true because of statement II. Carbon tetrachloride (CCl_4) is a nonpolar molecule because it is symmetrical and has no dipole moment, even though it contains polar bonds. In general, nonpolar compounds are not soluble in polar compounds. Water molecules are polar because hydrogen (H) and oxygen (O) have large differences in their electronegativities, resulting in a polar bond, and because of the asymmetric shape of the molecule. The polar bonds between the oxygen and hydrogen atoms result in a partial negative charge on the oxygen (O) side and a partial positive on the hydrogen (H) side. The two pairs of unbonded electrons in a water molecule result in a "bent" molecular shape. Combined, the asymmetric bent shape and bond polarity determine the molecular polarity. The polar bonds and asymmetric shape of water molecules both explain why water is a polar solvent that does not dissolve a nonpolar compound like carbon tetrachloride.

Tip

Have students determine if bonds are polar or not, based on differences in electronegativity and/ or location on the periodic table, and diagram molecules to be able to determine if their shape is symmetrical or not. Once students can determine if a molecule contains polar bonds AND has an asymmetrical shape, they should be able to then determine if a molecule is polar or not. Students may benefit from exercises in which they diagram a molecule and label the dipole moment. Students should also have laboratory experience creating solutions from polar and nonpolar compounds. They will see that most solutions are only possible when the solute and solvent are either both polar or both nonpolar.

12. Correct Answer: I True, II True, CE Yes

Explanation: Both statements I and II are true, and statement I is true because of statement II. Water molecules are bent because the four electron pairs repel each other, resulting in a tetrahedral geometry. All electrons repel each other whether they are bonding or nonbonding lone pairs. The fact that lone pairs of electrons repel bonding electrons in a water molecule where the oxygen atom has two single bonds and two lone pairs, explains why the two bonds in the H – O – H line are at an angle.

I   II

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$$
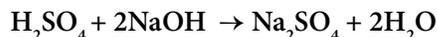
13.   When 1.0 mol H_2SO_4 reacts with 1.0 mol   in the reaction represented by the equation
       NaOH according to the reaction   BECAUSE   above, the molar mass of H_2SO_4 is more
       by the equation above, NaOH is the   than twice the molar mass of NaOH.
       limiting reactant

$$2NO_2(g) \leftrightarrows N_2O_4(g)$$
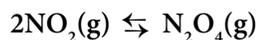
       When the reaction represented by the
14.   equation above is at equilibrium in a sealed   in the reaction represented above,
       container, a decrease in the volume of the BECAUSE a shift toward NO_2 decreases the pressure
       reaction container will shift the equilibrium   of the system.
       toward NO_2

15.   Evaporation of water results in an increase   water molecules are distributed more
       in entropy   BECAUSE   randomly in the gas state than in the liquid
                                                            state.

13. Correct Answer: I True, II True, CE No

Explanation: Both statements I and II are true. The stoichiometry shows that 1.0 mol of NaOH will react with only 0.5 mol of H_2SO_4, leaving 0.5 mol of H_2SO_4 unreacted, indicating that NaOH is the limiting reactant. The molar mass of H_2SO_4 is 98.08 g/mol, which is more than twice NaOH's molar mass of 40.00 g/mol. However, the molar masses are not relevant because the limiting reactant is determined by mole ratios, not by the molar masses of the reactants.

Tip

Have students work with reactions in order to determine which reactant is limiting. When there are only two reactants, students can easily compare the initial amount needed of each reactant. Have students choose one reactant (A) and then use the balanced chemical equation to determine the amount of the other reactant (B) necessary to react with A. If the amount of B actually present exceeds the amount required, then B is in excess and A is the limiting reactant. If the amount of B present is less than required, then B is the limiting reactant.

14. Correct Answer: I False, II False, CE No

Explanation: Both statements I and II are false. PV is constant; as volume decreases, the pressure will increase. To accommodate for this volume change, the equilibrium will shift in the direction that decreases the number of moles of gas. Since the formation of N_2O_4 uses 2 moles and produces only 1, the number of moles will decrease, countering the increased pressure. Therefore, increasing pressure will produce more N_2O_4, shifting the equilibrium to the right.

Tip

Have students apply Le Châtelier's principle to a variety of types of equilibrium reactions. For reactions involving only gaseous species, students should be able to apply the ideal gas law as well. Point out to students that if PV is to remain constant, then any decrease in volume must result in an increase in pressure. The system reestablishes equilibrium by shifting in the direction with fewer moles.

15. Correct Answer: I True, II True, CE Yes

Explanation: Both statements I and II are true, and statement I is true because of statement II. Entropy is a measure of disorder in a system. Ice is more ordered than liquid water, which is more ordered than the particles in water vapor. Intermolecular forces in the liquid state result in an ordered, but fluid, arrangement of molecules, but these forces are not a factor in the gas state because the intermolecular distances are much greater. The fact that molecules of water in the gas state have a higher entropy than liquid water molecules corresponds with an increase in entropy during evaporation.

I

II

16. When magnesium (Mg) reacts with chlorine (Cl), the atoms combine in a 1 to 2 ratio to form $MgCl_2$ BECAUSE   each magnesium atom gains two electrons and each chlorine atom loses one electron.

17. If the volume on a buret can be accurately read to the nearest 0.01 mL, then the volume of exactly 20 mL of a solution released from the buret should be recorded as 20.00 mL   BECAUSE   it is standard practice to record data to two decimal places.

16. **Correct Answer: I True, II False, CE No**

Explanation: Statement I is true, and statement II is false. Magnesium (Mg) is divalent and chlorine (Cl) is monovalent. The 1 to 2 ratio gives each atom a complete octet of electrons. Therefore, one atom of Mg would react with two atoms of Cl to produce $MgCl_2$. Alkaline earth metals in group 2 have two valence electrons and they tend to react to lose those electrons. Halogens are one electron short of an octet, so they tend to react to gain one electron. When $MgCl_2$ is formed, each magnesium atom would lose two electrons, and each chlorine atom would gain one electron.

Tip

Have students draw Lewis structures for elements on the left and right sides of the periodic table. These elements commonly lose or gain electrons to form ions and ionic compounds. Have students then label elements by writing a superscript indicating the charge of the cation or anion formed when valence electrons are lost or gained in order to form a complete outer shell. For example, Mg loses two electrons, so its cation would have two more protons than electrons. It would be written as Mg^{2+}. When determining the formula for an ionic compound, the absolute value of the charge of the cation multiplied by its subscript in the ionic formula should equal the absolute value of the charge of the anion multiplied by its subscript.

17. **Correct Answer: I True, II False, CE No**

Explanation: Statement I is true, and statement II is false. Because the buret can be read accurately to 0.01 mL, the volume of a solution should be measured using two decimal places. However, the standard practice is to record data and report measurements using correct significant figures, not just to use two decimal places. Statement II is not the correct explanation of statement I, because the standard practice is stated incorrectly.

Five-Choice Completion Questions

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

18. This is the Lewis structure of an ammonia (NH_3) molecule.

H:N:H
H
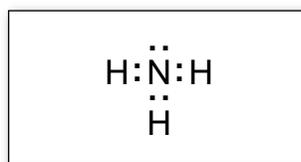
Which of the following describes the shape of an ammonia molecule?

A) T-shaped

B) Tetrahedral

C) Square planar

D) Trigonal planar

E) Trigonal pyramidal

19. The air trapped in a glass tube occupies 2.0 liters at 1.0 atm. The sample of air is compressed until the pressure on the trapped air molecules is increased to 4.0 atm. Assuming constant temperature, what is the new volume of the air (in L)?

A) 0.25L

B) 0.50L

C) 2.0L

D) 4.0L

E) 8.0L

20. Which of these properties generally decreases when moving left to right across a period, or row, of the periodic table?

A) Reactivity

B) Atomic radius

C) Electron affinity

D) Ionization energy

E) Number of valence electrons

18. Correct Answer: E

Explanation: Choice (E) is the correct answer. The lone pair on the N atom repels the bonding electrons of the three NH bonds to create a three-legged stool shape. According to valence shell electron pair repulsion (VSEPR) theory, the shape of the molecule and the angles between bonds are determined by the repulsion of all valence shell electrons. The lone electron pair and the three NH bonding electron pairs repel each other toward the apexes of a tetrahedron. Because the lone pair is not part of the molecular shape, the result is that the three bonds form a three-sided pyramid and are separated by an angle slightly less than the tetrahedral angle, 109.5°.

Tip

Students should be able to translate a Lewis structure for any molecule into a molecular shape. A useful exercise is to have students fill in the information for a number of different molecules. In most cases, it is important for students to first determine the total number of valence electrons for a given molecule, the hybridization, and the molecular polarity for the molecule before they can determine the molecular geometry or shape.

19. Correct Answer: B

Explanation: Choice (B) is the correct answer. The ideal gas law can be used to determine new values for a gas based on changing conditions. Rearranging the ideal gas law formula, $PV = nRT$, and solving for the universal gas constant, R, results in $R = PV/nT$. When comparing a gas at two different conditions, you can set the two conditions equal to each other: $P_1V_1/n_1T_1 = P_2V_2/n_2T_2$. Since temperature ($T$) and amount of gas ($n$) are constant in this situation, the equation simplifies to $P_1V_1 = P_2V_2$. Solving for the final volume results in $V_2 = P_1V_1/P_2$. Plugging in the initial volume and pressure and final pressure for the gas gives:
$V_2 = (1.0\text{atm})(2.0\text{L})/(4.0\text{L}) = 0.50\text{L}$

Tip

Have students work with the ideal gas law formula, using both static and changing conditions. Students should be able to rearrange the ideal gas law expression and solve for any one value given quantities for the other values when no change occurs. Additionally, students should be able to use the ideal gas law to determine how a change in one of the four variables causes a change in another, while the two remaining variables remain constant. Starting with the expression $P_1V_1/n_1T_1 = P_2V_2/n_2T_2$, the student can cancel out the two variables that remain constant and solve for the unknown. Students should practice this with any number of situations in which two variables remain constant and one changing variable causes a change in another.

20. Correct Answer: B

Explanation: Choice (B) is the correct answer. Atomic radii decrease from left to right because the effective nuclear charge of atoms increases across the rows, drawing the valence shell electrons closer. Choice (A) is incorrect because reactivity first decreases as the tendency to lose electrons decreases, then increases as the tendency to gain electrons increases. Choices (C) and (D) are both incorrect because electrons become more tightly held as the number of protons and electrons increase, resulting in increasing electron affinity and ionization energy. Choice (E) is incorrect because each element has one more valence electron than the previous element.

21. Which of these represents the ground-state electron configuration of a neutral aluminum (Al) atom?

    A) $1s^2 2s^2 2p^1$
    B) $1s^2 2s^2 2p^6 3s^1$
    C) $1s^2 2s^2 2p^6 3s^2 3p^1$
    D) $1s^2 2s^2 2p^6 3s^2 3p^5$
    E) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4s^2$

22. Which of the following molecules is nonpolar, but has polar bonds?

    A) Carbon dioxide (CO_2)
    B) Hydrogen chloride (HCl)
    C) Water (H_2O)
    D) Sulfur dioxide (SO_2)
    E) Phosphorus trichloride (PCl_3)

23.

Substance	Molar mass (g)	Boiling point (°C)
Methane	16	-162
Water	18	100

The table above lists the molar masses and boiling points of methane and water at standard pressure. Which of the following best explains the large difference between the boiling points of methane and water?

A) Methane is an organic compound.
B) Water needs more energy to boil because it ionizes into hydrogen and hydroxide ions.
C) Most compounds with low molar masses have low boiling points, except water.
D) London dispersion forces are not present for simple hydrocarbons with low molar mass.
E) Hydrogen bonding in water increases the attractive forces between molecules.

21. **Correct Answer: C**
Explanation: Choice (C) is the correct answer. Aluminum has the configuration of neon ($1s^2 2s^2 2p^6$) plus a full 3s orbital and one electron in the 3p orbital. Choice (A) is the configuration of boron (just above aluminum), choice (B) is the configuration of sodium, choice (D) is the configuration of chlorine and choice (E) is the configuration of scandium.

> **Tip**
> Students should understand the organization of the periodic table and recognize the connection between electron configurations of atoms and the blocks in the table (s-block, p-block, d-block and f-block). Students should have experience identifying elements in the periodic table given an electron configuration and vice versa. Also, an Aufbau diagram can help simplify the process of determining the sequence with which orbitals fill with electrons and help scaffold students' understanding of the periodic table.

22. **Correct Answer: A**
Explanation: Choice (A) is the correct answer. The electronegativity difference between carbon and oxygen is large enough to make these bonds polar, but the overall molecule is nonpolar because it is linear. Choices (B), (C), (D) and (E) are polar molecules with polar bonds. Choices (C), (D) and (E) are polar because of geometry.

> **Tip**
> Students should have experience identifying polar bonds in a molecule using differences in electronegativity. Students should be able to then determine if a molecule with polar bonds is polar overall, based on its shape and symmetry. As a basis for identifying polar molecules, students should have practice drawing Lewis structures, identifying molecular geometries and contrasting the two.

23. **Correct Answer: E**
Explanation: Choice (E) is the correct answer. The value of a boiling point reflects the strengths of the intermolecular forces between liquid molecules. In order to boil, liquid molecules must overcome these attractive forces to separate and form a vapor. Water molecules have very strong, attractive forces because they form hydrogen bonds. Water molecules are also polar, with large dipoles that attract each other. Methane cannot form hydrogen bonds, and it is nonpolar. The only attractive forces between methane molecules are London dispersion forces. Choice (A) is incorrect because many organic compounds have higher boiling points than water. Choice (B) is incorrect because ionization is different from boiling. Ionization requires the covalent bonds between molecules to break; this requires a lot more energy than boiling, which is the liquid molecules overcoming attractive forces so they can form vapors. Choice (C) does not explain the difference in boiling points; it only restates it. Choice (D) is incorrect because London dispersion forces are the most important intermolecular force for hydrocarbons.

24. Which of the following best explains how some nonpolar substances can be liquids at room temperature?

A) The molecules share electrons, forming bonds.

B) The molecules form temporary dipoles with partial charges.

C) The molecules transfer electrons, forming ions with opposite charges.

D) The molecules form positive ions that are held together by free electrons.

E) The molecules form temporary bonds between hydrogen and electronegative atoms.

25. The phase diagram for carbon dioxide (CO_2) is shown to the right. Crossing through which of the following represents a phase change directly from solid to gas?

A) point Y

B) point Z

C) line WX

D) line XY

E) line XZ

Phase Diagram of Carbon Dioxide
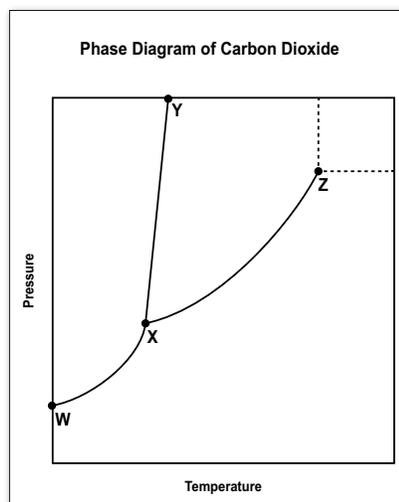
26. How many milliliters of 0.20 molar (M) sulfuric acid (H_2SO_4) solution will be needed to exactly neutralize 200 mL of 0.10 M sodium hydroxide (NaOH) solution?

A) 50.0 mL

B) 80.0 mL

C) 100 mL

D) 200 mL

E) 400 mL

24. Correct Answer: B

Explanation: Choice (B) is the correct answer. In liquids, the intermolecular attractive forces are strong enough to hold molecules close together. Because of the nature of the electron cloud, there are temporary dipoles in nonpolar molecules that can induce dipoles in nearby molecules. The induced dipoles cause the molecules to attract each other. Choices (A), (C) and (D) are incorrect because they describe covalent, ionic and metallic bonding, respectively. Choice (E) is incorrect because nonpolar substances do not have electronegative atoms, so they cannot form hydrogen bonds.

25. Correct Answer: C

Explanation: Choice (C) is the correct answer. Crossing line WX (by decreasing pressure, increasing temperature, or both) represents a phase change directly from solid to gas, otherwise known as sublimation. Above the line, carbon dioxide is solid, and below the line, it is gas. At the line, the two phases of matter are in equilibrium. Choice (A) is an arbitrary point between solid and liquid phases. Choice (B) represents the point past which there is no physical distinction between vapor and liquid phases. Choice (D) represents a change between solid and liquid, and choice (E) represents a change between liquid and gas.

Tip

Students should have experience labeling important features of phase diagrams for multiple substances, including states of matter and triple and critical points. Phase diagrams for H_2O and CO_2 are the most commonly found. Students should be able to describe the conditions under which a substance will change states using the information provided in a phase diagram. An important distinction that students need to make is that while phase diagrams for different substances might look similar, the actual temperature and pressure values for the triple point can differ greatly and will determine the behavior of a substance under standard conditions.

26. Correct Answer: A

Explanation: Choice (A) is the correct answer. Sodium hydroxide = NaOH = 1 mol Na^+ and 1 mol OH^-. Sulfuric acid = H_2SO_4 = 2 mol H^+ and 1 mol SO_4^{2-}. Therefore, to neutralize 1 mol of sulfuric acid (2 mol H^+), you need 2 mol of sodium hydroxide (2×1 mol OH^-).

(200 mL) × (1 L / 1000 mL) = 0.2 L
0.10 M = 0.1 mol/ 1 L
0.20 M = 0.2 mol/ 1 L

Therefore: (0.20 L NaOH) × (0.10 mol NaOH/L) × (1 mol H_2SO_4/2 mol NaOH) × (1L/0.20 mol H_2SO_4) = 0.050 L = 50 mL

Choice (B) is the mass of two moles of NaOH. Choice (C) is incorrect because it uses equal molar equivalents of NaOH and H_2SO_4, rather than 2 moles NaOH per mole of H_2SO_4. Choice (D) could be the result of inverting the stoichiometry fraction and calculating for 2 moles H_2SO_4 per 1 mole NaOH, or assuming that half as much H_2SO_4 solution is needed because of its molarity. Choice (E) is two times the amount of NaOH solution to be neutralized.

Tip

Students should have experience using dimensional analysis to determine stoichiometric values for common reactions. One step that is often overlooked is the development of a balanced equation for the reaction. In this case, a balanced equation (H_2SO_4+2NaOH $\rightarrow$ Na_2SO_4+2H_2O) will produce a molar ratio of 2:1 for NaOH to H_2SO_4. This is a critical step in the dimensional analysis process. Once the molar ratio is determined, the student can convert L NaOH $\Longrightarrow$ mol NaOH $\Longrightarrow$ mol H_2SO_4 $\Longrightarrow$ L H_2SO_4.

27.

Solution	Concentration (mol/L)	pH
I	0.1	14
II	0.1	2.9
III	0.01	2.0
IV	0.001	3.0

The table shown above describes four solutions needed for an acid-base laboratory experiment. Which solution(s) were prepared using weak acids?

A) I only

B) II only

C) I and II only

D) III and IV only

E) II, III and IV

28. Potassium permanganate ($KMnO_4$) reacts with sodium sulfite (Na_2SO_3) in water to produce manganese dioxide (MnO_2), sodium sulfate (Na_2SO_4) and potassium hydroxide (KOH), as shown by the equation below.

$$2KMnO_4 + 3Na_2SO_3 + H_2O \rightarrow 2MnO_2 + 3Na_2SO_4 + 2KOH$$
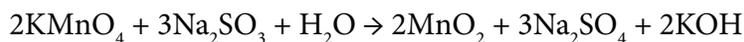
Which is the reducing agent in this reaction?

A) K^+

B) MnO_4^-

C) Na^+

D) SO_3^{2-}

E) H_2O

29. Analysis of a sample of an unknown hydrocarbon yields 2.4 grams (g) of carbon and 0.30 g of hydrogen. These results indicate an empirical formula of C_2H_3. Based on this information and the usual bonding patterns of the atoms involved, which of these formulas COULD be the molecular formula?

A) C_2H_6

B) C_3H_4

C) C_3H_6

D) C_4H_6

E) C_6H_9

27. **Correct Answer: B**

Explanation: Choice (B) is correct. The data for Solution II are based on a dilute acetic acid solution. Together, the concentration of 0.1 M and pH of 2.9 indicate that the solution most likely contains a weak acid. These data demonstrate that the acid does not completely dissociate (else the pH would be 1.0). Solution I is a strong base, in choices (A) and (C). Solutions III and IV, in choices (D) and (E), are both examples of strong acids. For all three of these solutions, the concentrations and pH values together demonstrate that they completely dissociate.

28. **Correct Answer: D**

Explanation: Choice (D) is the correct answer. SO_3^{2-} is the reducing agent, or reductant, in this reaction because it is oxidized to SO_4^{2-}. The oxidation state of sulfur in SO_3^{2-} is +4: $(+4 \times 1) + (-2 \times 3) = -2$. The oxidation state of sulfur in SO_4^{2-} is +6 to give the sulfate ion a -2 charge: $(+6 \times 1) + (-2 \times 4) = -2$. Choice (B) is wrong because MnO_4^- is reduced to MnO_2; the oxidation state of Mn decreases from +7 to +4, so MnO_4^- is an oxidizing agent. Choices (A), (C) and (E) are incorrect because the elements K, Na, H and O do not change oxidation state.

> **Tip**
>
> **Students should have experience determining oxidation numbers for each atom in a chemical formula. This can be fairly easy for some chemical species, but students should be comfortable applying the rules for assigning oxidation numbers to a variety of molecules. In particular, students should be comfortable recognizing that oxidation numbers for a particular element can change during a redox reaction. Once they are able to determine oxidation numbers for each atom in a redox reaction equation, they should be able to determine which element, ion or compound is the reducing agent and which is the oxidizing agent based on identifying which element has an increase in oxidation number (the reducing agent) and which one has a reduction in oxidation number (the oxidizing agent).**

29. **Correct Answer: D**

Explanation: Choice (D) is the correct answer. Empirical formulas state the simplest ratio of atoms for each element in a compound. Choice (D) is correct because C_4H_6 is the simplest molecular formula for the given empirical formula. C_4H_6 can be the formula for both butadiene (a linear 4-carbon chain with 2 double bonds) and cyclobutene (a 4-carbon chain cycloalkene). Choices (A), (B) and (C) are incorrect because the C:H ratio must be 2:3. Choice (E) is not possible; a 6-carbon hydrocarbon will only have an even number of hydrogen atoms.

> **Tip**
>
> **Students should be able to evaluate possible molecular formulas given an empirical formula, recognizing that there are specific limitations involved and that the ratio between the constituent atoms must remain the same. Students should also be comfortable drawing molecular structures for hydrocarbons given a molecular formula. In doing so, students should realize that certain ratios are generally not possible given the "rules" of C-H bonding for different types of hydrocarbons.**

30. An analytical chemist is given a sample of aluminum oxide (Al_2O_3). She finds that it contains approximately 12 moles of oxygen. Knowing that the atomic mass of aluminum is 27 g/mol and the atomic mass of oxygen is 16 g/mol, what is the total mass of this Al_2O_3 sample?

    A) 102 g

    B) 192 g

    C) 408 g

    D) 1224 g

    E) 3672 g

31.
$$\ldots C_3H_8O + \ldots O_2 \rightarrow \ldots CO_2 + \ldots H_2O$$

    The equation above represents the complete combustion of propanol (C_3H_8O). When this equation is balanced and all coefficients are reduced to lowest whole-number terms, the coefficient for O_2 is

    A) 6

    B) 8

    C) 9

    D) 12

    E) 18

32. The graph to the right shows how potential energy changes during a chemical reaction. Which aspect of the graph provides the best evidence that the chemical reaction is exothermic?

    A) The potential energy at point 2

    B) The time needed to reach point 3

    C) The time elapsed between points 2 and 3

    D) The energy difference between points 1 and 2

    E) The energy difference between points 1 and 3
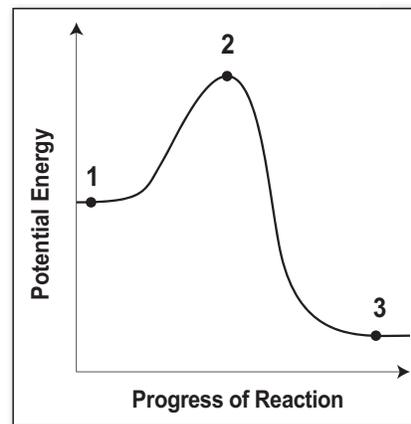
30. Correct Answer: C

Explanation: Choice (C) is the correct answer. Using the atomic mass of aluminum and oxygen, calculate the molar mass of Al_2O_3:

$$2 \text{ mol Al} \times (27 \text{ g/ mol}) = 54 \text{ g/mol}$$
$$3 \text{ mol O} \times (16 \text{ g/mol}) = 48 \text{ g/mol}$$
$$Al_2O_3 = 54 \text{ g/mol} + 48 \text{ g/mol} = 102 \text{ g/mol}$$

Next, knowing the moles of oxygen in the Al_2O_3 sample (12), that there are 3 moles of oxygen in every mole Al_2O_3, and the atomic mass of Al_2O_3, calculate the mass of the sample:
$12 \text{ mol O} \times (1 \text{ mol } Al_2O_3/3 \text{ mol O}) \times (102 \text{ g } Al_2O_3/1 \text{ mol } Al_2O_3) = 408 \text{ g } Al_2O_3$.

Choice (A) is the mass of 1 mol of aluminum (III) oxide. Choice (B) is the mass of 12 mols of oxygen. Choice (D) ignores the stoichiometry fraction, and choice (E) inverts the stoichiometry fraction.

31. Correct Answer: C

Explanation: Choice (C) is the correct answer. The balanced equation is $2 \, C_3H_8O + 9 \, O_2 \rightarrow 6 \, CO_2 + 8 \, H_2O$. The coefficient for O_2 is 9. Choices (A) and (B) are the coefficients of the products. Choice (D) is the sum of the coefficients of the products minus the coefficient of C_3H_8O. Choice (E) is the number of oxygen *atoms* in the balanced chemical equation (ignoring the subscript, 2, in the O_2 molecule).

32. Correct Answer: E

Explanation: Choice (E) is the correct answer. This is the potential energy difference between reactants and products. Because the change is negative, the reaction must release energy, so it is exothermic. Choice (A) is the potential energy of the transition state, when the reaction always has the highest potential energy. Choices (B) and (C) may provide information about the reaction rate, but not about whether the reaction is exothermic. Choice (D) is the activation energy, which is the amount of energy the reaction needs to proceed.

Tip

Students should have experience interpreting energy diagrams for different types of processes (e.g., change in state, chemical reactions). Students should be able to explain a potential energy diagram in terms of the net gain (endothermic) or loss (exothermic) of heat relative to the system and how that net change can be represented graphically over the progress of the reaction with respect to potential energy. Additionally, students should be comfortable interpreting other parts of a potential energy diagram, such as the activation energy.

33. The table to the right lists values for three properties of water. How much heat must be added to 10 grams of ice at 0°C to convert it to liquid water at 100°C?

    A) 800 cal

    B) 1,000 cal

    C) 1,800 cal

    D) 6,200 cal

    E) 7,200 cal

Property	Value
Heat of Fusion (cal/g)	80
Heat of Vaporization (cal/g)	540
Specific Heat (cal/g·°C)	1.00

34. Which of the following solutions, when titrated with 0.1M NaOH, could produce the titration curve shown below?

    A) $Ca(OH)_2(aq)$
    B) $HCl(aq)$
    C) $H_2SO_4(aq)$
    D) $H_3PO_4(aq)$
    E) $Na_2CO_3(aq)$

Volume of NaOH Added
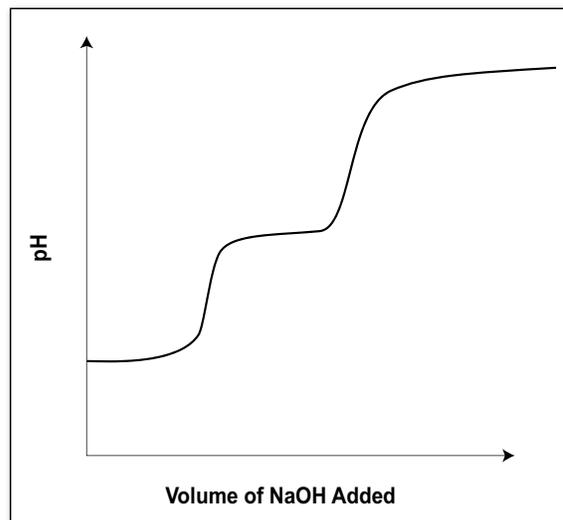
33.   Correct Answer: C

Explanation: Choice (C) is the correct answer. The heat of fusion is the enthalpy change for melting a solid, so the heat needed to melt the ice is $10g \times 80$ cal/g = 800 calories. The specific heat is the heat required to raise the temperature of 1 g of a substance by 1°C, so the heat needed to raise the temperature of the water from 0°C to 100°C is $10g \times 100°C \times 1.00$ cal/g•°C = 1,000 calories. The total energy is then 800 + 1,000 = 1,800 calories. Choice (A) is the heat needed to melt the ice alone. Choice (B) is the heat needed to raise the temperature alone. Choice (D) is the amount of heat needed to melt 10g of ice and boil 10g of water, but is missing the heat needed to raise the temperature of the water. Choice (E) is the amount of heat needed to melt the ice, raise the temperature to 100°C and boil the water.

34.   Correct Answer: C

Explanation: Choice (C) is the correct answer. H_2SO_4 is a diprotic acid, or an acid with two ionizable protons. The titration curve shown has two upward changes in pH, one for each ionizable proton of a diprotic acid. This reflects the fact that their neutralization occurs in more than one stage. Choice (B) is incorrect because HCl is monoprotic. The acid-base titration of an HCl solution should have only one inflection. Choices (A) and (E) are all basic in solution, so their acid-base titrations would involve a known concentration of an acid, not of a base like NaOH. Choice (D) is a triprotic acid.

Tip

Students should have experience conducting titrations to identify unknown solutions and should have practice recognizing acids and bases using different theories, including recognizing that substances formed by the reaction of acids and bases (salts) may be acidic or basic in solution. Students should recognize the relative strengths of common acids and bases, and thereby recognize when a given salt is acidic in solution and when it is basic.

SAT **Subject Tests**
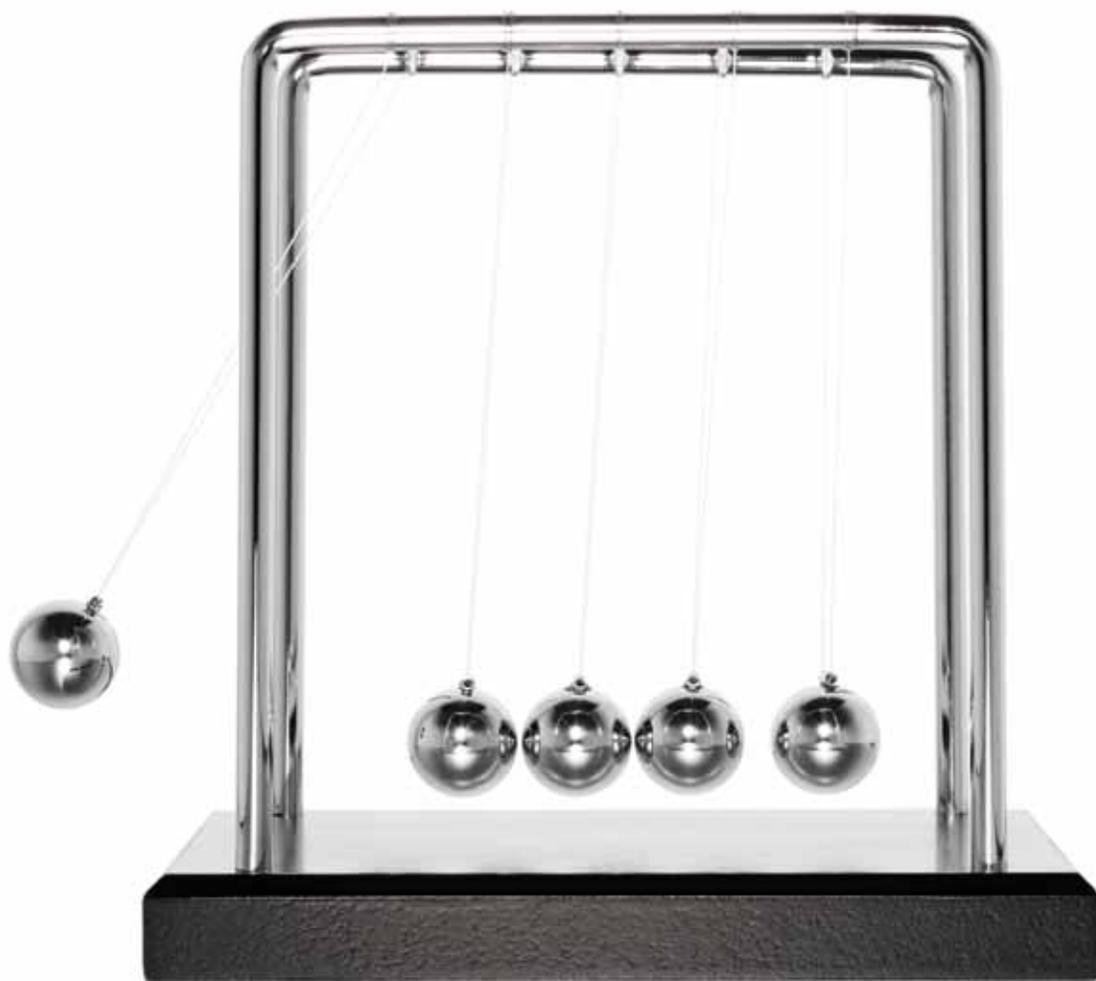
Physics

Sample Questions and
Answer Explanations

Physics

Note: To simplify calculations, you may use g = 10 m/s² for the acceleration due to gravity at the Earth's surface.

Directions: Each set of lettered choices below refers to the numbered questions immediately following it. Select the one-lettered choice that best answers each question, and then fill in the corresponding circle on the answer sheet. A choice may be used once, more than once or not at all in each set.

Questions 1–3

    A)   Inertia

    B)   Unbalanced forces

    C)   Action and reaction force pairs

    D)   Universal gravitation

    E)   Simple harmonic motion

Select the concept above that should be used to describe each of the following.

1.   A block moves up and down on a spring. The magnitude of the force of the spring on the block is directly proportional to the distance the spring is stretched.

2.   An object slides on a horizontal, frictionless surface.

3.   There is an attractive force between any two objects. The size of this force depends upon the masses of the objects and the distance between them.

1. **Correct Answer: E**

    Explanation: Choice (E) is the correct answer. A block moving up and down on a spring is an example of simple harmonic motion, whereas the up and down motion of the block is oscillatory and occurs due to the restoring force of the spring. Hooke's law governs the simple harmonic motion of a weight on a spring. Although the motion can be derived from the other principles, Hooke's law is the direct expression of the relationship between displacement and restoring force. The mathematical expression of the law is $\mathbf{F} = -k\mathbf{x}$, where $\mathbf{F}$ is the restoring force, k is the spring constant, and $\mathbf{x}$ is the displacement from the rest position. (Bold letters are used to indicate vectors.)

    Tip Students should have opportunities to explore oscillating motion in springs or pendulums. These experiences can be enhanced by computer simulations of simple harmonic motion that allow students to manipulate restoring forces and mass in these systems, and to quickly gather and analyze data. Students should also have opportunities to solve problems (conceptual and mathematical) that include simple harmonic motion: for example, in regard to some timekeeping devices such as a watch spring or a pendulum in a clock.

2. **Correct Answer: A**

    Explanation: Newton's first law states that the velocity of an object will remain unchanged as long as the forces acting on it are balanced. This law is also known as the law of inertia. There are no unbalanced forces involved in this example. In this case the only forces acting on the object are gravity and the normal force, which are equal in magnitude, opposite in direction, and therefore balanced. The third law (which describes action and reaction force pairs) and universal gravitation are not particularly useful for a description here; simple harmonic motion does not apply in this example.

    Tip Because frictionless surfaces do not exist in nature, it may be difficult for students to fully grasp this idea. Students should have experience measuring the force needed to move rigid objects across a variety of surfaces, and use graphical analysis to infer the effect of very low or no friction on forces and motion. These experiences can be enhanced by exposure to computer simulations of objects in motion that allow users to set coefficients of friction to a variety of values, including zero, and to quickly gather and analyze data. Students should also have opportunities to solve problems (conceptual and mathematical) that include frictionless surfaces.

3. **Correct Answer: D**

    Explanation: Choice (D) is the correct answer. The law of universal gravitation states that the gravitational force between two objects equals the product of their masses divided by the square of the distance separating them and then multiplied by a constant. The mathematical statement of the law of universal gravitation is

    $F = G\dfrac{m_1 m_2}{d^2}$, whereas F is the force of attraction between the objects, G is the gravitational constant, m_1 and m_2

    are the masses of the objects, and d is the distance between the objects. $G = 6.67 \times 10^{-11}$ Nm^2/kg^2. G is not to be confused with g, the acceleration due to gravity on Earth equal to 9.81 m/s^2. Choice (C) might be appealing, but it is incorrect; although the gravitational attraction between two objects results in action and reaction force pairs, the law of universal gravitation describes the relationship between the size of the force and mass and distance.

    Tip Because Earth dominates the gravitational field students experience in their everyday lives, it may be difficult for them to imagine that any object in the universe exerts a force on every other. Students may think that gravity does not exist beyond Earth's atmosphere due to descriptions of weightlessness in outer space that are prevalent in popular media. Students should have experience solving problems that require both conceptualization and calculation of the force of gravity between objects, including moons, planets and stars, as well as objects on Earth, such as two students in the classroom.

Physics

Questions 4–6 refer to the labeled arrows in the diagram below that shows two direct current electrical circuits.

At one point, the wires of the circuits are parallel. The wire of circuit X passes between the poles of a permanent magnet. Arrow *A* points up out of the plane of the paper. Arrow *E* follows a circle that comes out of the paper on the left side of the wire and goes back into the paper on the right side of the wire.

Two Direct Current Circuits
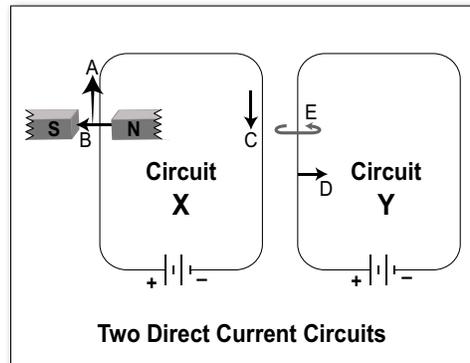
    A) Arrow *A* only

    B) Arrow *B* only

    C) Arrow *C* only

    D) Arrows *A* and *D*

    E) Arrows *B* and *E*

4. The arrow or arrows showing the direction of conventional current flow.

5. The arrow or arrows showing the direction of a magnetic field line.

6. The arrow or arrows showing the direction of a force vector.

Questions 7–8 refer to the following particles.

    A) Alpha

    B) Electron

    C) Neutron

    D) Photon

    E) Proton

7. Which particle would balance the equation for the nuclear reaction shown below if it was to replace the question mark? $^{238}_{92}U \rightarrow {}^{234}_{90}Th + \,?$

8. Which particle changes energy levels to create the absorption and emission spectra of atoms?

4.   Correct Answer: C

Explanation: Choice (C) is the correct answer. Conventional current flows from the positive terminal of the battery or power source to the negative terminal of the battery or power source. The other arrows show directions of force vectors and magnetic fields.

> **Tip**
>
> Students should have experience building circuits and measuring current. These experiences could be enhanced by computer simulations that model what is happening in the wires since this cannot be directly observed.

5.   Correct Answer: E

Explanation: Choice (E) is the correct answer. The magnetic field of a permanent magnet is directed from N to S (arrow *B*), and the right-hand rule shows the direction of magnetic field lines with respect to the direction of current flow (arrow *E*). The other arrows show force vectors and current direction.

> **Tip**
>
> Students should have experience building circuits and observing a relationship between current and magnetic fields. For example, a magnetic interaction can be demonstrated through the deflection of a compass under a current-carrying wire. In addition, students should be taught the convention for drawing magnetic field lines. Instruction can be supported using magnets and iron filings.

6.   Correct Answer: D

Explanation: Choice (D) is the correct answer. The right-hand rule for directions of current, magnetic field and force on a current-carrying wire indicates the force on the wire is up (arrow *A*), and parallel wires carrying currents in opposite directions repel each other (arrow *D*).

7.   Correct Answer: A

Explanation: Choice (A) is the correct answer. An alpha particle is a helium nucleus, which is written as $_2^4 \text{He}$. The superscript 4 balances the number of nucleons (i.e., the atomic mass) and the subscript 2 balances the number of protons (i.e., the atomic number).

> **Tip**
>
> Students may not know that an alpha particle is a helium nucleus with two protons and two neutrons. Additionally, students may not understand the symbolic representations of isotopes.

8.   Correct Answer: B

Explanation: Choice (B) is the correct answer. The absorption and emission spectra are generated by the energy emitted when electrons are transferred from lower to higher or from higher to lower energy levels.

> **Tip**
>
> Students may not be familiar with absorption or emission spectra. Students may have selected choice (D), Photon, because photons are emitted when electrons change energy levels.

Physics

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

9. Four identical objects are dropped or thrown from the top of a 10-meter high bridge at the same time. The objects are dropped or thrown as follows:

    I.   Object 1 is dropped straight down with an initial speed of 0 m/s.

    II.   Object 2 is thrown straight up with an initial speed of 5 m/s.

    III. Object 3 is thrown horizontally with an initial speed of 10 m/s.

    IV.   Object 4 is thrown horizontally with an initial speed of 20 m/s.

    Which objects will land in the water beneath the bridge at the same time? (Ignore the effect of air resistance.)

    A) I and II only

    B) II and III only

    C) III and IV only

    D) I, III and IV only

    E) I, II, III and IV

10. A helicopter rises at constant speed to an altitude of h in time t. If the helicopter has mass m and the magnitude of acceleration due to gravity is g, what is the power needed for the helicopter to rise?

    A) mgt

    B) mgh

    C) mgh/t

    D) mgt/h^2

    E) $\frac{1}{2}m(h/t)^2$

11. A player kicks a soccer ball from the ground with an initial velocity of 10 m/s. The ball leaves the ground at an angle of 23° above the horizontal field.

    Given that sin 23° = 0.4, cos 23° = 0.9, and g = 10 m/s², approximately how far away does the ball land? (Ignore the effect of air resistance.)

    A) 3.6 m

    B) 4.0 m

    C) 4.5 m

    D) 7.2 m

    E) 9.0 m
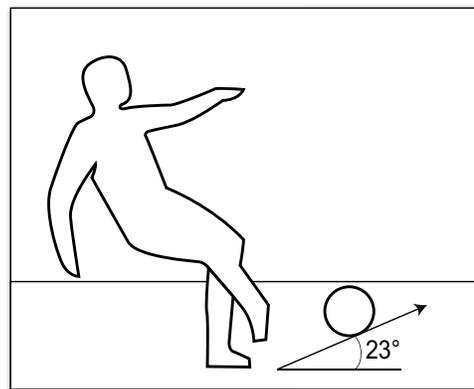
9.   Correct Answer: D

Explanation: Choice (D) is the correct answer. Object 2 will be delayed while it accelerates from an initial velocity of 5 m/s upward to a velocity of 0 m/s (at which point it will also have farther to fall). Only the downward force, the force of gravity, affects the downward acceleration for objects in free fall. Because objects 1, 3 and 4 have zero initial velocity in the vertical direction, they will land in the water beneath the bridge at the same time. Horizontal velocity is a separate vector from downward velocity. It does not increase "hang time" because the force of gravity downward is the same for all objects; all falling objects accelerate at the same rate. Therefore, objects 1, 3 and 4 will cover the distance to the water in the same amount of time.

Tip

In students' everyday experience, falling objects tend to either fall quickly or fall with significant air resistance. These experiences may lead students to neglect the acceleration of falling objects, perceiving their motion as both constant and largely dependent on an object's size and shape. Static images (such as stroboscopic photographs) and diagrams of falling objects can be useful for supporting explanations of their motion. However, students may not internalize these abstract representations. Videos of falling objects with and without horizontal velocity may be used as opportunities to observe objects in freefall. By manipulating these media with pause or slow playback, students can make more detailed measurements of motion without the abstraction of static images and diagrams.

10.   Correct Answer: C

Explanation: Choice (C) is the correct answer. Power is a measure of the rate at which work is done. The work done to raise the helicopter equals the change in energy of the helicopter. When increased to a height of h, the helicopter gains gravitational potential energy equal to mgh. The power needed for the helicopter to rise is then equal to the change in energy divided by the time. Mathematical expressions describing this problem are: $P = W/t = \Delta E/t = mgh/t$, where P is power, W is work, t is time, ΔE is change in energy, m is mass, g is acceleration due to gravity and h is height.

Tip

The terms power, energy and force are often used incorrectly and interchangeably in everyday speech. Students should understand that power is a rate, and that rates are discussed with respect to time; power is the rate at which work is done ($P=W/t$). Students should have opportunities to recognize commonalities among rates used in physics, such as velocity, acceleration, current and power. Students should also have opportunities to measure force, work, energy and power to understand how these terms are related and to understand their differences.

11.   Correct Answer: D

Explanation: Choice (D) is the correct answer. The vertical velocity vector equals $v_y = v_0 \sin 23° = 10 \times 0.40 = 4$ m/s, and the ball reaches its maximum height at time = (4 m/s)/(10 m/s²) = 0.4 seconds, so the ball travels for a total of 0.8 seconds. The horizontal velocity vector is $v_y = v_0 \cos 23° = 10 \times .9 = 9$ m/s. Therefore, the distance from where the ball was kicked to the point where the ball hits the ground is d = vxt = $9 \times 0.8 = 7.2$ m.

Tip

Students should have opportunities to solve two-dimensional projectile motion problems. They should learn how to determine the components of vectors in two dimensions, and that the acceleration in the vertical direction can be approximated as 10 m/s² downward and the velocity in the horizontal direction is constant. The vertical motion can be used to calculate the maximum height and "hang time," which is twice the time to reach maximum height, and the horizontal motion can be used to solve for the range.

Physics

12. During a long climb, a rock climber stops to rest and eat an orange. She accidentally drops the orange and it falls to the ground 180 meters below. Assuming negligible air resistance and using 10 m/s² for the acceleration due to gravity, how long does it take the orange to reach the ground?

    A) 3.0 s

    B) 4.2 s

    C) 6.0 s

    D) 18 s

    E) 36 s

13. A 100 N penguin is sliding down a 7° incline at constant velocity.

    What is the force of friction on the penguin? (sin 7° = 0.12)

    A) 0.0012 N

    B) 0.07 N

    C) 12 N

    D) 70 N

    E) 100 N
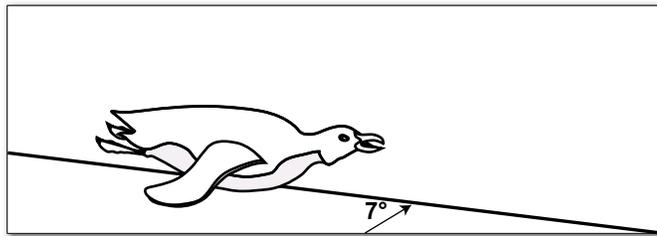
14. A 500 N skydiver jumps out of a stationary helicopter and accelerates until she reaches a constant velocity. One minute later, the skydiver opens a parachute and accelerates until she reaches a constant velocity again. If an upward force is positive, which two graphs together show the upward and downward forces on the skydiver over time?

    A) I and III

    B) I and IV

    C) II and III

    D) II and IV

    E) III and IV
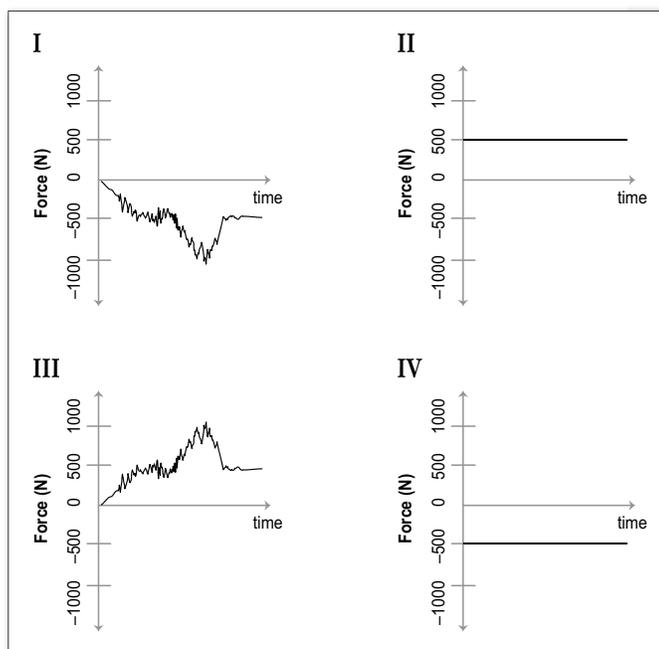
12. Correct Answer: C

Explanation: Choice (C) is the correct answer. The time it takes for the orange to reach the ground can be calculated using the kinematic equation relating displacement, acceleration, time and initial velocity. Because the orange was dropped, its initial velocity is equal to zero. The equation can be simplified and applied as shown:

$$d = (1/2)gt^2 \rightarrow t = (2\ d/g)^{1/2}$$

$$t = (2 \times 180\ \text{m}/(10\ \text{m/s}^2))^{1/2} = (36\ \text{s}^2)^{1/2} = 6.0\ \text{s}$$

Tip

Students should have experience in solving kinematics problems.

13. Correct Answer: C

Explanation: Choice (C) is the correct answer. The component of the penguin's weight parallel to the surface of the incline equals 100 sin 7° = 12 N. Because velocity is constant, the forces acting on the penguin are balanced. Therefore the force of friction pointing up the incline is equal to the 12 N force pointing down the incline.

Tip

Students should consider the forces acting on objects on inclines. For an object at rest, the force of friction balances the parallel component of the force due to gravity. Students should practice drawing force diagrams for objects on inclines and resolving vectors into components parallel and perpendicular to the incline.

14. Correct Answer: E

Explanation: Choice (E) is the correct answer. The graphs show unbalanced forces during acceleration and balanced forces when velocity is constant. The skydiver accelerates at first, when the upward force of air resistance is smaller than the downward force of gravity. The upward force increases until the forces are balanced and velocity becomes constant. When the parachute opens, the forces are unbalanced again because the upward force of air resistance becomes greater than the downward force of gravity. Then forces become balanced again when a new constant velocity is reached. Choice (A) is incorrect because it shows two forces that vary but are always balanced, which would indicate constant velocity. Choices (B) and (C) are incorrect because they show forces that cannot be balanced at any time; in choice (B) the forces are both negative, and in choice (C) the forces are both positive. Choice (D) is incorrect because it shows two forces that are both constant and always balanced, representing constant velocity the entire time.

Tip

Students should have opportunities to draw diagrams that show all of the forces acting on an object at rest, moving at a constant velocity and accelerating. Students should be asked to interpret these diagrams in terms of the effect of forces on the object's motion. Students should have opportunities to graph forces and motion over time, and use one type of graph to predict the shape of the other.

Physics

15. Three railway cars, each with a mass of 80,000 kg, are on the same track.
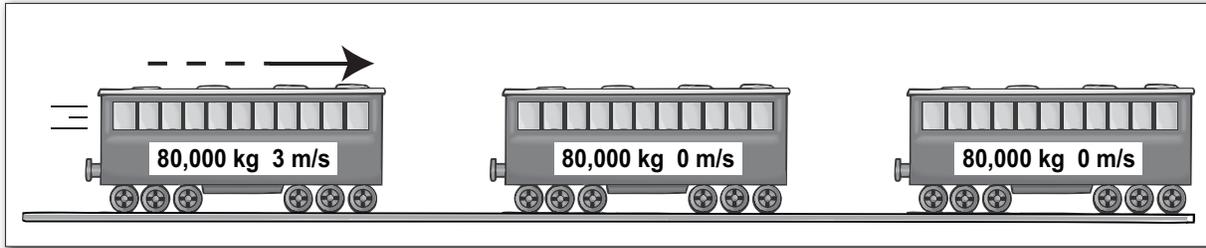
The car on the left is moving with a velocity of 3 m/s, and the other two cars are stationary. The moving car collides with the middle car. The two cars couple and continue to move together until they couple with the third car. If the direction of positive motion is to the right, what is the final velocity of the three coupled cars?

A) -3 m/s

B) -1 m/s

C) 1 m/s

D) 1.5 m/s

E) 3 m/s

16. An airbag reduces injury to a passenger during a car crash. This benefit is due primarily to which of the following?

A) The air bag reduces the force by reducing the passenger's change in velocity.

B) The air bag reduces the change in momentum by increasing the passenger's impulse.

C) The air bag reduces the impulse by reducing the change in the passenger's momentum.

D) The air bag reduces the force by increasing the time it takes the passenger to stop moving.

E) The air bag reduces the change in velocity by reducing the time it takes the passenger to stop moving.

17. A disk with a 0.20 meter diameter is spinning once per second. What is the centripetal acceleration of a point on the edge of this disk?

A) 0.04π m/s^2

B) 0.20π m/s^2

C) $0.16\pi^2$ m/s^2

D) $0.40\pi^2$ m/s^2

E) $0.80\pi^2$ m/s^2

15.   Correct Answer: C

Explanation: Choice (C) is the correct answer. It is correct because of conservation of momentum:

$m_1v_1 = m_2v_2$; $v_2 = 3$ m/s $(80{,}000\text{kg})/(160{,}000\text{kg}) = 1.5$ m/s. $m_2v_2 = m_3v_3$; $v_3 = 1.5$ m/s $(160{,}000\text{kg})/(240{,}000\text{kg}) = 1$ m/s

Because the cars couple, there is no recoil and all motion continues in the positive direction. The problem also could be solved with: $m_1v_1 = m_3v_3$.

Conceptually, if the mass triples, then the velocity will decrease by a factor of 3. Choice (A) is incorrect because only the mass of one car was used, and because the sign is wrong. Choice (B) is incorrect because the sign is wrong; there is no reversal of direction because there is no recoil. Choice (D) is incorrect because the mass of two, not three, cars was used. Choice (E) is incorrect because the mass of only one car was used.

16.   Correct Answer: D

Explanation: Choice (D) is the correct answer. Impulse equals force times the time over which it acts. Impulse also equals mass times change in velocity — that is, change in momentum: $F\Delta t = m\Delta v$

Velocity must go to zero, so Δv is constant. The mass (m) of the passenger is also constant. However, both the force (F) and the time it takes the passenger to stop moving (Δt) can change as long as the product ($F\Delta t$) is constant. Presumably, the air bag applies a force over a longer period of time than would the dashboard or windshield. The increase in contact time results in a decrease in force applied to the passenger. Choices (A) and (E) are incorrect because the change in velocity (Δv) is constant. Choices (B) and (C) are incorrect because impulse ($m\Delta v$) does not change, as both the change in velocity and mass are constant. Choices (A) and (E) are incorrect because the change in velocity (Δv) is constant.

Tip

Cars and other forms of transportation provide useful opportunities to demonstrate the relevance of Newton's first and second laws, as well as related concepts of momentum and impulse. Students should understand how Newton's first law applies to objects in a moving car. When the car comes to a sudden stop, the objects in the car will keep moving until acted upon by an outside force. For passengers safely restrained, this outside force is provided by a seat belt (and by an air bag, for passengers in the front seat). If no seat belt or air bag is used, the outside force will be provided by the next available surfaces, such as the dashboard and windshield. The relevance of Newton's second law, momentum and impulse can be demonstrated by discussing the relationships among time, acceleration and force in this context.

17.   Correct Answer: D

Explanation: Choice (D) is the correct answer. $a_c = 4\pi^2r/T^2$

The radius r is half the diameter, or 0.1 m, and the period T is 1.0 s. Then, $a_c = 4\pi^2(0.1)/(1.0)^2 = 0.40\pi^2\text{m/s}^2$.

Choice (A) is incorrect because it uses a different formula, $4\pi r^2$. This is the formula for the surface area of a sphere. Choice (B) uses the information to generate an answer with the correct units, but without applying the equation for centripetal acceleration (although it includes π). This answer also represents the velocity, $\pi D/T$, rather than the acceleration. Choice (C) is incorrect because it uses an incorrect formula, $4\pi D^2$. This is the formula for the surface area of a sphere, but with the diameter in place of the radius. Choice (E) is incorrect because it uses the diameter instead of the radius in the equation for acceleration.

Tip

Students should know that circular motion requires a change in velocity, which is acceleration. Though the speed may be constant, the direction of the velocity is changing. Students should have opportunities to calculate centripetal acceleration and recognize that the force needed for circular motion is a "center pointing" or "centripetal" force, not a "center fleeing" or "centrifugal" force. The latter is not actually a force; phenomena typically attributed to centrifugal forces should be explained using inertia.

Physics

18. A baseball player uses a ball at the end of a string to practice hitting. The string is attached to a fixed point overhead. Which of the following data alone would allow for the best estimate of the time, it takes for the ball to swing from its point of release to the player, assuming the player wants to hit the ball when it has zero speed?
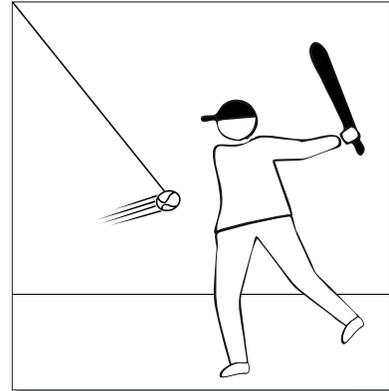
    A) The mass and weight of the ball

    B) The mass and acceleration due to gravity

    C) The vertical distance the ball drops and the weight of the ball

    D) The length of the string attached to the ball and the acceleration due to gravity

    E) The mass of the ball and the initial distance between the ball and the player

19. The diagram to the right shows a planet with a very eccentric orbit around a star. The plane of the planet's orbit is perpendicular to the line of sight between Earth and the star. The planet was observed seven times over several months. The planet was first observed at point T. It was observed again at point U, 50 days later. Which other two observations could be 50 days apart?
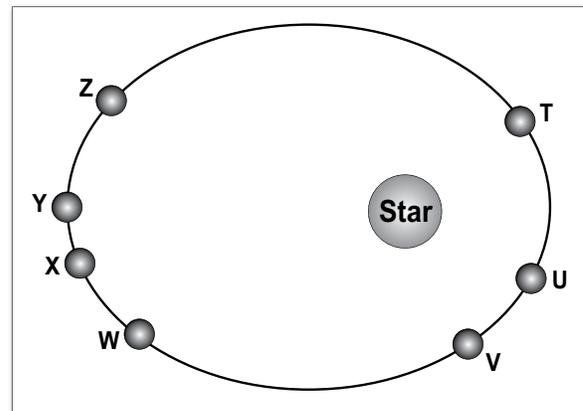
    A) V and W

    B) W and Y

    C) X and Y

    D) X and Z

    E) Y and Z

20. A 20-μF capacitor has a 30-V potential difference across it. What is the charge on the capacitor in coulombs?

    A) 6.7×10^{-7} C

    B) 6.0×10^{-4} C

    C) 1.5 C

    D) 6.0×10^{2} C

    E) 1.5×10^{6} C

18. **Correct Answer: D**
    Explanation: Choice (D) is the correct answer. Only the length of the pendulum determines the period, according to the equation $T = 2\pi(l/g)^{1/2}$, in which T is the period, l is the length of the string, and g is acceleration due to gravity. If the length were known, the equation would give the time needed for the ball to swing from its maximum height to the player and back again. Choice (A) is incorrect because the mass of a pendulum is not related to the period of the pendulum. Choices (B), (C) and (E) are incorrect because they all affect the speed of the ball but not the time of the swing.

19. **Correct Answer: C**
    Explanation: Choice (C) is the correct answer. Satellites travel fastest when they are closest to the body they orbit. In this case, the planet is traveling fastest between points T and U and slowest at point Y. The distance between X and Y is much shorter than the distance between T and U, so it could take the planet the same amount of time to travel between points T and U as between points X and Y. Further, Kepler's second law of planetary motion states that satellites sweep out equal areas in equal amounts of time. The area of the sector between T, U and the star seems about equal to the area between X, Y and the star. Therefore, it could take the same amount of time to travel from T to U as from X to Y. Choices (A) and (D) represent distances that are the same as or longer than the distance between points T and U. Because these points are all farther from the star, the time for the planet to travel between each pair would be longer than 50 days. Choices (B) and (E) would sweep out larger areas than T to U, even though they are the same or shorter in distance than T to U; therefore, the time for the planet to travel between each pair would be longer than 50 days.

Tip

In addition to solving quantitative problems, students should also have opportunities to solve qualitative problems using Kepler's laws. They should understand the relative strength of gravitational fields at different distances from objects and the effect this has on the speeds of satellites and planets. This phenomenon results in the remarkable relationship between time and the area swept out in orbit.

20. **Correct Answer: B**
    Explanation: Choice (B) is the correct answer.

$$C = q/\Delta V \text{ and } q = C\,\Delta V = (20 \times 10^{-6}\ \text{F}) \times (30\ \text{V}) = 6 \times 10^{-4}\ \text{C}$$

In this formula, C is capacitance, q is charge, and ΔV is the potential difference. Note that the unit C (not italicized) is coulomb. Choices (A) and (E) are incorrect because they use ratios of capacitance and potential difference rather than the product of these values. Choice (C) is incorrect for the same reason, and because the micro (μ) part of μF has been ignored. Choice (D) is incorrect because the micro (μ) part of μF has been ignored.

21. A 4.0-μF parallel-plate capacitor has an electrical potential difference of 5.0 V. Which of the following changes would most likely increase the potential difference to 10.0 V?

    A) Doubling the area of the capacitor plates

    B) Doubling the charge on each plate

    C) Decreasing the the distance between the plates by half

    D) Decreasing the charge on each plate by half

    E) Decreasing the time taken to charge the capacitor by half

22. A team of physics students is building a robot. They connect two motors to the parallel 6 volt circuit shown above. The arm motor uses 12 watts, and the wheel motor uses 18 watts. A student checks the current at three points in the circuit when both devices are in use. Which of the following lists these three points in order from lowest to highest current?
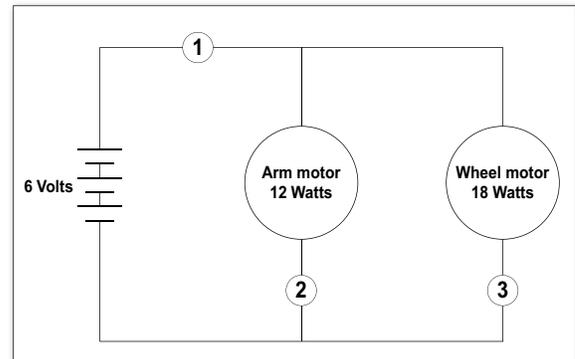
    A) 1, 2, 3

    B) 1, 3, 2

    C) 2, 1, 3

    D) 2, 3, 1

    E) 3, 2, 1

23. An incandescent light bulb uses the resistance of a tungsten filament to convert electrical energy into other forms of energy. If only about 10% of this energy is converted into visible light, how many kilojoules does a 100-watt light bulb give off in an hour in energy forms that we cannot see?

    A) 36 kJ

    B) 90 kJ

    C) 324 kJ

    D) 360 kJ

    E) 32,400 kJ

21.   Correct Answer: B

Explanation: Choice (B) is the correct answer. The parallel-plate capacitor is composed of two oppositely charged parallel plates. As the charge across the capacitor increases, the positive plate becomes more positively charged and the negative plate becomes more negatively charged. This results in a greater potential difference across the plates, since the positive plate will be at a higher potential and the negative plate will be at a lower potential. The relationship between capacitance, charge and potential difference is quantified in the formula $C = q/\Delta V$, where C is capacitance, q is charge, and V is potential difference. As shown below, increasing the potential difference from 5.0V to 10.0V is achieved through doubling the charge:

$$q_1 = C(\Delta V_1) = (4.0 \ \mu\text{F})(5.0 \ \text{V}) = 2.0 \times 10^{-5} \ \text{C}$$
$$q_2 = C(\Delta V_2) = (4.0 \ \mu\text{F})(10.0 \ \text{V}) = 4.0 \times 10^{-5} \ \text{C}$$

In the calculation above, note that the unit C (not italicized) is the coulomb. Choices (A) and (C) are incorrect because these changes would require an entirely different capacitor and because larger capacitor plates or a shorter distance between them with an equal amount of charge would have a smaller potential difference. Choice (D) is incorrect because it would also result in a decrease rather than an increase in the potential difference. Choice (E) is incorrect because it would not affect the resulting potential difference.

Tip

In addition to quantitative problem solving, students should have opportunities to demonstrate conceptual understanding of phenomena, including capacitance, how the design of a capacitor affects capacitance and methods of charging.

22.   Correct Answer: D

Explanation: Choice (D) is the correct answer. Current is equal to power divided by voltage, and in a parallel circuit, the current is equal to the sum of the currents in each branch. Therefore, the current is highest at point 1, and the current is greater at point 3 than at point 2. Choices (A), (B) and (C) are incorrect because the current in the circuit cannot be smaller than the current in any branch. Choice (E) is incorrect because it is the result of using an inverse, rather than a direct, relationship between current and power.

Tip

In addition to being able to solve quantitative problems, students should have a conceptual understanding of electrical circuit interactions. Students should understand that current and power are both rates; current is the rate that electricity flows through a circuit, and power is the rate that energy is used by a device. Students should know that devices that need more power would increase the current in a circuit. Students should also understand the difference between series and parallel circuits, and recognize that homes are wired in parallel. Students should know that for parallel circuits, as more devices are in use, the current in the circuit increases.

23.   Correct Answer: C

Explanation: Choice (C) is the correct answer. Power is the rate of energy use, so energy is then the product of power and time: E = (100 W)(3600 s) = 360,000 J = 360 kJ.

Because only 10% of this energy is converted to visible light, the remaining 90%, or 324 kJ, is converted to other forms of energy. Choice (A) is incorrect because 36 kJ is 10% of the energy that is visible light. Choice (B) is incorrect because it ignores the conversions of units from hours to seconds and joules to kilojoules. Choice (D) is incorrect because 360 kJ is 100% of the energy used. Choice (E) is incorrect because it uses the efficiency without converting from joules to kilojoules.

Tip

Students should understand that energy conversions typically include energy loss. This loss is often in the form of heat, and efficiency determines the fraction of useful energy that remains. Students should have opportunities to apply these concepts to real-world problems such as the efficiency of various types of light bulbs.

Physics

24. **A beam of electrons passes through a magnetic field between two magnets resting on the table, as shown below.**

Beam of Electrons
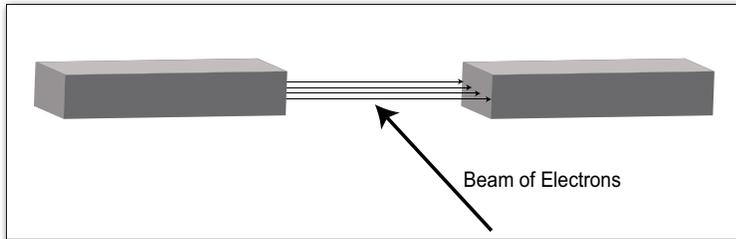
How will the magnetic field affect the electron beam?

A) The beam will rotate around the two magnets.

B) The beam will bend up away from the table.

C) The beam will bend down into the table.

D) The beam will be attracted to the north pole of a magnet.

E) The beam will be attracted to the south pole of a magnet.

25. **A fire truck is moving left with its siren on. A car is moving right, approaching the truck. A man is standing on the sidewalk to the left of the car, and a woman is standing on the sidewalk to the right of the truck. The truck driver, the car driver, the man and the woman all hear the siren as having a different pitch. Which of the following lists the people in order by the pitch they hear, from lowest pitch to highest pitch?**

A) Truck driver, woman, man, car driver

B) Woman, truck driver, man, car driver

C) Car driver, truck driver, man, woman

D) Car driver, man, truck driver, woman

E) Man, woman, car driver, truck driver
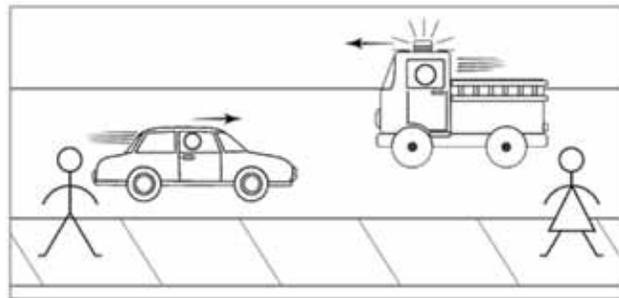
24. **Correct Answer: B**
Explanation: Choice (B) is the correct answer. The direction of electron flow is opposite the direction of conventional current. Either a right-hand rule can be applied with the thumb pointing opposite the direction of the beam of electrons or a left-hand rule can be applied with the thumb pointing in the direction of the beam of electrons. In either application, the fingers point in the direction of the magnetic field and the palm faces the direction of the force on the beam. Choice (A) is an incorrect application of a right-hand rule for magnetic fields. Choice (C) is incorrect because it reverses the direction of the applied force. Choices (D) and (E) are incorrect because they confound attraction between electrical charges with magnetic poles.

25. **Correct Answer: B**
Explanation: Choice (B) is correct because, when the distance between the source and observer is decreasing, the wavelength is foreshortened and the observed frequency (pitch) increases. The greater the relative speed, the more the wavelength is foreshortened and the higher the frequency (pitch). The distance between the woman and the source of the sound is increasing because the truck is moving away (the observed frequency decreases). The truck driver's relative speed to the sound is zero. The man's relative speed to the sound is equal to the speed of the truck. The car driver's speed relative to the sound is greatest because it is the sum of his speed plus that of the truck.

26. The diagram to the right shows a beam of light passing through a piece of glass in water. The dashed lines are perpendicular to the surfaces of the glass. Which of the following describes the changes in the speed and frequency of the light as it passes through the glass?

Water

Glass

Water
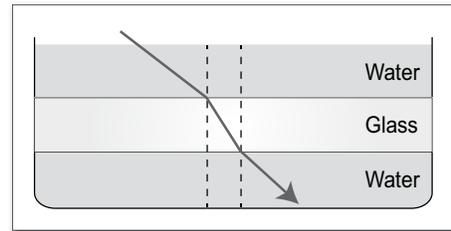
A) Both the frequency and speed of the light increase in the glass.

B) Both the frequency and speed of the light decrease in the glass.

C) The frequency increases but the speed of the light decreases in the glass.

D) The frequency decreases but the speed of the light stays constant in the glass.

E) The frequency stays constant but the speed of the light decreases in the glass.

27. The diagram to the right shows how a concave mirror creates a real image of an object. The object is 20 cm from the mirror and the image appears at a distance of 5 cm from the mirror. What is the focal length of the mirror?
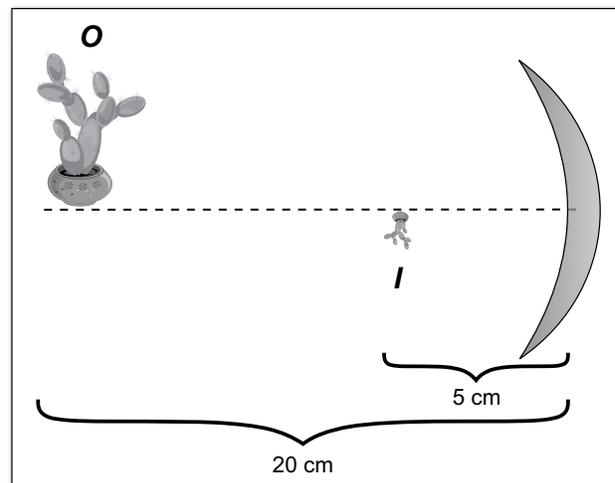
A) 2.5 cm

B) 4 cm

C) 25 cm

D) 20 cm

E) 40 cm

O

I

5 cm

20 cm

28. The image to the right shows a two-slit diffraction pattern produced by monochromatic light with bands 2.0 cm apart. Which of the following changes would increase the distance between the bands?
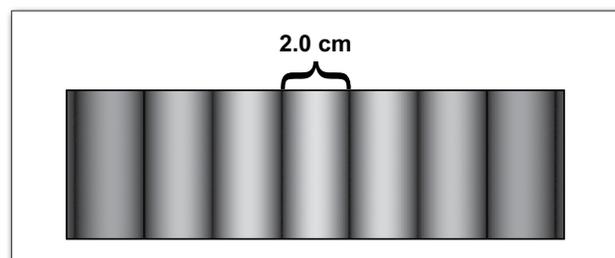
A) Moving the slits closer together

B) Making the light source brighter

C) Moving the slits closer to the screen

D) Increasing the frequency of the light

E) Shortening the wavelength of the light

2.0 cm

26.   **Correct Answer: E**

Explanation: Choice (E) is the correct answer. According to Snell's law, $\sin\Theta_1/\sin\Theta_2 = v_1/v_2$, where Θ_1 and Θ_2 are the angles to the normal of the beam and v_1 and v_2 are velocities of mediums 1 and 2. For a beam of light incident on a surface, if the angle in the new medium is smaller, then the speed must have decreased. The frequency of light does not change in transparent media. Choices (A), (B), (C) and (D) are all incorrect because they state that the frequency of the light changes.

Tip

Students should understand the relationship between waves and media, including the effects of media on speed and wavelength. Students should know that frequency remains constant. For light, the color represents the frequency. Because light does not change color when it moves through transparent media such as glass, the frequency does not change. Students should understand that the separation of frequencies by glass prisms does not change the frequencies of the spectrum.

27.   **Correct Answer: B**

Explanation: Choice (B) is the correct answer. $f = d_i d_o/(d_o + d_i) = (5 \times 20)/(5 + 20) = 4$ cm, where f is the focal length, d_o is the distance of the object from the mirror, and d_i is the distance of the image from the mirror. Choices (A) and (C) could be the inverted formula with a misplaced decimal. Choice (C) is also the sum of the object and image distances. Choice (D) is the object distance. Choice (E) is 10 times the focal length.

28.   **Correct Answer: A**

Explanation: Choice (A) is the correct answer. $\lambda = xd/L$, where λ is wavelength, x is the distance between bands, d is the distance between slits, and L is the distance to the screen. Moving the slits closer together will spread the diffraction pattern. Assuming the wavelength and distance L are constant, x will increase as the value of d in the formula decreases.

Tip

Students should have opportunities to observe wave behavior with various arrangements of sources, barriers and slits to understand how interference patterns are generated.

Physics

29. The table to the right lists several properties of water. Which of the following processes requires the most energy input?

Property	Value
Specific Heat	1.0 cal/g•°C
Latent Heat of Fusion	80 cal/g
Latent Heat of Vaporization	540 cal/g

   A) Melting 100 g of ice at 0°C

   B) Freezing 100 g of water at 0°C

   C) Boiling 100 g of water at 100°C

   D) Condensing 100 g of steam at 100°C

   E) Heating 100 g of water from 0°C to 100°C

30. Ethanol melts at 156 K and has a latent heat of fusion of 25 cal/g. It requires 3,080 cal to raise 100 g of solid ethanol at 156 K to liquid ethanol at 166 K. What is the specific heat of ethanol?

   A) 0.58 cal/g·K

   B) 1.7 cal/g·K

   C) 2.5 cal/g·K

   D) 3.1 cal/g·K

   E) 5.8 cal/g·K

31. The schematic to the right shows how energy is transferred in a refrigeration system. Which statement explains why work is an input into this system?
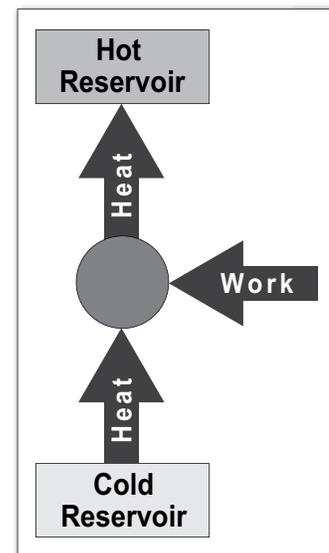
   A) Work is needed to move thermal energy against a temperature gradient.

   B) Work is needed to reduce the amount of thermal energy lost during transfer.

   C) Work uses energy from the cold reservoir to reduce the temperature of the system.

   D) Work adds energy to the cold reservoir to increase the heat flow to the hot reservoir.

   E) Work adds heat to the system, causing the temperature of both reservoirs to increase.

29. Correct Answer: C

Explanation: Choice (C) is the correct answer. The process of boiling 100 g of water at 100°C requires (540 cal/g) × 100 g = 54,000 calories of energy input. Choices (A) and (E) require less energy input. Melting 100 g of ice at 0°C requires (80 cal/g) × 100 g = 8,000 calories, and heating 100 g of water from 0°C to 100°C requires (1 cal/g·°C) × 100 g × 100°C = 10,000 calories. Choices (B) and (D) are incorrect because, rather than requiring an energy input, these processes result in an output of energy.

Tip

In addition to solving quantitative problems with specific and latent heats, students should have opportunities to demonstrate understanding of heat transfer in different processes. They should be able to determine which processes absorb or release heat.

30. Correct Answer: A

Explanation: Choice (A) is the correct answer. Total heat = heat to melt ethanol + heat to raise temperature. Then 3080 cal = $k_f \cdot m + c \cdot m \cdot \Delta T$ = 25 × 100 + c × 100 × 10, where k_f is the heat of fusion, c is the specific heat, m is mass, and ΔT is the change in temperature in kelvins. c = (3080 – 2500)/(10 × 100) = 0.58 cal/g·K. Choice (B) is the result of inverting the fraction. Choice (C) is 2500/(10 × 100). Choice (D) is 3080/(10 × 100). Choice (E) is the result of ignoring the rise in temperature.

31. Correct Answer: A

Explanation: Choice (A) is the correct answer. The heat pump works on the system by removing thermal energy from the cold reservoir (the inside of the refrigerator) and transferring it into the space outside the refrigerator (the hot reservoir). Choice (B) is incorrect because it incorrectly relates work and efficiency. Choice (C) is incorrect because the cold reservoir is not the source of energy for work. Choice (D) is incorrect because energy is not added to the cold reservoir. Choice (E) is incorrect because the temperature of the cold reservoir does not increase.

32. The principle of complementarity states that phenomena can have properties that are contradictory. These contradictory properties can be observed separately, but not simultaneously. Which of the following pairs of phenomena are examples of complementarity?

    A) Mass and weight

    B) Heat and temperature

    C) Light waves and particles

    D) Magnetic and electric fields

    E) Frequency and intensity of sound

33. If m_p = the mass of a proton, m_n = the mass of a neutron, m_{He} = the mass of a helium nucleus, and c = the speed of light, the expression for the energy released during the formation of a helium nucleus is:

    A) $E = \left[\left(2m_p + 2m_n \right) - m_{He} \right] c^2$

    B) $E = \left(2m_p + 2m_n \right) c^2$

    C) $E = m_{He} c^2$

    D) $E = \left[\left(2m_p + 2m_n \right) - m_{He} \right] c$

    E) $E = \left[m_{He} - \left(2m_p + 2m_n \right) \right] c^2$

34. The diagram to the right shows two forces acting on an object with magnitudes X and Y. The forces are perpendicular to each other. What is the magnitude of the net force acting on the object?

    A) X – Y

    B) X + Y

    C) $\sqrt{X\text{-}Y}$

    D) $\sqrt{X^2\text{-}Y^2}$

    E) $\sqrt{X^2+Y^2}$
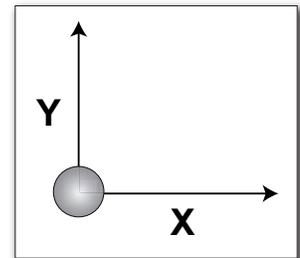
35. In the field of chaos theory, which of the following would be classified as chaotic?

    A) Cloud formation

    B) Digits of the number pi

    C) The mechanism of a clock

    D) The electromagnetic spectrum

    E) Atomic masses of chemical elements

32. **Correct Answer: C**
Explanation: Choice (C) is the correct answer. Light has both the properties of waves (i.e., electromagnetic waves) and particles. For example, light demonstrates wave-like behavior as observed through the interference patterns formed in Young's double-slit experiment. However, light also exhibits particle-like behavior, which can be demonstrated by the photoelectric effect. These contradictory properties of light support the wave-particle duality of light. Light can exhibit wave and particle properties, but not at the same time. The other answer choices include pairs that are observed without the need to propose contradictory properties.

Tip

Students should know that complementarity is the principle proposed by Niels Bohr to deal with the wave-particle duality that arose from Einstein's explanation of the photoelectric effect. Students should also know that this wave-particle duality can be applied to other particles. For example, the wave behavior of electrons can explain the quantized energy levels in atoms.

33. **Correct Answer: A**
Explanation: Choice (A) is the correct answer. The binding energy is the energy equivalent of the mass difference between the nucleons and the nucleus. This mass is converted to energy when the nucleus is formed. Choices (B) and (C) are the energy equivalents of the nucleons and nucleus, respectively. Choice (D) neglects to square c. Choice (E) is the negative of the correct answer.

34. **Correct Answer: E**
Explanation: Choice (E) is the correct answer. The resultant force, R, is the hypotenuse of the right triangle with X as the adjacent side and Y as the opposite side. The magnitude of the net force can be found using the Pythagorean theorem, $R^2 = X^2 + Y^2$, where R, X and Y are the magnitudes of vectors R, X and Y. Choices (A) and (B) could be solutions to vector addition in one dimension. Choices (C) and (D) misinterpret the Pythagorean theorem.

35. **Correct Answer: A**
Explanation: Choice (A) is the correct answer. Chaos theory applies to nondeterministic systems in which slight variations in initial conditions can result in very different and unpredictable outcomes. The other choices are very predictable or are not systems that are changing.
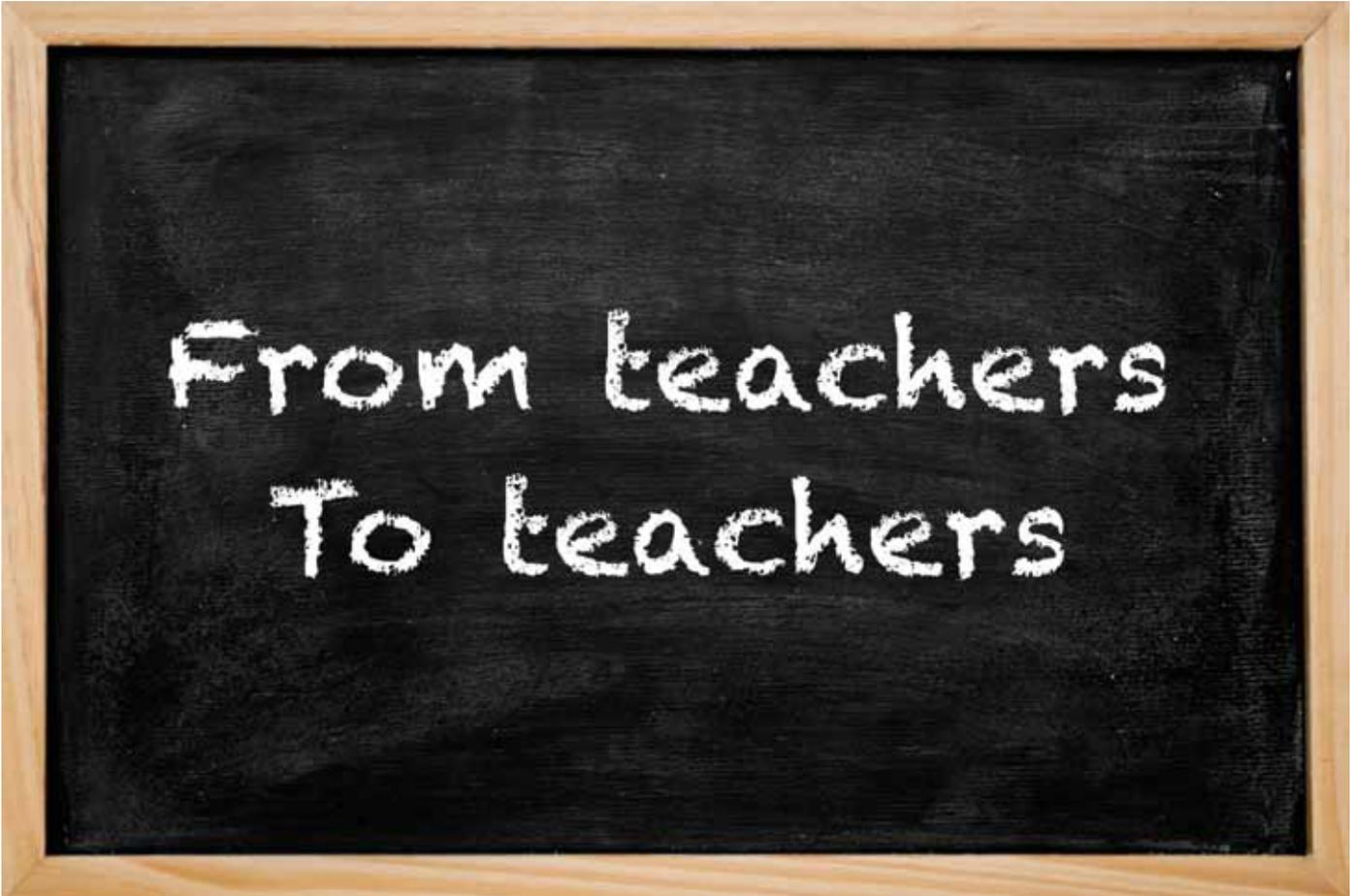
From teachers
To teachers

Best Practices

Student Benefits

David Knuffke, *Deer Park High School, Deer Park, NY*

"My students benefit from taking the SAT Subject Tests both for their college applications, and also as a preparation for the New York State Chemistry Regents Exam. The SAT Subject Test is more specific and more extensive than the NYS Chemistry Regents, so students who prepare for the SAT will also be preparing for the Regents Exam."

William G. Cumming, *Gilmour Academy, Gates Mills, OH*

"SAT Subject Tests are a valuable, external validation of students' work; the score and the experience are valuable. Another benefit I see is practice with such assessments."

Jesus E. Hernandez, *Queens Metropolitan High School, Forest Hills, NY*

"I recommend Subject Tests to my STEM major-oriented students and students applying to engineering/science colleges."

Dr. Bill Smith, *Bristol High School, Bristol, PA*

"I recommend that all students consider taking the SAT Subject Tests in their strongest subject(s). I inform them that I earned two full tuition scholarships when I graduated high school and both universities cited my SAT Subject Tests performance in chemistry on my acceptance and scholarship letters."

Carrie Jacobus, *River Dell High School, Oradell, NJ*

"SAT Subject Tests provide my students with validation of how well they know the material — it's a corroboration that they are on the right path. The tests can also enhance their college applications and help them with college admissions."

Briant McKellips, *D'Evelyn Jr./Sr. High School, Denver, CO*

"I personally recommend that the students take SAT Subject Tests in multiple areas if possible. For example, I recommend that, even for my physics students who are not interested in pursuing science as a major, they should take the Physics Subject Test to show colleges that even our "regular" physics course is rigorously college prep and that they are college ready."

Advising Students

Julianne M. Zedalis, *The Bishop's School, La Jolla, CA*

"After taking AP Biology (or biology) at Bishop's, students are very prepared to tackle the SAT Subject Test in Biology with minimum additional preparation; we spend considerable time preparing and reviewing for the AP Exam. I strongly suggest that students take the SAT Subject Test in Biology in either May (before the AP Exam in Biology) or in June (after the AP Exam in Biology). When registering, students are often confused about the "E/M" designation; since my AP Biology course is molecular-based (micro to macro), I strongly suggest that they take the "M" version."

Angela Benjamin, *Woodrow Wilson Senior High School, Washington, DC*

"I encourage students — especially those taking AP Physics B — to take the Subject Tests in the spring, right after they have completed the course."

Connie Wells, *Pembroke Hill School, Kansas City, MO*

"In math and English, little extra study time is necessary, as students at my school take these courses every year. In a subject such as physics, however, students usually take the Subject Test after their junior year (and after first-year physics). To take the Physics Subject Test, our students need to study units in optics, electrical circuits, and modern physics, since these topics are not covered extensively in our first-year course but are covered in the senior courses in AP Physics."

Jesus E. Hernandez, *Queens Metropolitan High School, Forest Hills, NY*

"I recommend taking the test in June (juniors) because information is fresh or beginning of senior year if they practice during the summer. Students should also practice in the same conditions they will encounter during the test."

Leslie Haines, *Walter Williams High School, Burlington, NC*

"I recommend that my students go ahead and take the Biology Subject Test right after AP Biology; they may find out later that their college of choice requires it."

Helping Students Prepare

David Knuffke, *Deer Park High School, Deer Park, NY*

"My advice is to begin the process of studying for the exam early and earnestly. There is quite a bit of scope of knowledge assessed on the Chemistry Subject Test, so students need to begin the review process earlier than they might think. Similarly, if students want to do well on the exam, they will need to work hard to make sure they can navigate the particulars of the exam in the time that they have available to them on exam day. I also encourage my students to ask me if they have any questions, and to make it a point to attend our review sessions as much as they can."

Deborah (Debbie) Sayers, *Hardin Valley Academy, Knoxville, TN*

"Exposure and encouragement have the greatest impact. Sometimes students are unaware of what is available to them. They don't consider the SAT Subject Tests because they don't know they exist. Or they think hours and hours of special preparation is required beyond the AP Chemistry course. In addition, many lack confidence that they will score well. Teachers can have great impact on students by simply convincing them that this is an endeavor worth their time and effort."

Peggy Bertrand, *Oak Ridge High School, Oak Ridge, TN*

"I use a clicker system in my class to test conceptual physics understanding. It gives the kids a lot of low-level practice in multiple-choice exam strategies along with helping them learn, or relearn, content. I know this helps them handle multiple-choice tests in general. Get a clicker system, or use an alternative strategy."

David Knuffke, *Deer Park High School, Deer Park, NY*

"I provide students with a study schedule. I hold sequential review sessions on topics of the course in the month prior to the exam. I provide students with practice exams and a variety of review structures to help students assimilate the content that they will need. Finally, I have found there is a lot of value in encouraging students to engage in the following techniques:

1. Analogies: Construct analogies and metaphors to relate concepts of the course. This works best when students create their own analogies.

2. The 12-year-old test: I always tell students that if they can't explain a concept to an imaginary, intelligent 12-year-old (or at least their parents), then they probably don't understand the concept well enough to be comfortable encountering it on the SAT Subject Tests."

Deborah (Debbie) Sayers, *Hardin Valley Academy, Knoxville, TN*

"The three most important things I suggest to students preparing for SAT Subject Tests are:

1. Review AP Chemistry notes and content because this will cover SAT Chemistry content as well.

2. Take several practice SAT Subject Tests.

3. Spend practice time on the multiple-choice questions where the answer to the first question determines the direction and content of subsequent questions (the relationship analysis questions)."

Angela Benjamin, *Woodrow Wilson Senior High School, Washington, DC*

"1. Take the course

2. Invest in a practice book

3. Apply the time"

Dr. Bill Smith, *Bristol High School, Bristol, PA*

"Practice, practice, practice. I'm not being humorous here. There may be other important things, but practicing problem-solving and answering essay-type explanations for the big ideas of chemistry has worked for my students so far."

William G. Cumming, *Gilmour Academy, Gates Mills, OH*

"First and foremost — pay attention in class and do your work! Second — study the chemistry-specific questioning styles (relationship analysis questions). Finally — get a test-prep book to further familiarize yourself with the test."

CollegeBoard

SAT Subject Tests™

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○ Chemistry
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○ U.S. History
○ World History
○ French

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○ Modern Hebrew
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○ Chinese Listening
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● Quality Assurance Mark

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○ U.S. History
○ World History
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COMPLETE MARK ● EXAMPLES OF INCOMPLETE MARKS Ⓐ ⊗ ⊖ Ⓘ ⊙ ✏ 🖊 Ⓜ

You must use a No. 2 pencil and marks must be complete. Do not use a mechanical pencil. *It is very important that you fill in the entire circle darkly and completely. If you change your response, erase as completely as possible. Incomplete marks or erasures may affect your score.*

○ Literature   ○ Mathematics Level 1   ○ German
○ Biology E   ○ Mathematics Level 2   ○ Italian
○ Biology M   ○ U.S. History   ○ Latin
○ Chemistry   ○ World History   ○ Modern Hebrew
○ Physics   ○ French   ○ Spanish

Background Questions: ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨

1 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   26 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   51 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   76 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
2 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   27 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   52 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   77 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
3 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   28 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   53 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   78 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
4 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   29 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   54 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   79 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
5 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   30 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   55 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   80 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
6 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   31 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   56 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   81 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
7 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   32 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   57 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   82 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
8 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   33 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   58 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   83 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
9 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   34 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   59 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   84 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
10 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   35 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   60 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   85 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
11 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   36 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   61 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   86 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
12 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   37 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   62 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   87 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
13 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   38 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   63 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   88 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
14 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   39 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   64 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   89 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
15 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   40 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   65 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   90 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
16 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   41 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   66 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   91 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
17 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   42 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   67 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   92 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
18 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   43 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   68 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   93 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
19 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   44 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   69 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   94 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
20 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   45 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   70 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   95 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
21 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   46 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   71 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   96 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
22 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   47 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   72 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   97 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
23 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   48 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   73 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   98 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
24 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   49 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   74 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   99 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
25 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   50 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   75 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   100 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ

Important: Fill in items 8 and 9 exactly as shown on the back of test book.

8 BOOK CODE (Copy and grid as on back of test book.)

9 BOOK ID (Copy from back of test book.)

10 TEST BOOK SERIAL NUMBER (Copy from front of test book.)

Book code column: 0 1 2 3 4 5 6 7 8 9 / A B C D E F G H I J K L M N O P Q R S T U V W X Y Z / 0 1 2 3 4 5 6 7 8 9

Serial number columns: 0 1 2 3 4 5 6 7 8 9 (×6)

Quality Assurance Mark ●

Chemistry *Fill in circle CE only if II is correct explanation of I.

	I	II	CE*		I	II	CE*
101	Ⓣ Ⓕ	Ⓣ Ⓕ	○	109	Ⓣ Ⓕ	Ⓣ Ⓕ	○
102	Ⓣ Ⓕ	Ⓣ Ⓕ	○	110	Ⓣ Ⓕ	Ⓣ Ⓕ	○
103	Ⓣ Ⓕ	Ⓣ Ⓕ	○	111	Ⓣ Ⓕ	Ⓣ Ⓕ	○
104	Ⓣ Ⓕ	Ⓣ Ⓕ	○	112	Ⓣ Ⓕ	Ⓣ Ⓕ	○
105	Ⓣ Ⓕ	Ⓣ Ⓕ	○	113	Ⓣ Ⓕ	Ⓣ Ⓕ	○
106	Ⓣ Ⓕ	Ⓣ Ⓕ	○	114	Ⓣ Ⓕ	Ⓣ Ⓕ	○
107	Ⓣ Ⓕ	Ⓣ Ⓕ	○	115	Ⓣ Ⓕ	Ⓣ Ⓕ	○
108	Ⓣ Ⓕ	Ⓣ Ⓕ	○				

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R/C	W/S1	FS/S2	CS/S3	WS

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Notes

Best Practices

Notes

About the SAT Subject Tests

For more than 75 years, SAT Subject Tests have played an integral role in providing institutions with insights into a student's achievement and readiness for college-level study in specific subject areas. The hour-long exams are offered in five major subject areas: Mathematics, History, Science, Literature and Languages.

SAT Subject Tests are offered six times a year in nearly 7,000 test centers in more than 170 countries. Fee waivers are available for students to take up to six SAT Subject Tests, increasing access for all students.

SAT Subject Tests continue to evolve, maintaining their vital role in the college-going process with new research studies, test and student experience enhancements and updates of student practice tools.

SAT Subject Tests Offered

SAT Subject Tests in nonlanguage subjects assess a student's comprehension of fundamental concepts, their content knowledge and their ability to apply that knowledge to solve routine and nonroutine problems.

SAT Subject Tests in languages assess a student's understanding of the language and ability to communicate in that language in a variety of cultural contexts. When there is a listening component on the test, the skills include reading comprehension, language usage and listening comprehension.

Math Level 1 Math Level 2	U.S. History World History	Biology E/M Chemistry Physics	Literature
Spanish French German	Modern Hebrew Latin Italian	Chinese with Listening Japanese with Listening Korean with Listening	Spanish with Listening French with Listening German with Listening

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