ETS®

GRE®

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Physics Test Practice Book

This practice book contains

- one actual full-length GRE Physics Test
- test-taking strategies

Become familiar with

- test structure and content
- test instructions and answering procedures

Compare your practice test results with the performance of those who took the test at a GRE administration.

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Learning.
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This book is provided **FREE** with test registration by the Graduate Record Examinations Board.

Note to Test Takers: Keep this practice book until you receive your score report.
The book contains important information about content specifications and scoring.

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Table of Contents

Purpose of the GRE Subject Tests

The GRE Subject Tests are designed to help graduate school admission committees and fellowship sponsors assess the qualifications of applicants in specific fields of study. The tests also provide you with an assessment of your own qualifications.

Scores on the tests are intended to indicate knowledge of the subject matter emphasized in many undergraduate programs as preparation for graduate study. Because past achievement is usually a good indicator of future performance, the scores are helpful in predicting success in graduate study. Because the tests are standardized, the test scores permit comparison of students from different institutions with different undergraduate programs. For some Subject Tests, subscores are provided in addition to the total score; these subscores indicate the strengths and weaknesses of your preparation, and they may help you plan future studies.

The GRE Board recommends that scores on the Subject Tests be considered in conjunction with other relevant information about applicants. Because numerous factors influence success in graduate school, reliance on a single measure to predict success is not advisable. Other indicators of competence typically include undergraduate transcripts showing courses taken and grades earned, letters of recommendation, the GRE Writing Assessment score, and GRE General Test scores. For information about the appropriate use of GRE scores, write to GRE Program, Educational Testing Service, Mail Stop 57-L, Princeton, NJ 08541, or visit our Web site at www.gre.org/codelst.html.

Development of the Subject Tests

Each new edition of a Subject Test is developed by a committee of examiners composed of professors in the subject who are on undergraduate and graduate faculties in different types of institutions and in different regions of the United States and Canada. In selecting members for each committee, the GRE Program seeks the advice of the appropriate professional associations in the subject.

The content and scope of each test are specified and reviewed periodically by the committee of examiners. Test questions are written by the committee and by other faculty who are also subject-matter specialists and by subject-matter specialists at ETS. All questions proposed for the test are reviewed by the committee and revised as necessary. The accepted questions are assembled into a test in accordance with the content specifications developed by the committee to ensure adequate coverage of the various aspects of the field and, at the same time, to prevent overemphasis on any single topic. The entire test is then reviewed and approved by the committee.

Subject-matter and measurement specialists on the ETS staff assist the committee, providing information and advice about methods of test construction and helping to prepare the questions and assemble the test. In addition, each test question is reviewed to eliminate language, symbols, or content considered potentially offensive, inappropriate for major subgroups of the test-taking population, or likely to perpetuate any negative attitude that may be conveyed to these subgroups. The test as a whole is also reviewed to ensure that the test questions, where applicable, include an appropriate balance of people in different groups and different roles.

Because of the diversity of undergraduate curricula, it is not possible for a single test to cover all the material you may have studied. The examiners, therefore, select questions that test the basic knowledge and skills most important for successful graduate study in the particular field. The committee keeps the test up-to-date by regularly developing new editions and revising existing editions. In this way, the test content changes steadily but gradually, much like most curricula. In addition, curriculum surveys are conducted periodically to ensure that the content of a test reflects what is currently being taught in the undergraduate curriculum.

After a new edition of a Subject Test is first administered, examinees' responses to each test question are analyzed in a variety of ways to determine whether each question functioned as expected. These analyses may reveal that a question is ambiguous, requires knowledge beyond the scope of the test, or is inappropriate for the total group or a particular subgroup of examinees taking the test. Answers to such questions are not used in computing scores.

Following this analysis, the new test edition is equated to an existing test edition. In the equating process, statistical methods are used to assess the difficulty of the new test. Then scores are adjusted so that examinees who took a difficult edition of the test are not penalized, and examinees who took an easier edition of the test do not have an advantage. Variations in the number of questions in the different editions of the test are also taken into account in this process.

Scores on the Subject Tests are reported as three digit scaled scores with the third digit always zero. The maximum possible range for all Subject Test total scores is from 200 to 990. The actual range of scores for a particular Subject Test, however, may be smaller. The maximum possible range of Subject Test subscores is 20 to 99; however, the actual range of subscores for any test or test edition may be smaller. Subject Test score interpretive information is provided in Interpreting Your GRE Scores, which you will receive with your GRE score report, and on the GRE Web site at www.gre.org/codelst.html.

Content of the Physics Test

The test consists of about 100 five-choice questions, some of which may be grouped in sets and based on such materials as diagrams, graphs, experimental data, and descriptions of physical situations.

The aim of the test is to determine the extent of the examinees' grasp of fundamental principles and their ability to apply these principles in the solution of problems. Most test questions can be answered on the basis of a mastery of the first three years of undergraduate physics. The test questions are constructed to simplify mathematical manipulations. As a result, neither calculators nor tables of logarithms are needed. If the solution to a problem requires the use of logarithms, the necessary values are included with the question.

The International System (SI) of units is used predominantly in the test. A table of information (see page 10) representing various physical constants and a few conversion factors among SI units is presented in the test book. Whenever necessary, additional values of physical constants are printed with the text of the question.

The approximate percentages of the test on the major content topics have been set by the committee of examiners, with input from a nationwide survey of undergraduate physics curricula. The percentages reflect the committee's determination of the relative emphasis placed on each topic in a typical undergraduate program. These percentages are given below along with the major subtopics included in each content category. Nearly all the questions in the test will relate to material in this listing; however, there may be occasional questions on other topics not explicitly listed here

1. CLASSICAL MECHANICS (such as kinematics, Newton's laws, work and energy, oscillatory motion, rotational motion about a fixed axis, dynamics of systems of particles, central forces and celestial mechanics, three-dimensional particle dynamics, Lagrangian and Hamiltonian formalism, noninertial reference frames, elementary topics in fluid dynamics) 20%

2. ELECTROMAGNETISM (such as electrostatics, currents and DC circuits, magnetic fields in free space, Lorentz force, induction, Maxwell's equations and their applications, electromagnetic waves, AC circuits, magnetic and electric fields in matter) 18%

3. OPTICS AND WAVE PHENOMENA (such as wave properties, superposition, interference, diffraction, geometrical optics, polarization, Doppler effect) 9%

4. THERMODYNAMICS AND STATISTICAL MECHANICS (such as the laws of thermodynamics, thermodynamic processes, equations of state, ideal gases, kinetic theory, ensembles, statistical concepts and calculation of thermodynamic quantities, thermal expansion and heat transfer) 10%

5. QUANTUM MECHANICS (such as fundamental concepts, solutions of the Schrödinger equation (including square wells, harmonic oscillators, and hydrogenic atoms), spin, angular momentum, wave function symmetry, elementary perturbation theory) 12%

6. ATOMIC PHYSICS (such as properties of electrons, Bohr model, energy quantization, atomic structure, atomic spectra, selection rules, black-body radiation, x-rays, atoms in electric and magnetic fields) 10%

7. SPECIAL RELATIVITY (such as introductory concepts, time dilation, length contraction, simultaneity, energy and momentum, four-vectors and Lorentz transformation, velocity addition) 6%

8. LABORATORY METHODS (such as data and error analysis, electronics, instrumentation, radiation detection, counting statistics, interaction of charged particles with matter, lasers and optical interferometers, dimensional analysis, fundamental applications of probability and statistics) 6%

9. SPECIALIZED TOPICS: Nuclear and Particle physics (e.g., nuclear properties, radioactive decay, fission and fusion, reactions, fundamental properties of elementary particles), Condensed Matter (e.g., crystal structure, x-ray diffraction, thermal properties, electron theory of metals, semiconductors, superconductors), Miscellaneous (e.g., astrophysics, mathematical methods, computer applications) 9%

Those taking the test should be familiar with certain mathematical methods and their applications in physics. Such mathematical methods include single and multivariate calculus, coordinate systems (rectangular, cylindrical, and spherical), vector algebra and vector differential operators, Fourier series, partial differential equations, boundary value problems, matrices and determinants, and functions of complex variables. These methods may appear in the test in the context of various content categories as well as occasional questions concerning only mathematics in the specialized topics category above.

Preparing for a Subject Test

GRE Subject Test questions are designed to measure skills and knowledge gained over a long period of time. Although you might increase your scores to some extent through preparation a few weeks or months before you take the test, last-minute cramming is unlikely to be of further help. The following information may be helpful.

- A general review of your college courses is probably the best preparation for the test. However, the test covers a broad range of subject matter, and no one is expected to be familiar with the content of every question.
- Use this practice book to become familiar with the types of questions in the GRE Physics Test, paying special attention to the directions. If you thoroughly understand the directions before you take the test, you will have more time during the test to focus on the questions themselves.

Test-Taking Strategies

The questions in the practice test in this book illustrate the types of multiple-choice questions in the test. When you take the test, you will mark your answers on a separate machine-scorable answer sheet. Total testing time is two hours and fifty minutes; there are no separately timed sections. Following are some general test-taking strategies you may want to consider.

- Read the test directions carefully, and work as rapidly as you can without being careless. For each question, choose the best answer from the available options.
- All questions are of equal value; do not waste time pondering individual questions you find extremely difficult or unfamiliar.
- You may want to work through the test quite rapidly, first answering only the questions about which you feel confident, then going back and answering questions that require more thought, and concluding with the most difficult questions if there is time.
- If you decide to change an answer, make sure you completely erase it and fill in the oval corresponding to your desired answer.
- Questions for which you mark no answer or more than one answer are not counted in scoring.
- As a correction for haphazard guessing, one-fourth of the number of questions you answer incorrectly is subtracted from the number of questions you answer correctly. It is improbable that mere guessing will improve your score significantly; it may even lower your score.
  If, however, you are not certain of the correct answer but have some knowledge of the question and are able to eliminate one or more of the answer choices, your chance of getting the right answer is improved, and it may be to your advantage to answer the question.
- Record all answers on your answer sheet. Answers recorded in your test book will not be counted.
- Do not wait until the last five minutes of a testing session to record answers on your answer sheet.

What Your Scores Mean

Your raw score — that is, the number of questions you answered correctly minus one-fourth of the number you answered incorrectly — is converted to the scaled score that is reported. This conversion ensures that a scaled score reported for any edition of a Subject Test is comparable to the same scaled score earned on any other edition of the same test. Thus, equal scaled scores on a particular Subject Test indicate essentially equal levels of performance regardless of the test edition taken. Test scores should be compared only with other scores on the same Subject Test. (For example, a 680 on the Computer Science Test is not equivalent to a 680 on the Mathematics Test.)

Before taking the test, you may find it useful to know approximately what raw scores would be required to obtain a certain scaled score. Several factors influence the conversion of your raw score to your scaled score, such as the difficulty of the test edition and the number of test questions included in the computation of your raw score. Based on recent editions of the Physics Test, the table on the next page gives the range of raw scores associated with selected scaled scores for three different test editions. (Note that when the number of scored questions for a given test is greater than the number of possible scaled scores, it is likely that two or more raw scores will convert to the same scaled score.) The three test editions in the table that follows were selected to reflect varying degrees of difficulty. Examinees should note that future test editions may be somewhat more or less difficult than the test editions illustrated in the table.

Range of Raw Scores* Needed to Earn Selected Scaled Scores on Three Physics Test Editions That Differ in Difficulty

Scaled Score	Raw Scores		
	Form A	Form B	Form C
900	73	68-69	64
800	58-59	54-55	50
700	44	41	38
600	30	27	27
Number of Questions Used to Compute Raw Score			
	100	100	98

*Raw Score = Number of correct answers minus one-fourth the number of incorrect answers, rounded to the nearest integer

For a particular test edition, there are many ways to earn the same raw score. For example, on the edition listed above as "Form A," a raw score of 44 would earn a scaled score of 700. Below are a few of the possible ways in which a scaled score of 700 could be earned on that edition.

Examples of Ways to Earn a Scaled Score of 700 on the Edition Labeled As "Form A"

Raw Score	Questions Answered Correctly	Questions Answered Incorrectly	Questions Not Answered	Number of Questions Used to Compute Raw Score
44	44	0	56	100
44	49	20	31	100
44	55	44	1	100

Practice Test

To become familiar with how the administration will be conducted at the test center, first remove the answer sheet (pages 75 and 76). Then go to the back cover of the test book (page 70) and follow the instructions for completing the identification areas of the answer sheet. When you are ready to begin the test, note the time and begin marking your answers on the answer sheet.

FORM GR0177

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GRADUATE RECORD EXAMINATIONS®

PHYSICS TEST

Do not break the seal
until you are told to do so.

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TABLE OF INFORMATION

Rest mass of the electron	$m_e = 9.11 \times 10^{-31}$ kilogram $= 9.11 \times 10^{-28}$ gram
Magnitude of the electron charge	$e = 1.60 \times 10^{-19}$ coulomb $= 4.80 \times 10^{-10}$ statcoulomb (esu)
Avogadro's number	$N_A = 6.02 \times 10^{23}$ per mole
Universal gas constant	$R = 8.31$ joules/(mole • K)
Boltzmann's constant	$k = 1.38 \times 10^{-23}$ joule/K $= 1.38 \times 10^{-16}$ erg/K
Speed of light	$c = 3.00 \times 10^{8}$ m/s $= 3.00 \times 10^{10}$ cm/s
Planck's constant	$h = 6.63 \times 10^{-34}$ joule • second $= 4.14 \times 10^{-15}$ eV • second
	$\hbar = h/2\pi$
Vacuum permittivity	$\epsilon_0 = 8.85 \times 10^{-12}$ coulomb^2/(newton • meter^2)
Vacuum permeability	$\mu_0 = 4\pi \times 10^{-7}$ weber/(ampere • meter)
Universal gravitational constant	$G = 6.67 \times 10^{-11}$ meter^3/(kilogram • second^2)
Acceleration due to gravity	$g = 9.80$ m/s^2 $= 980$ cm/s^2
1 atmosphere pressure	1 atm $= 1.0 \times 10^{5}$ newtons/meter^2 $= 1.0 \times 10^{5}$ pascals (Pa)
1 angstrom	1Å $= 1 \times 10^{-10}$ meter
	1 weber/m^2 = 1 tesla = 10^4 gauss

Moments of inertia about center of mass

Rod	$\frac{1}{12} M\ell^2$
Disc	$\frac{1}{2} MR^2$
Sphere	$\frac{2}{5} MR^2$

This test starts on page 12

PHYSICS TEST

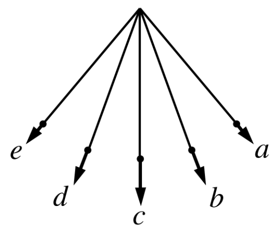
Time—170 minutes

100 Questions

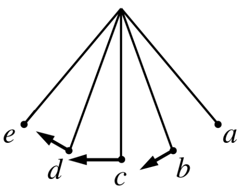
Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding space on the answer sheet.

1. Which of the following best illustrates the acceleration of a pendulum bob at points a through e ?

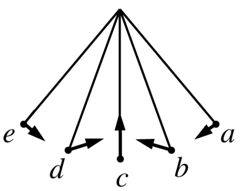
(A)



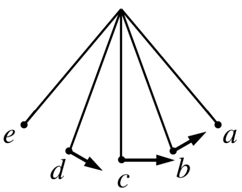
(B)



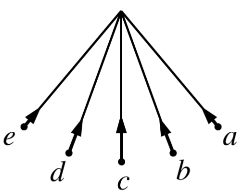
(C)



(D)



(E)



2. The coefficient of static friction between a small coin and the surface of a turntable is 0.30. The turntable rotates at 33.3 revolutions per minute. What is the maximum distance from the center of the turntable at which the coin will not slide?

(A) 0.024 m
(B) 0.048 m
(C) 0.121 m
(D) 0.242 m
(E) 0.484 m

3. A satellite of mass m orbits a planet of mass M in a circular orbit of radius R. The time required for one revolution is

(A) independent of M
(B) proportional to $\sqrt{m}$
(C) linear in R
(D) proportional to $R^{3/2}$
(E) proportional to R^2

4. In a nonrelativistic, one-dimensional collision, a particle of mass $2m$ collides with a particle of mass m at rest. If the particles stick together after the collision, what fraction of the initial kinetic energy is lost in the collision?

(A) 0
(B) $\frac{1}{4}$
(C) $\frac{1}{3}$
(D) $\frac{1}{2}$
(E) $\frac{2}{3}$

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GO ON TO THE NEXT PAGE.

SCRATCHWORK

5. A three-dimensional harmonic oscillator is in thermal equilibrium with a temperature reservoir at temperature T. The average total energy of the oscillator is

(A) $\frac{1}{2}kT$

(B) kT

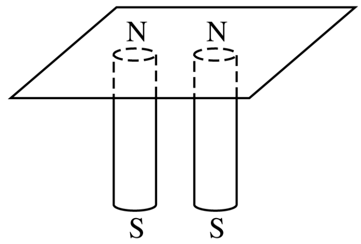
(C) $\frac{3}{2}kT$

(D) $3kT$

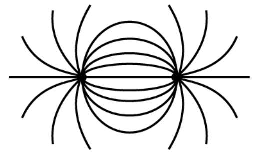
(E) $6kT$

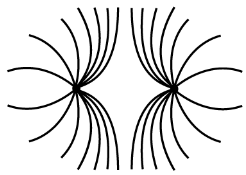
6. An ideal monatomic gas expands quasi-statically to twice its volume. If the process is isothermal, the work done by the gas is W_i. If the process is adiabatic, the work done by the gas is W_a. Which of the following is true?

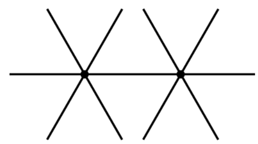
(A) $W_i = W_a$
(B) $0 = W_i < W_a$
(C) $0 < W_i < W_a$
(D) $0 = W_a < W_i$
(E) $0 < W_a < W_i$

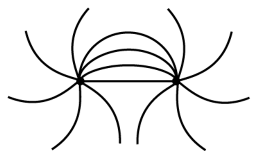


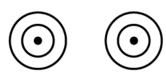
7. Two long, identical bar magnets are placed under a horizontal piece of paper, as shown in the figure above. The paper is covered with iron filings. When the two north poles are a small distance apart and touching the paper, the iron filings move into a pattern that shows the magnetic field lines. Which of the following best illustrates the pattern that results?

(A) 

(B) 

(C) 

(D) 

(E) 

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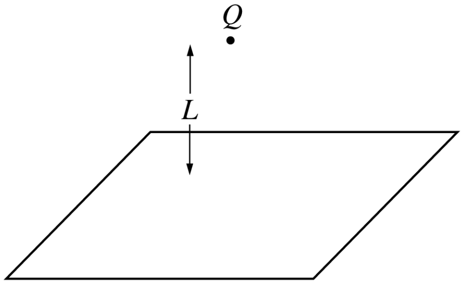
SCRATCHWORK



8. A positive charge Q is located at a distance L above an infinite grounded conducting plane, as shown in the figure above. What is the total charge induced on the plane?

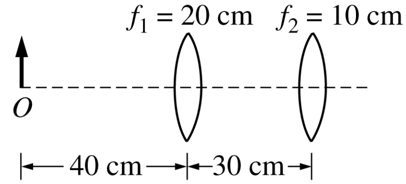
(A) $2Q$
(B) Q
(C) 0
(D) $-Q$
(E) $-2Q$

9. Five positive charges of magnitude q are arranged symmetrically around the circumference of a circle of radius r. What is the magnitude of the electric field at the center of the circle? $(k = 1/4\pi\epsilon_0)$

(A) 0
(B) kq/r^2
(C) $5kq/r^2$
(D) $(kq/r^2)\cos(2\pi/5)$
(E) $(5kq/r^2)\cos(2\pi/5)$

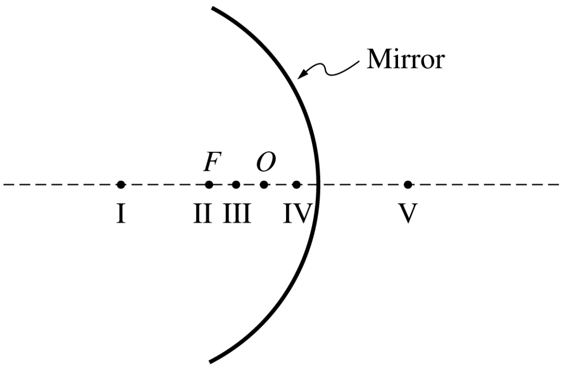
10. A 3-microfarad capacitor is connected in series with a 6-microfarad capacitor. When a 300-volt potential difference is applied across this combination, the total energy stored in the two capacitors is

(A) 0.09 J
(B) 0.18 J
(C) 0.27 J
(D) 0.41 J
(E) 0.81 J



11. An object is located 40 centimeters from the first of two thin converging lenses of focal lengths 20 centimeters and 10 centimeters, respectively, as shown in the figure above. The lenses are separated by 30 centimeters. The final image formed by the two-lens system is located

(A) 5.0 cm to the right of the second lens
(B) 13.3 cm to the right of the second lens
(C) infinitely far to the right of the second lens
(D) 13.3 cm to the left of the second lens
(E) 100 cm to the left of the second lens



12. A spherical, concave mirror is shown in the figure above. The focal point F and the location of the object O are indicated. At what point will the image be located?

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

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SCRATCHWORK

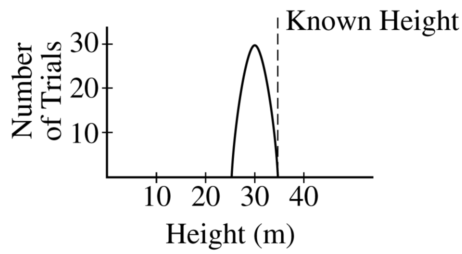
13. Two stars are separated by an angle of 3×10^{-5} radians. What is the diameter of the smallest telescope that can resolve the two stars using visible light ($\lambda \cong 600$ nanometers) ? (Ignore any effects due to Earth's atmosphere.)

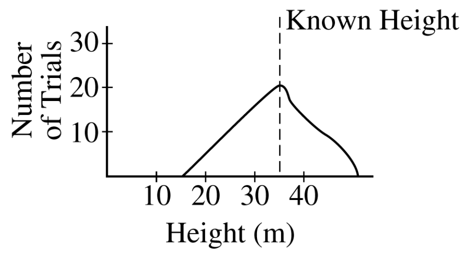
(A) 1 mm
(B) 2.5 cm
(C) 10 cm
(D) 2.5 m
(E) 10 m

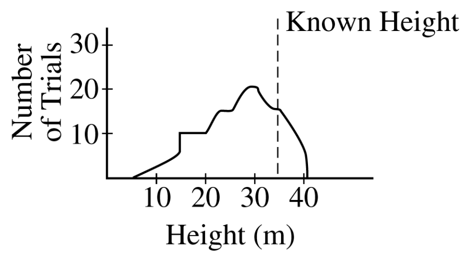
14. An 8-centimeter-diameter by 8-centimeter-long NaI(Tl) detector detects gamma rays of a specific energy from a point source of radioactivity. When the source is placed just next to the detector at the center of the circular face, 50 percent of all emitted gamma rays at that energy are detected. If the detector is moved to 1 meter away, the fraction of detected gamma rays drops to

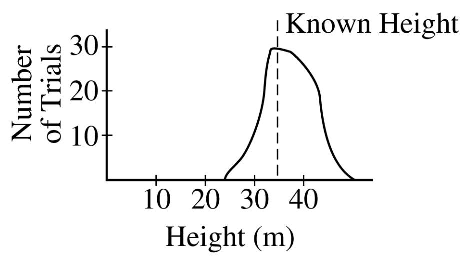
(A) 10^{-4}
(B) 2×10^{-4}
(C) 4×10^{-4}
(D) $8\pi \times 10^{-4}$
(E) $16\pi \times 10^{-4}$

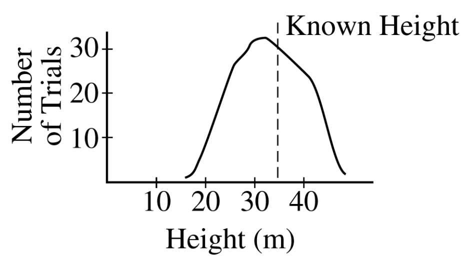
15. Five classes of students measure the height of a building. Each class uses a different method and each measures the height many different times. The data for each class are plotted below. Which class made the most precise measurement?

(A)


(B)


(C)


(D)


(E)


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SCRATCHWORK

16. A student makes 10 one-second measurements of the disintegration of a sample of a long-lived radioactive isotope and obtains the following values.

3, 0, 2, 1, 2, 4, 0, 1, 2, 5

How long should the student count to establish the rate to an uncertainty of 1 percent?

(A) 80 s
(B) 160 s
(C) 2,000 s
(D) 5,000 s
(E) 6,400 s

17. The ground state electron configuration for phosphorus, which has 15 electrons, is

(A) $1s^2 2s^2 2p^6 3s^1 3p^4$

(B) $1s^2 2s^2 2p^6 3s^2 3p^3$

(C) $1s^2 2s^2 2p^6 3s^2 3d^3$

(D) $1s^2 2s^2 2p^6 3s^1 3d^4$

(E) $1s^2 2s^2 2p^6 3p^2 3d^3$

18. The energy required to remove both electrons from the helium atom in its ground state is 79.0 eV. How much energy is required to ionize helium (i.e., to remove one electron) ?

(A) 24.6 eV
(B) 39.5 eV
(C) 51.8 eV
(D) 54.4 eV
(E) 65.4 eV

19. The primary source of the Sun's energy is a series of thermonuclear reactions in which the energy produced is c^2 times the mass difference between

(A) two hydrogen atoms and one helium atom
(B) four hydrogen atoms and one helium atom
(C) six hydrogen atoms and two helium atoms
(D) three helium atoms and one carbon atom
(E) two hydrogen atoms plus two helium atoms and one carbon atom

20. In the production of X rays, the term "bremsstrahlung" refers to which of the following?

(A) The cut-off wavelength, λ_{min}, of the X-ray tube
(B) The discrete X-ray lines emitted when an electron in an outer orbit fills a vacancy in an inner orbit of the atoms in the target metal of the X-ray tube
(C) The discrete X-ray lines absorbed when an electron in an inner orbit fills a vacancy in an outer orbit of the atoms in the target metal of the X-ray tube
(D) The smooth, continuous X-ray spectra produced by high-energy blackbody radiation from the X-ray tube
(E) The smooth, continuous X-ray spectra produced by rapidly decelerating electrons in the target metal of the X-ray tube

21. In the hydrogen spectrum, the ratio of the wavelengths for Lyman-α radiation ($n = 2$ to $n = 1$) to Balmer-α radiation ($n = 3$ to $n = 2$) is

(A) 5/48
(B) 5/27
(C) 1/3
(D) 3
(E) 27/5

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SCRATCHWORK

22. An astronomer observes a very small moon orbiting a planet and measures the moon's minimum and maximum distances from the planet's center and the moon's maximum orbital speed. Which of the following CANNOT be calculated from these measurements?

(A) Mass of the moon
(B) Mass of the planet
(C) Minimum speed of the moon
(D) Period of the orbit
(E) Semimajor axis of the orbit

23. A particle is constrained to move in a circle with a 10-meter radius. At one instant, the particle's speed is 10 meters per second and is increasing at a rate of 10 meters per second squared. The angle between the particle's velocity and acceleration vectors is

(A) 0°
(B) 30°
(C) 45°
(D) 60°
(E) 90°

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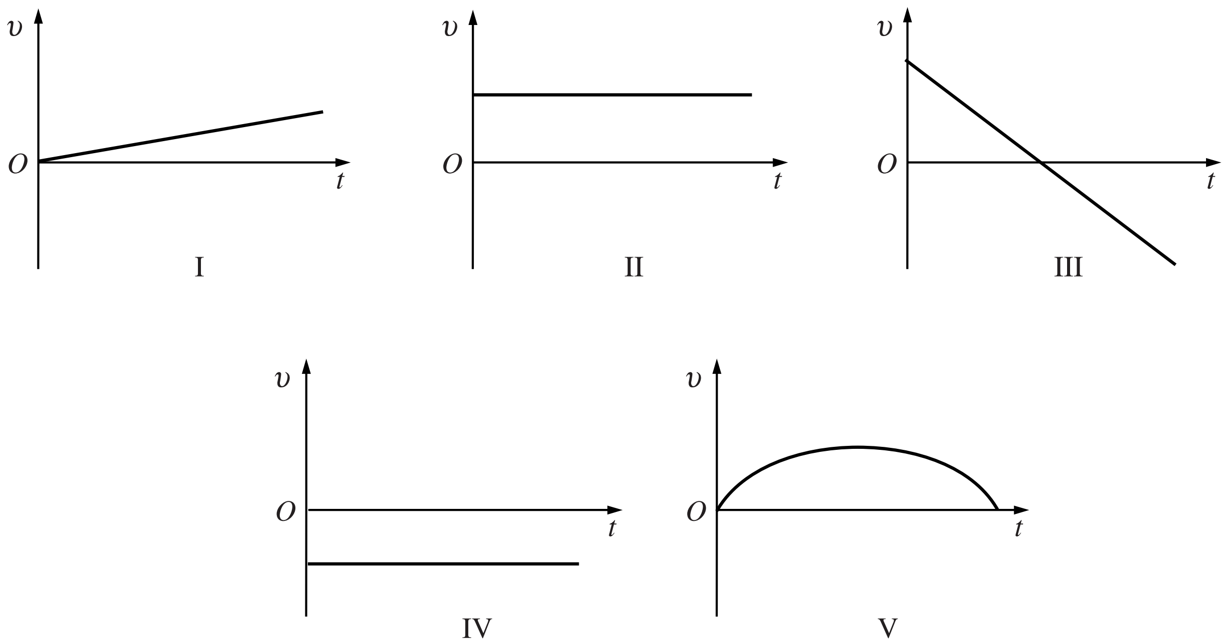
SCRATCHWORK



24. A stone is thrown at an angle of 45° above the horizontal x-axis in the $+x$-direction. If air resistance is ignored, which of the velocity *versus* time graphs shown above best represents v_x *versus* t and v_y *versus* t, respectively?

	v_x vs. t	v_y vs. t
(A)	I	IV
(B)	II	I
(C)	II	III
(D)	II	V
(E)	IV	V

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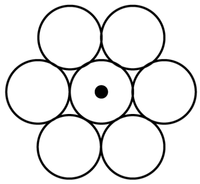
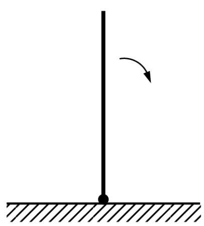
SCRATCHWORK



25. Seven pennies are arranged in a hexagonal, planar pattern so as to touch each neighbor, as shown in the figure above. Each penny is a uniform disk of mass m and radius r. What is the moment of inertia of the system of seven pennies about an axis that passes through the center of the central penny and is normal to the plane of the pennies?

(A) $(7/2)\ mr^2$
(B) $(13/2)\ mr^2$
(C) $(29/2)\ mr^2$
(D) $(49/2)\ mr^2$
(E) $(55/2)\ mr^2$



26. A thin uniform rod of mass M and length L is positioned vertically above an anchored frictionless pivot point, as shown above, and then allowed to fall to the ground. With what speed does the free end of the rod strike the ground?

(A) $\sqrt{\frac{1}{3}gL}$
(B) $\sqrt{gL}$
(C) $\sqrt{3gL}$
(D) $\sqrt{12gL}$
(E) $12\sqrt{gL}$

27. The eigenvalues of a Hermitian operator are always

(A) real
(B) imaginary
(C) degenerate
(D) linear
(E) positive

$$|\psi_1\rangle = 5|1\rangle - 3|2\rangle + 2|3\rangle$$
$$|\psi_2\rangle = |1\rangle - 5|2\rangle + x|3\rangle$$

28. The states $|1\rangle$, $|2\rangle$, and $|3\rangle$ are orthonormal. For what value of x are the states $|\psi_1\rangle$ and $|\psi_2\rangle$ given above orthogonal?

(A) 10
(B) 5
(C) 0
(D) -5
(E) -10

29. The state $\psi = \frac{1}{\sqrt{6}}\psi_{-1} + \frac{1}{\sqrt{2}}\psi_1 + \frac{1}{\sqrt{3}}\psi_2$ is a linear combination of three orthonormal eigenstates of the operator $\hat{O}$ corresponding to eigenvalues -1, 1, and 2. What is the expectation value of $\hat{O}$ for this state?

(A) $\frac{2}{3}$
(B) $\sqrt{\frac{7}{6}}$
(C) 1
(D) $\frac{4}{3}$
(E) $\frac{(\sqrt{3} + 2\sqrt{2} - 1)}{\sqrt{6}}$

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SCRATCHWORK

30. Which of the following functions could represent the radial wave function for an electron in an atom? (r is the distance of the electron from the nucleus; A and b are constants.)

I. $A\,e^{-br}$
II. $A\sin(br)$
III. A/r

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

31. Positronium is an atom formed by an electron and a positron (antielectron). It is similar to the hydrogen atom, with the positron replacing the proton. If a positronium atom makes a transition from the state with $n = 3$ to a state with $n = 1$, the energy of the photon emitted in this transition is closest to

(A) 6.0 eV
(B) 6.8 eV
(C) 12.2 eV
(D) 13.6 eV
(E) 24.2 eV

32. If the total energy of a particle of mass m is equal to twice its rest energy, then the magnitude of the particle's relativistic momentum is

(A) $mc/2$
(B) $mc/\sqrt{2}$
(C) mc
(D) $\sqrt{3}mc$
(E) $2mc$

33. If a charged pion that decays in 10^{-8} second in its own rest frame is to travel 30 meters in the laboratory before decaying, the pion's speed must be most nearly

(A) 0.43×10^8 m/s
(B) 2.84×10^8 m/s
(C) 2.90×10^8 m/s
(D) 2.98×10^8 m/s
(E) 3.00×10^8 m/s

34. In an inertial reference frame S, two events occur on the x-axis separated in time by Δt and in space by Δx. In another inertial reference frame S', moving in the x-direction relative to S, the two events could occur at the same time under which, if any, of the following conditions?

(A) For any values of Δx and Δt
(B) Only if $|\Delta x/\Delta t| < c$
(C) Only if $|\Delta x/\Delta t| > c$
(D) Only if $|\Delta x/\Delta t| = c$
(E) Under no condition

35. If the absolute temperature of a blackbody is increased by a factor of 3, the energy radiated per second per unit area does which of the following?

(A) Decreases by a factor of 81.
(B) Decreases by a factor of 9.
(C) Increases by a factor of 9.
(D) Increases by a factor of 27.
(E) Increases by a factor of 81.

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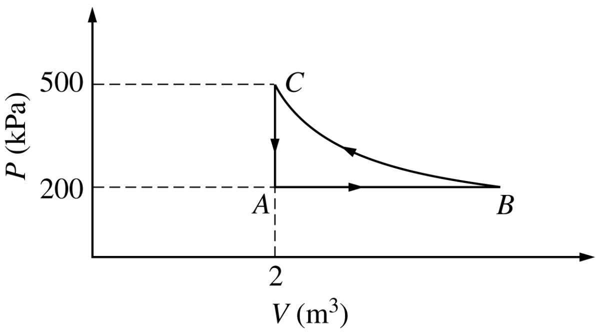
SCRATCHWORK

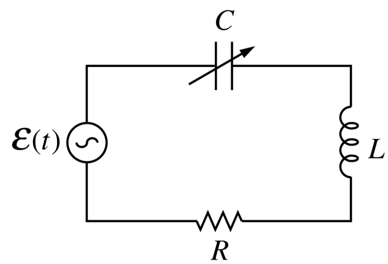
36. Consider the quasi-static adiabatic expansion of an ideal gas from an initial state i to a final state f. Which of the following statements is NOT true?

(A) No heat flows into or out of the gas.
(B) The entropy of state i equals the entropy of state f.
(C) The change of internal energy of the gas is $-\int PdV$.
(D) The mechanical work done by the gas is $\int PdV$.
(E) The temperature of the gas remains constant.



37. A constant amount of an ideal gas undergoes the cyclic process $ABCA$ in the PV diagram shown above. The path BC is isothermal. The work done by the gas during one complete cycle, beginning and ending at A, is most nearly

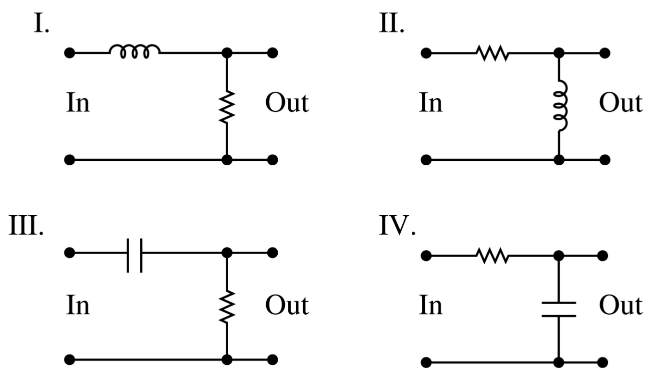
(A) 600 kJ
(B) 300 kJ
(C) 0
(D) −300 kJ
(E) −600 kJ



38. An AC circuit consists of the elements shown above, with $R = 10{,}000$ ohms, $L = 25$ millihenries, and C an adjustable capacitance. The AC voltage generator supplies a signal with an amplitude of 40 volts and angular frequency of 1,000 radians per second. For what value of C is the amplitude of the current maximized?

(A) 4 nF
(B) 40 nF
(C) 4 μF
(D) 40 μF
(E) 400 μF

39. Which two of the following circuits are high-pass filters?



(A) I and II
(B) I and III
(C) I and IV
(D) II and III
(E) II and IV

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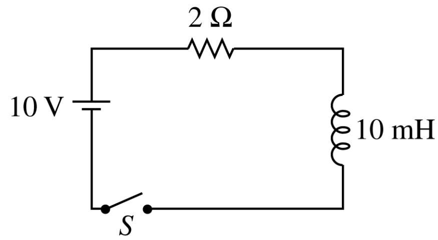
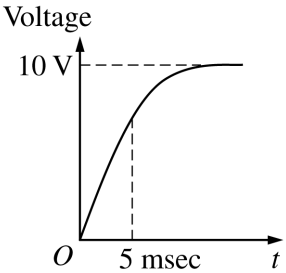
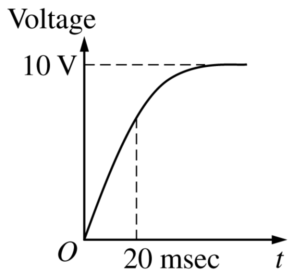
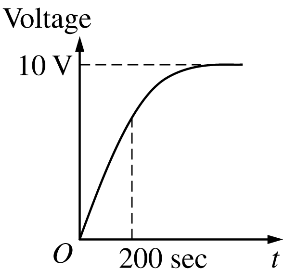
SCRATCHWORK

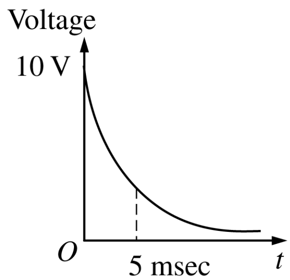


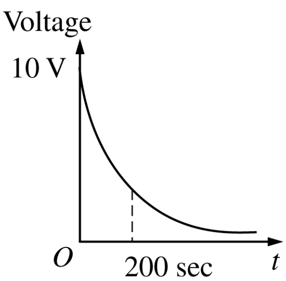
40. In the circuit shown above, the switch S is closed at $t = 0$. Which of the following best represents the voltage across the inductor, as seen on an oscilloscope?

(A) 

(B) 

(C) 

(D) 

(E) 

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SCRATCHWORK

41. Maxwell's equations can be written in the form shown below. If magnetic charge exists and if it is conserved, which of these equations will have to be changed?

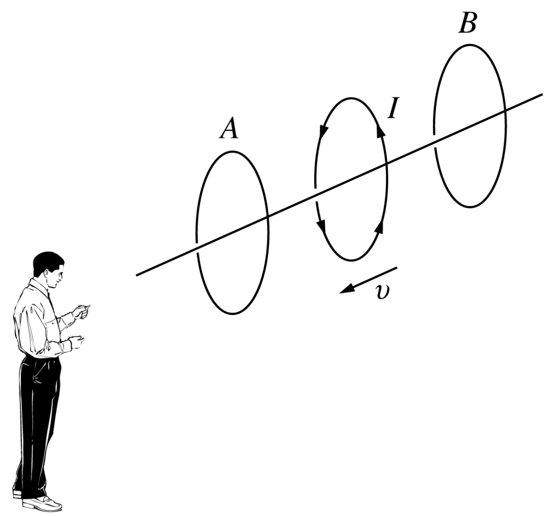
I. $\nabla \cdot \mathbf{E} = \rho/\epsilon_0$

II. $\nabla \cdot \mathbf{B} = 0$

III. $\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$

IV. $\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t}$

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



42. Three wire loops and an observer are positioned as shown in the figure above. From the observer's point of view, a current I flows counterclockwise in the middle loop, which is moving towards the observer with a velocity v. Loops A and B are stationary. This same observer would notice that

(A) clockwise currents are induced in loops A and B
(B) counterclockwise currents are induced in loops A and B
(C) a clockwise current is induced in loop A, but a counterclockwise current is induced in loop B
(D) a counterclockwise current is induced in loop A, but a clockwise current is induced in loop B
(E) a counterclockwise current is induced in loop A, but no current is induced in loop B

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SCRATCHWORK

43. The components of the orbital angular momentum operator $\mathbf{L} = (L_x, L_y, L_z)$ satisfy the following commutation relations.

$[L_x, L_y] = i\hbar L_z$,

$[L_y, L_z] = i\hbar L_x$,

$[L_z, L_x] = i\hbar L_y$.

What is the value of the commutator $[L_x L_y, L_z]$?

(A) $2i\hbar L_x L_y$

(B) $i\hbar\left(L_x^2 + L_y^2\right)$

(C) $-i\hbar\left(L_x^2 + L_y^2\right)$

(D) $i\hbar\left(L_x^2 - L_y^2\right)$

(E) $-i\hbar\left(L_x^2 - L_y^2\right)$

44. The energy eigenstates for a particle of mass m in a box of length L have wave functions $\phi_n(x) = \sqrt{2/L}\sin(n\pi x/L)$ and energies $E_n = n^2\pi^2\hbar^2/2mL^2$, where $n = 1, 2, 3, \ldots$. At time $t = 0$, the particle is in a state described as follows.

$$\Psi(t = 0) = \frac{1}{\sqrt{14}}[\phi_1 + 2\phi_2 + 3\phi_3]$$

Which of the following is a possible result of a measurement of energy for the state Ψ ?

(A) $2E_1$
(B) $5E_1$
(C) $7E_1$
(D) $9E_1$
(E) $14E_1$

45. Let $|\, n\,\rangle$ represent the normalized n^{th} energy eigenstate of the one-dimensional harmonic oscillator, $H|\, n\,\rangle = \hbar\omega\left(n + \frac{1}{2}\right)|\, n\,\rangle$. If $|\,\psi\,\rangle$ is a normalized ensemble state that can be expanded as a linear combination $|\,\psi\,\rangle = \frac{1}{\sqrt{14}}|\,1\,\rangle - \frac{2}{\sqrt{14}}|\,2\,\rangle + \frac{3}{\sqrt{14}}|\,3\,\rangle$ of the eigenstates, what is the expectation value of the energy operator in this ensemble state?

(A) $\frac{102}{14}\hbar\omega$

(B) $\frac{43}{14}\hbar\omega$

(C) $\frac{23}{14}\hbar\omega$

(D) $\frac{17}{\sqrt{14}}\hbar\omega$

(E) $\frac{7}{\sqrt{14}}\hbar\omega$

46. A free particle with initial kinetic energy E and de Broglie wavelength λ enters a region in which it has potential energy V. What is the particle's new de Broglie wavelength?

(A) $\lambda(1 + E/V)$

(B) $\lambda(1 - V/E)$

(C) $\lambda(1 - E/V)^{-1}$

(D) $\lambda(1 + V/E)^{1/2}$

(E) $\lambda(1 - V/E)^{-1/2}$

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SCRATCHWORK

47. A sealed and thermally insulated container of total volume V is divided into two equal volumes by an impermeable wall. The left half of the container is initially occupied by n moles of an ideal gas at temperature T. Which of the following gives the change in entropy of the system when the wall is suddenly removed and the gas expands to fill the entire volume?

(A) $2nR \ln 2$

(B) $nR \ln 2$

(C) $\frac{1}{2} nR \ln 2$

(D) $-nR \ln 2$

(E) $-2nR \ln 2$

48. A gaseous mixture of O_2 (molecular mass 32 u) and N_2 (molecular mass 28 u) is maintained at constant temperature. What is the ratio $\frac{v_{rms}(N_2)}{v_{rms}(O_2)}$ of the root-mean-square speeds of the molecules?

(A) $\frac{7}{8}$

(B) $\sqrt{\frac{7}{8}}$

(C) $\sqrt{\frac{8}{7}}$

(D) $\left(\frac{8}{7}\right)^2$

(E) $\ln\left(\frac{8}{7}\right)$

49. In a Maxwell-Boltzmann system with two states of energies ϵ and 2ϵ, respectively, and a degeneracy of 2 for each state, the partition function is

(A) $e^{-\epsilon/kT}$

(B) $2e^{-2\epsilon/kT}$

(C) $2e^{-3\epsilon/kT}$

(D) $e^{-\epsilon/kT} + e^{-2\epsilon/kT}$

(E) $2[e^{-\epsilon/kT} + e^{-2\epsilon/kT}]$

50. At 20°C, a pipe open at both ends resonates at a frequency of 440 hertz. At what frequency does the same pipe resonate on a particularly cold day when the speed of sound is 3 percent lower than it would be at 20°C ?

(A) 414 Hz
(B) 427 Hz
(C) 433 Hz
(D) 440 Hz
(E) 453 Hz

51. Unpolarized light of intensity I_0 is incident on a series of three polarizing filters. The axis of the second filter is oriented at 45° to that of the first filter, while the axis of the third filter is oriented at 90° to that of the first filter. What is the intensity of the light transmitted through the third filter?

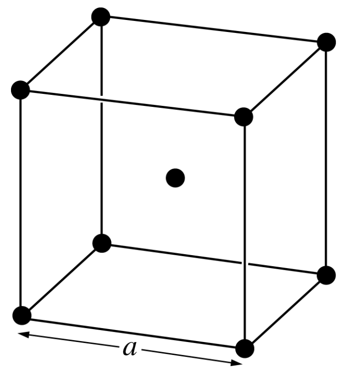
(A) 0

(B) $I_0/8$

(C) $I_0/4$

(D) $I_0/2$

(E) $I_0/\sqrt{2}$



52. The conventional unit cell of a body-centered cubic Bravais lattice is shown in the figure above. The conventional cell has volume a^3. What is the volume of the primitive unit cell?

(A) $a^3/8$
(B) $a^3/4$
(C) $a^3/2$
(D) a^3
(E) $2a^3$

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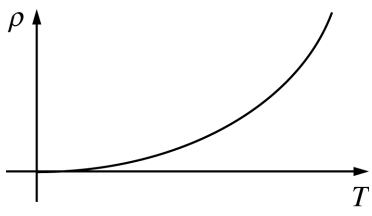
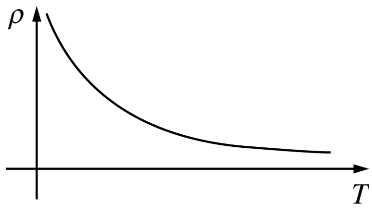
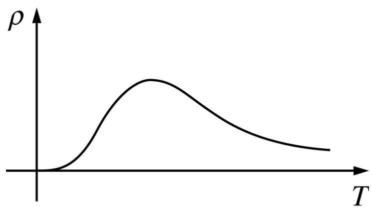
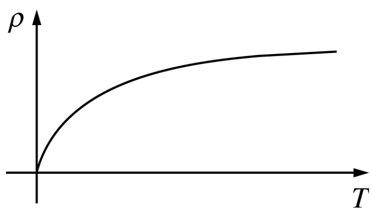
SCRATCHWORK

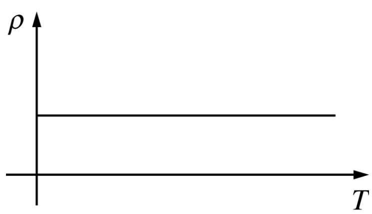
53. Which of the following best represents the temperature dependence of the resistivity of an undoped semiconductor?

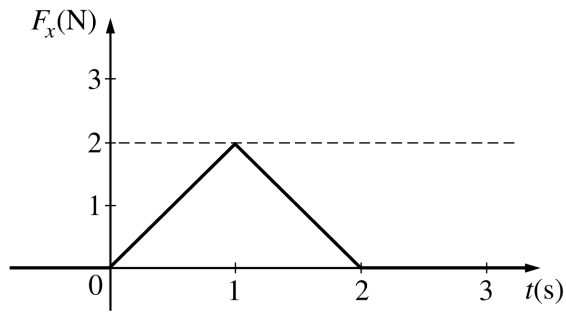
(A) 

(B) 

(C) 

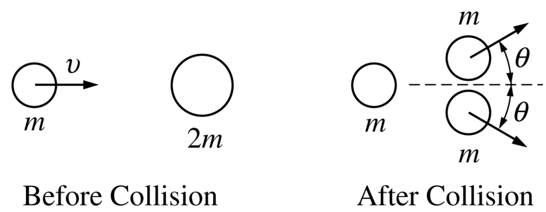
(D) 

(E) 



54. The figure above shows a plot of the time-dependent force $F_x(t)$ acting on a particle in motion along the x-axis. What is the total impulse delivered to the particle?

(A) 0
(B) 1 kg•m/s
(C) 2 kg•m/s
(D) 3 kg•m/s
(E) 4 kg•m/s



55. A particle of mass m is moving along the x-axis with speed v when it collides with a particle of mass $2m$ initially at rest. After the collision, the first particle has come to rest, and the second particle has split into two equal-mass pieces that move at equal angles $\theta > 0$ with the x-axis, as shown in the figure above. Which of the following statements correctly describes the speeds of the two pieces?

(A) Each piece moves with speed v.
(B) One of the pieces moves with speed v, the other moves with speed less than v.
(C) Each piece moves with speed $v/2$.
(D) One of the pieces moves with speed $v/2$, the other moves with speed greater than $v/2$.
(E) Each piece moves with speed greater than $v/2$.

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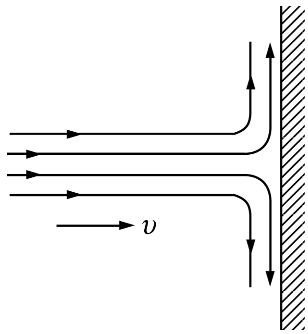
SCRATCHWORK

56. A balloon is to be filled with helium and used to suspend a mass of 300 kilograms in air. If the mass of the balloon is neglected, which of the following gives the approximate volume of helium required? (The density of air is 1.29 kilograms per cubic meter and the density of helium is 0.18 kilogram per cubic meter.)

(A) 50 m^3
(B) 95 m^3
(C) 135 m^3
(D) 270 m^3
(E) 540 m^3



57. A stream of water of density ρ, cross-sectional area A, and speed υ strikes a wall that is perpendicular to the direction of the stream, as shown in the figure above. The water then flows sideways across the wall. The force exerted by the stream on the wall is

(A) $\rho \upsilon^2 A$
(B) $\rho \upsilon A/2$
(C) $\rho g h A$
(D) $\upsilon^2 A/\rho$
(E) $\upsilon^2 A/2\rho$

58. A proton moves in the $+z$-direction after being accelerated from rest through a potential difference V. The proton then passes through a region with a uniform electric field E in the $+x$-direction and a uniform magnetic field B in the $+y$-direction, but the proton's trajectory is not affected. If the experiment were repeated using a potential difference of $2V$, the proton would then be

(A) deflected in the $+x$-direction
(B) deflected in the $-x$-direction
(C) deflected in the $+y$-direction
(D) deflected in the $-y$-direction
(E) undeflected

59. For an inductor and capacitor connected in series, the equation describing the motion of charge is

$$L\frac{d^2Q}{dt^2} + \frac{1}{C}Q = 0,$$

where L is the inductance, C is the capacitance, and Q is the charge. An analogous equation can be written for a simple harmonic oscillator with position x, mass m, and spring constant k. Which of the following correctly lists the mechanical analogs of L, C, and Q ?

	$\underline{L}$	$\underline{C}$	$\underline{Q}$
(A)	m	k	x
(B)	m	$1/k$	x
(C)	k	x	m
(D)	$1/k$	$1/m$	x
(E)	x	$1/k$	$1/m$

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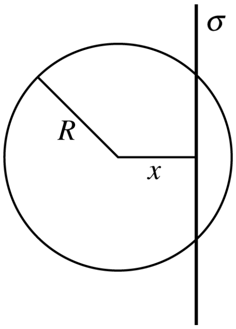
SCRATCHWORK



60. An infinite, uniformly charged sheet with surface-charge density σ cuts through a spherical Gaussian surface of radius R at a distance x from its center, as shown in the figure above. The electric flux Φ through the Gaussian surface is

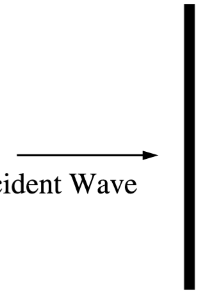
(A) $\dfrac{\pi R^2 \sigma}{\epsilon_0}$

(B) $\dfrac{2\pi R^2 \sigma}{\epsilon_0}$

(C) $\dfrac{\pi (R - x)^2 \sigma}{\epsilon_0}$

(D) $\dfrac{\pi (R^2 - x^2) \sigma}{\epsilon_0}$

(E) $\dfrac{2\pi (R^2 - x^2) \sigma}{\epsilon_0}$



61. An electromagnetic plane wave, propagating in vacuum, has an electric field given by $E = E_0 \cos(kx - \omega t)$ and is normally incident on a perfect conductor at $x = 0$, as shown in the figure above. Immediately to the left of the conductor, the total electric field E and the total magnetic field B are given by which of the following?

	$\underline{E}$	$\underline{B}$
(A)	0	0
(B)	$2E_0 \cos \omega t$	0
(C)	0	$(2E_0/c) \cos \omega t$
(D)	$2E_0 \cos \omega t$	$(2E_0/c) \cos \omega t$
(E)	$2E_0 \cos \omega t$	$(2E_0/c) \sin \omega t$

62. A nonrelativistic particle with a charge twice that of an electron moves through a uniform magnetic field. The field has a strength of $\pi/4$ tesla and is perpendicular to the velocity of the particle. What is the particle's mass if it has a cyclotron frequency of 1,600 hertz?

(A) 2.5×10^{-23} kg
(B) 1.2×10^{-22} kg
(C) 3.3×10^{-22} kg
(D) 5.0×10^{-21} kg
(E) 7.5×10^{-21} kg

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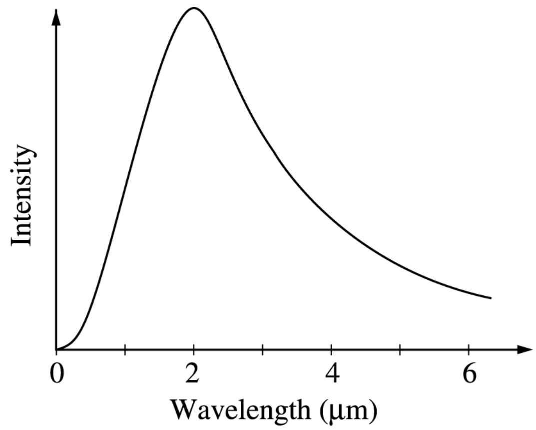
SCRATCHWORK



63. The distribution of relative intensity $I(\lambda)$ of blackbody radiation from a solid object *versus* the wavelength λ is shown in the figure above. If the Wien displacement law constant is 2.9×10^{-3} m·K, what is the approximate temperature of the object?

(A) 10 K
(B) 50 K
(C) 250 K
(D) 1,500 K
(E) 6,250 K

64. Electromagnetic radiation provides a means to probe aspects of the physical universe. Which of the following statements regarding radiation spectra is NOT correct?

(A) Lines in the infrared, visible, and ultraviolet regions of the spectrum reveal primarily the nuclear structure of the sample.
(B) The wavelengths identified in an absorption spectrum of an element are among those in its emission spectrum.
(C) Absorption spectra can be used to determine which elements are present in distant stars.
(D) Spectral analysis can be used to identify the composition of galactic dust.
(E) Band spectra are due to molecules.

$$C = 3kN_A\left(\frac{hv}{kT}\right)^2 \frac{e^{hv/kT}}{(e^{hv/kT} - 1)^2}$$

65. Einstein's formula for the molar heat capacity C of solids is given above. At high temperatures, C approaches which of the following?

(A) 0
(B) $3kN_A\left(\frac{hv}{kT}\right)$
(C) $3kN_A hv$
(D) $3kN_A$
(E) $N_A hv$

66. A sample of radioactive nuclei of a certain element can decay only by γ-emission and β-emission. If the half-life for γ-emission is 24 minutes and that for β-emission is 36 minutes, the half-life for the sample is

(A) 30 minutes
(B) 24 minutes
(C) 20.8 minutes
(D) 14.4 minutes
(E) 6 minutes

67. The ^{238}U nucleus has a binding energy of about 7.6 MeV per nucleon. If the nucleus were to fission into two equal fragments, each would have a kinetic energy of just over 100 MeV. From this, it can be concluded that

(A) ^{238}U cannot fission spontaneously
(B) ^{238}U has a large neutron excess
(C) nuclei near $A = 120$ have masses greater than half that of ^{238}U
(D) nuclei near $A = 120$ must be bound by about 6.7 MeV/nucleon
(E) nuclei near $A = 120$ must be bound by about 8.5 MeV/nucleon

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SCRATCHWORK

68. When $^{7}_{4}Be$ transforms into $^{7}_{3}Li$, it does so by

(A) emitting an alpha particle only
(B) emitting an electron only
(C) emitting a neutron only
(D) emitting a positron only
(E) electron capture by the nucleus with emission of a neutrino

69. Blue light of wavelength 480 nanometers is most strongly reflected off a thin film of oil on a glass slide when viewed near normal incidence. Assuming that the index of refraction of the oil is 1.2 and that of the glass is 1.6, what is the minimum thickness of the oil film (other than zero) ?

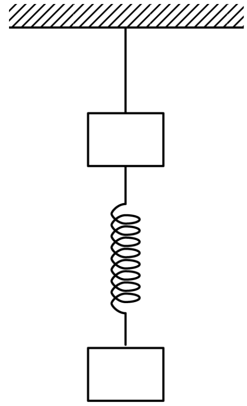
(A) 150 nm
(B) 200 nm
(C) 300 nm
(D) 400 nm
(E) 480 nm

70. Light from a laser falls on a pair of very narrow slits separated by 0.5 micrometer, and bright fringes separated by 1.0 millimeter are observed on a distant screen. If the frequency of the laser light is doubled, what will be the separation of the bright fringes?

(A) 0.25 mm
(B) 0.5 mm
(C) 1.0 mm
(D) 2.0 mm
(E) 2.5 mm

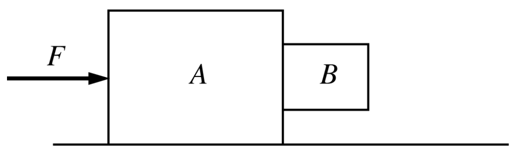
71. The ultraviolet Lyman alpha line of hydrogen with wavelength 121.5 nanometers is emitted by an astronomical object. An observer on Earth measures the wavelength of the light received from the object to be 607.5 nanometers. The observer can conclude that the object is moving with a radial velocity of

(A) 2.4×10^8 m/s toward Earth
(B) 2.8×10^8 m/s toward Earth
(C) 2.4×10^8 m/s away from Earth
(D) 2.8×10^8 m/s away from Earth
(E) 12×10^8 m/s away from Earth



72. Two identical blocks are connected by a spring. The combination is suspended, at rest, from a string attached to the ceiling, as shown in the figure above. The string breaks suddenly. Immediately after the string breaks, what is the downward acceleration of the upper block?

(A) 0
(B) $g/2$
(C) g
(D) $\sqrt{2}g$
(E) $2g$



73. For the system consisting of the two blocks shown in the figure above, the minimum horizontal force F is applied so that block B does not fall under the influence of gravity. The masses of A and B are 16.0 kilograms and 4.00 kilograms, respectively. The horizontal surface is frictionless and the coefficient of friction between the two blocks is 0.50. The magnitude of F is most nearly

(A) 50 N
(B) 100 N
(C) 200 N
(D) 400 N
(E) 1,600 N

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SCRATCHWORK

74. The Lagrangian for a mechanical system is

$$L = a\dot{q}^2 + bq^4,$$

where q is a generalized coordinate and a and b are constants. The equation of motion for this system is

(A) $\dot{q} = \sqrt{\frac{b}{a}}\, q^2$

(B) $\dot{q} = \frac{2b}{a} q^3$

(C) $\ddot{q} = -\frac{2b}{a} q^3$

(D) $\ddot{q} = +\frac{2b}{a} q^3$

(E) $\ddot{q} = \frac{b}{a} q^3$

$$\begin{pmatrix} a'_x \\ a'_y \\ a'_z \end{pmatrix} = \begin{bmatrix} 1/2 & \sqrt{3}/2 & 0 \\ -\sqrt{3}/2 & 1/2 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix}$$

75. The matrix shown above transforms the components of a vector in one coordinate frame S to the components of the same vector in a second coordinate frame S'. This matrix represents a rotation of the reference frame S by

(A) 30° clockwise about the x-axis
(B) 30° counterclockwise about the z-axis
(C) 45° clockwise about the z-axis
(D) 60° clockwise about the y-axis
(E) 60° counterclockwise about the z-axis

76. The mean kinetic energy of the conduction electrons in metals is ordinarily much higher than kT because

(A) electrons have many more degrees of freedom than atoms do
(B) the electrons and the lattice are not in thermal equilibrium
(C) the electrons form a degenerate Fermi gas
(D) electrons in metals are highly relativistic
(E) electrons interact strongly with phonons

77. An ensemble of systems is in thermal equilibrium with a reservoir for which $kT = 0.025$ eV. State A has an energy that is 0.1 eV above that of state B. If it is assumed the systems obey Maxwell-Boltzmann statistics and that the degeneracies of the two states are the same, then the ratio of the number of systems in state A to the number in state B is

(A) e^{+4}
(B) $e^{+0.25}$
(C) 1
(D) $e^{-0.25}$
(E) e^{-4}

78. The muon decays with a characteristic lifetime of about 10^{-6} second into an electron, a muon neutrino, and an electron antineutrino. The muon is forbidden from decaying into an electron and just a single neutrino by the law of conservation of

(A) charge
(B) mass
(C) energy and momentum
(D) baryon number
(E) lepton number

79. A particle leaving a cyclotron has a total relativistic energy of 10 GeV and a relativistic momentum of 8 GeV/c. What is the rest mass of this particle?

(A) 0.25 GeV/c^2
(B) 1.20 GeV/c^2
(C) 2.00 GeV/c^2
(D) 6.00 GeV/c^2
(E) 16.0 GeV/c^2

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SCRATCHWORK

80. A tube of water is traveling at 1/2 c relative to the lab frame when a beam of light traveling in the same direction as the tube enters it. What is the speed of light in the water relative to the lab frame? (The index of refraction of water is 4/3.)

(A) 1/2 c
(B) 2/3 c
(C) 5/6 c
(D) 10/11 c
(E) c

81. Which of the following is the orbital angular momentum eigenfunction $Y_\ell^m(\theta, \phi)$ in a state for which the operators $\mathbf{L}^2$ and L_z have eigenvalues $6\hbar^2$ and $-\hbar$, respectively?

(A) $Y_2^1(\theta, \phi)$

(B) $Y_2^{-1}(\theta, \phi)$

(C) $\frac{1}{\sqrt{2}}[Y_2^1(\theta, \phi) + Y_2^{-1}(\theta, \phi)]$

(D) $Y_3^2(\theta, \phi)$

(E) $Y_3^{-1}(\theta, \phi)$

82. Let $|\alpha\rangle$ represent the state of an electron with spin up and $|\beta\rangle$ the state of an electron with spin down. Valid spin eigenfunctions for a triplet state (^3S) of a two-electron atom include which of the following?

I. $|\alpha\rangle_1 |\alpha\rangle_2$
II. $\frac{1}{\sqrt{2}}(|\alpha\rangle_1 |\beta\rangle_2 - |\alpha\rangle_2 |\beta\rangle_1)$
III. $\frac{1}{\sqrt{2}}(|\alpha\rangle_1 |\beta\rangle_2 + |\alpha\rangle_2 |\beta\rangle_1)$

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

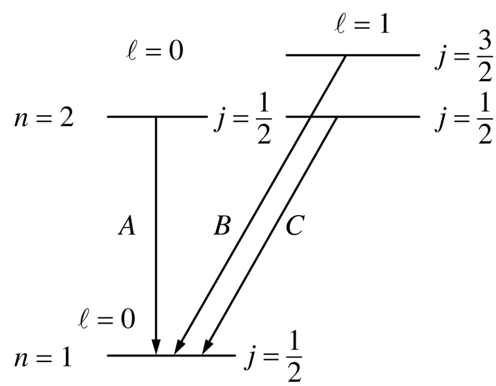
83. The state of a spin-$\frac{1}{2}$ particle can be represented using the eigenstates $|\uparrow\rangle$ and $|\downarrow\rangle$ of the S_z operator.

$$S_z|\uparrow\rangle = \tfrac{1}{2}\hbar|\uparrow\rangle$$

$$S_z|\downarrow\rangle = -\tfrac{1}{2}\hbar|\downarrow\rangle$$

Given the Pauli matrix $\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$, which of the following is an eigenstate of S_x with eigenvalue $-\frac{1}{2}\hbar$?

(A) $|\downarrow\rangle$
(B) $\frac{1}{\sqrt{2}}(|\uparrow\rangle + |\downarrow\rangle)$
(C) $\frac{1}{\sqrt{2}}(|\uparrow\rangle - |\downarrow\rangle)$
(D) $\frac{1}{\sqrt{2}}(|\uparrow\rangle + i|\downarrow\rangle)$
(E) $\frac{1}{\sqrt{2}}(|\uparrow\rangle - i|\downarrow\rangle)$



84. An energy-level diagram of the $n = 1$ and $n = 2$ levels of atomic hydrogen (including the effects of spin-orbit coupling and relativity) is shown in the figure above. Three transitions are labeled A, B, and C. Which of the transitions will be possible electric-dipole transitions?

(A) B only
(B) C only
(C) A and C only
(D) B and C only
(E) A, B, and C

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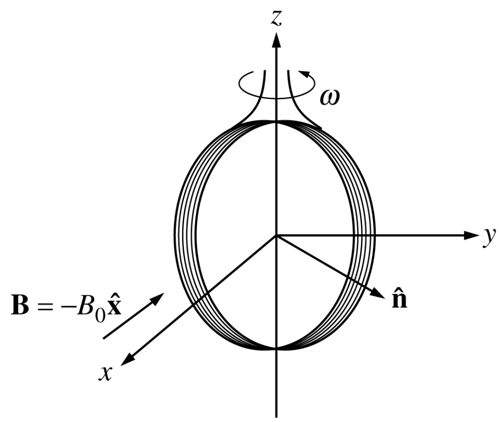
SCRATCHWORK

85. One end of a Nichrome wire of length $2L$ and cross-sectional area A is attached to an end of another Nichrome wire of length L and cross-sectional area $2A$. If the free end of the longer wire is at an electric potential of 8.0 volts, and the free end of the shorter wire is at an electric potential of 1.0 volt, the potential at the junction of the two wires is most nearly equal to

(A) 2.4 V
(B) 3.3 V
(C) 4.5 V
(D) 5.7 V
(E) 6.6 V



86. A coil of 15 turns, each of radius 1 centimeter, is rotating at a constant angular velocity $\omega = 300$ radians per second in a uniform magnetic field of 0.5 tesla, as shown in the figure above. Assume at time $t = 0$ that the normal $\hat{\mathbf{n}}$ to the coil plane is along the y-direction and that the self-inductance of the coil can be neglected. If the coil resistance is 9 ohms, what will be the magnitude of the induced current in milliamperes?

(A) $225\pi \sin \omega t$
(B) $250\pi \sin \omega t$
(C) $0.08\pi \cos \omega t$
(D) $1.7\pi \cos \omega t$
(E) $25\pi \cos \omega t$

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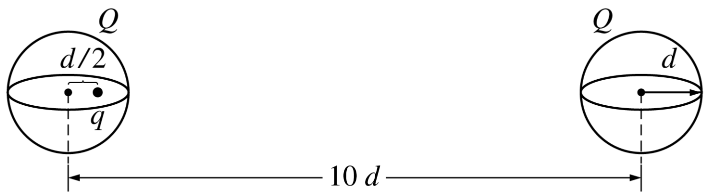

87. Two spherical, nonconducting, and very thin shells of uniformly distributed positive charge Q and radius d are located a distance $10d$ from each other. A positive point charge q is placed inside one of the shells at a distance $d/2$ from the center, on the line connecting the centers of the two shells, as shown in the figure above. What is the net force on the charge q ?

(A) $\dfrac{qQ}{361\pi\epsilon_0 d^2}$ to the left

(B) $\dfrac{qQ}{361\pi\epsilon_0 d^2}$ to the right

(C) $\dfrac{qQ}{441\pi\epsilon_0 d^2}$ to the left

(D) $\dfrac{qQ}{441\pi\epsilon_0 d^2}$ to the right

(E) $\dfrac{360qQ}{361\pi\epsilon_0 d^2}$ to the left

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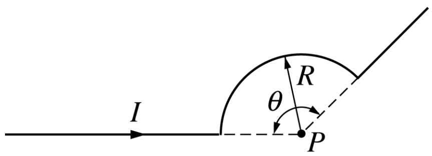


88. A segment of wire is bent into an arc of radius R and subtended angle θ, as shown in the figure above. Point P is at the center of the circular segment. The wire carries current I. What is the magnitude of the magnetic field at P?

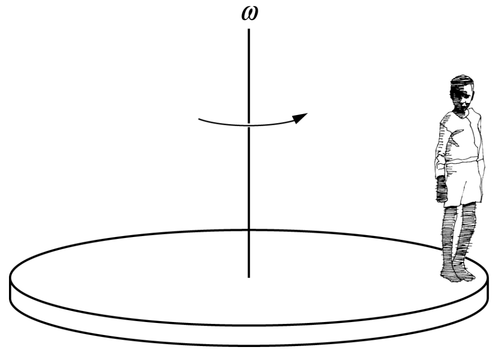
(A) 0

(B) $\dfrac{\mu_0 I\theta}{(2\pi)^2 R}$

(C) $\dfrac{\mu_0 I\theta}{4\pi R}$

(D) $\dfrac{\mu_0 I\theta}{4\pi R^2}$

(E) $\dfrac{\mu_0 I}{2\theta R^2}$



89. A child is standing on the edge of a merry-go-round that has the shape of a solid disk, as shown in the figure above. The mass of the child is 40 kilograms. The merry-go-round has a mass of 200 kilograms and a radius of 2.5 meters, and it is rotating with an angular velocity of $\omega = 2.0$ radians per second. The child then walks slowly toward the center of the-merry-go-round. What will be the final angular velocity of the merry-go-round when the child reaches the center? (The size of the child can be neglected.)

(A) 2.0 rad/s
(B) 2.2 rad/s
(C) 2.4 rad/s
(D) 2.6 rad/s
(E) 2.8 rad/s

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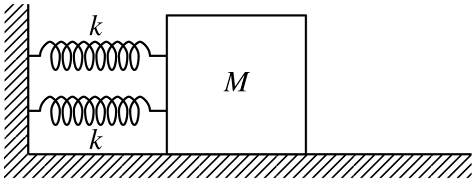

Figure 1

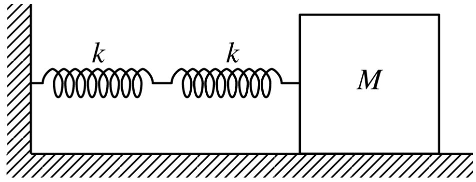

Figure 2

90. Two identical springs with spring constant k are connected to identical masses of mass M, as shown in the figures above. The ratio of the period for the springs connected in parallel (Figure 1) to the period for the springs connected in series (Figure 2) is

(A) $\frac{1}{2}$

(B) $\frac{1}{\sqrt{2}}$

(C) 1

(D) $\sqrt{2}$

(E) 2

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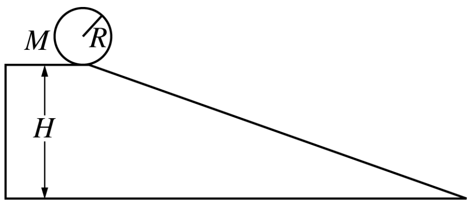


91. The cylinder shown above, with mass M and radius R, has a radially dependent density. The cylinder starts from rest and rolls without slipping down an inclined plane of height H. At the bottom of the plane its translational speed is $(8gH/7)^{1/2}$. Which of the following is the rotational inertia of the cylinder?

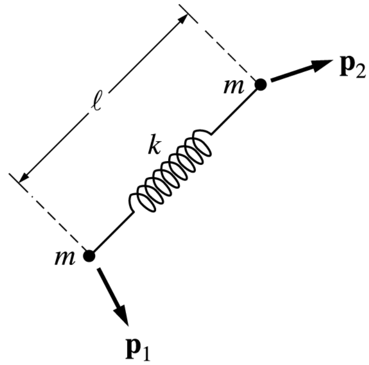
(A) $\frac{1}{2}MR^2$

(B) $\frac{3}{4}MR^2$

(C) $\frac{7}{8}MR^2$

(D) MR^2

(E) $\frac{7}{4}MR^2$



92. Two small equal masses m are connected by an ideal massless spring that has equilibrium length ℓ_0 and force constant k, as shown in the figure above. The system is free to move without friction in the plane of the page. If p_1 and p_2 represent the magnitudes of the momenta of the two masses, a Hamiltonian for this system is

(A) $\frac{1}{2}\left\{\frac{p_1^2}{m} + \frac{p_2^2}{m} - 2\,k(\ell - \ell_0)\right\}$

(B) $\frac{1}{2}\left\{\frac{p_1^2}{m} + \frac{p_2^2}{m} + 2\,k(\ell - \ell_0)^2\right\}$

(C) $\frac{1}{2}\left\{\frac{p_1^2}{m} + \frac{p_2^2}{m} - k(\ell - \ell_0)\right\}$

(D) $\frac{1}{2}\left\{\frac{p_1^2}{m} + \frac{p_2^2}{m} - k(\ell - \ell_0)^2\right\}$

(E) $\frac{1}{2}\left\{\frac{p_1^2}{m} + \frac{p_2^2}{m} + k(\ell - \ell_0)^2\right\}$

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SCRATCHWORK

93. The solution to the Schrödinger equation for the ground state of hydrogen is

$$\psi_0 = \frac{1}{\sqrt{\pi a_0^{\,3}}} e^{-r/a_0},$$

where a_0 is the Bohr radius and r is the distance from the origin. Which of the following is the most probable value for r ?

(A) 0
(B) $a_0/2$
(C) a_0
(D) $2a_0$
(E) ∞

94. The raising and lowering operators for the quantum harmonic oscillator satisfy

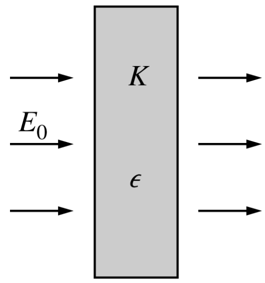
$$a^\dagger \,|\, n\rangle = \sqrt{n+1}\,|\, n+1\rangle, \;\; a|\, n\rangle = \sqrt{n}\,|\, n-1\rangle$$

for energy eigenstates $|n\rangle$ with energy E_n. Which of the following gives the first-order shift in the $n = 2$ energy level due to the perturbation

$$\Delta H = V(a + a^\dagger)^2,$$

where V is a constant?

(A) 0
(B) V
(C) $\sqrt{2}V$
(D) $2\sqrt{2}V$
(E) $5V$



95. An infinite slab of insulating material with dielectric constant K and permittivity $\epsilon = K\epsilon_0$ is placed in a uniform electric field of magnitude E_0 . The field is perpendicular to the surface of the material, as shown in the figure above. The magnitude of the electric field inside the material is

(A) $\dfrac{E_0}{K}$
(B) $\dfrac{E_0}{K\epsilon_0}$
(C) E_0
(D) $K\epsilon_0 E_0$
(E) KE_0

96. A uniformly charged sphere of total charge Q expands and contracts between radii R_1 and R_2 at a frequency f. The total power radiated by the sphere is

(A) proportional to Q
(B) proportional to f^2
(C) proportional to f^4
(D) proportional to (R_2/R_1)
(E) zero

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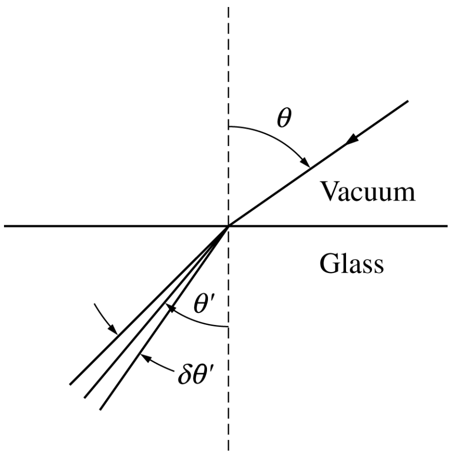

97. A beam of light has a small wavelength spread $\delta\lambda$ about a central wavelength λ. The beam travels in vacuum until it enters a glass plate at an angle θ relative to the normal to the plate, as shown in the figure above. The index of refraction of the glass is given by $n(\lambda)$. The angular spread $\delta\theta'$ of the refracted beam is given by

(A) $\delta\theta' = \left|\frac{1}{n}\delta\lambda\right|$

(B) $\delta\theta' = \left|\frac{dn(\lambda)}{d\lambda}\delta\lambda\right|$

(C) $\delta\theta' = \left|\frac{1}{\lambda}\frac{d\lambda}{dn}\delta\lambda\right|$

(D) $\delta\theta' = \left|\frac{\sin\theta}{\sin\theta'}\frac{\delta\lambda}{\lambda}\right|$

(E) $\delta\theta' = \left|\frac{\tan\theta'}{n}\frac{dn(\lambda)}{d\lambda}\delta\lambda\right|$

98. Suppose that a system in quantum state i has energy E_i. In thermal equilibrium, the expression

$$\frac{\sum_i E_i e^{-E_i/kT}}{\sum_i e^{-E_i/kT}}$$

represents which of the following?

(A) The average energy of the system
(B) The partition function
(C) Unity
(D) The probability to find the system with energy E_i
(E) The entropy of the system

99. A photon strikes an electron of mass m that is initially at rest, creating an electron-positron pair. The photon is destroyed and the positron and two electrons move off at equal speeds along the initial direction of the photon. The energy of the photon was

(A) mc^2
(B) $2mc^2$
(C) $3mc^2$
(D) $4mc^2$
(E) $5mc^2$

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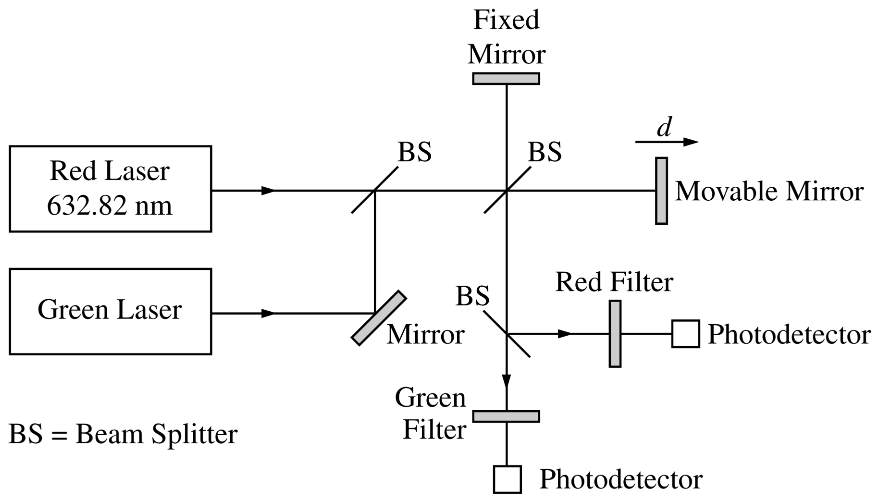

100. A Michelson interferometer is configured as a wavemeter, as shown in the figure above, so that a ratio of fringe counts may be used to compare the wavelengths of two lasers with high precision. When the mirror in the right arm of the interferometer is translated through a distance d, 100,000 interference fringes pass across the detector for green light and 85,865 fringes pass across the detector for red ($\lambda = 632.82$ nanometers) light. The wavelength of the green laser light is

(A) 500.33 nm
(B) 543.37 nm
(C) 590.19 nm
(D) 736.99 nm
(E) 858.65 nm

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I

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PRINT: ____
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SIGN: ____

6. TITLE CODE				
7	7	8	2	8

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TEST NAME Physics

FORM CODE GR0177

GRADUATE RECORD EXAMINATIONS SUBJECT TEST

B. The Subject Tests are intended to measure your achievement in a specialized field of study. Most of the questions are concerned with subject matter that is probably familiar to you, but some of the questions may refer to areas that you have not studied.

Your score will be determined by subtracting one-fourth the number of incorrect answers from the number of correct answers. Questions for which you mark no answer or more than one answer are not counted in scoring. If you have some knowledge of a question and are able to rule out one or more of the answer choices as incorrect, your chances of selecting the correct answer are improved, and answering such questions will likely improve your score. It is unlikely that pure guessing will raise your score; it may lower your score.

You are advised to use your time effectively and to work as rapidly as you can without losing accuracy. Do not spend too much time on questions that are too difficult for you. Go on to the other questions and come back to the difficult ones later if you can.

YOU MUST INDICATE ALL YOUR ANSWERS ON THE SEPARATE ANSWER SHEET. No credit will be given for anything written in this examination book, but you may write in the book as much as you wish to work out your answers. After you have decided on your response to a question, fill in the corresponding oval on the answer sheet. BE SURE THAT EACH MARK IS DARK AND COMPLETELY FILLS THE OVAL. Mark only one answer to each question. No credit will be given for multiple answers. Erase all stray marks. If you change an answer, be sure that all previous marks are erased completely. Incomplete erasures may be read as intended answers. Do not be concerned that the answer sheet provides spaces for more answers than there are questions in the test.

Example:

What city is the capital of France?

(A) Rome
(B) Paris
(C) London
(D) Cairo
(E) Oslo

Sample Answer

A ● C D E — CORRECT ANSWER PROPERLY MARKED

A B C D E
A B C D E
A B C D E
A B C D E
— IMPROPER MARKS

DO NOT OPEN YOUR TEST BOOK UNTIL YOU ARE TOLD TO DO SO.

Educational Testing Service

Educational Testing Service
Princeton, New Jersey 08541

Scoring Your Subject Test

Physics Test scores typically range from 450 to 950. The range for different editions of a given test may vary because different editions are not of precisely the same difficulty. The differences in ranges among different editions of a given test, however, usually are small. This should be taken into account, especially when comparing two very high scores. **The score conversion table on page 73 shows the score range for this edition of the test only.**

The worksheet on page 72 lists the correct answers to the questions. Columns are provided for you to mark whether you chose the correct (C) answer or an incorrect (I) answer to each question. Draw a line across any question you omitted, because it is not counted in the scoring. At the bottom of the page, enter the total number correct and the total number incorrect. Divide the total incorrect by 4 and subtract the resulting number from the total correct. This is the adjustment made for guessing. Then round the result to the nearest whole number. This will give you your raw total score. Use the total score conversion table to find the scaled total score that corresponds to your raw total score.

Example: Suppose you chose the correct answers to 44 questions and incorrect answers to 30. Dividing 30 by 4 yields 7.5. Subtracting 7.5 from 44 equals 36.5, which is rounded to 37. The raw score of 37 corresponds to a scaled score of 650.

Worksheet for the Physics Test, Form GR0177 Answer Key and Percentage* of Examinees Answering Each Question Correctly

QUESTION Number	Answer	P +	TOTAL C	I
1	C	54		
2	D	30		
3	D	71		
4	C	62		
5	D	28		
6	E	34		
7	B	89		
8	D	65		
9	A	63		
10	A	53		
11	A	28		
12	E	40		
13	B	42		
14	C	27		
15	A	68		
16	D	14		
17	B	81		
18	A	45		
19	B	36		
20	E	49		
21	B	60		
22	A	54		
23	C	45		
24	C	86		
25	E	48		
26	C	30		
27	A	82		
28	E	61		
29	C	63		
30	A	44		
31	A	53		
32	D	62		
33	D	31		
34	C	23		
35	E	82		
36	E	70		
37	D	36		
38	D	35		
39	D	45		
40	D	40		
41	E	66		
42	C	64		
43	D	39		
44	D	54		
45	B	50		
46	E	29		
47	B	46		
48	C	57		
49	E	61		
50	B	50		

QUESTION Number	Answer	P +	TOTAL C	I
51	B	45		
52	C	12		
53	B	32		
54	C	77		
55	E	62		
56	D	54		
57	A	68		
58	B	58		
59	B	87		
60	D	55		
61	C	18		
62	A	35		
63	D	52		
64	A	56		
65	D	44		
66	D	33		
67	E	19		
68	E	51		
69	B	26		
70	B	53		
71	D	32		
72	E	39		
73	D	43		
74	D	50		
75	E	57		
76	C	49		
77	E	44		
78	E	52		
79	D	69		
80	D	28		
81	B	50		
82	D	16		
83	C	30		
84	D	26		
85	A	25		
86	E	24		
87	A	42		
88	C	42		
89	E	37		
90	A	33		
91	B	41		
92	E	45		
93	C	42		
94	E	29		
95	A	42		
96	E	13		
97	E	20		
98	A	72		
99	D	20		
100	B	72		

Correct (C) ______________________

Incorrect (I) ______________________

Total Score:

C – I/4 = ____________

Scaled Score (SS) = ____________

* The P+ column indicates the percent of Physics Test examinees who answered each question correctly; it is based on a sample of November 2001 examinees selected to represent all Physics Test examinees tested between July 1, 2000, and June 30, 2003.

Score Conversions and Percents Below*
for GRE Physics Test, Form GR0177

TOTAL SCORE					
Raw Score	Scaled Score	%	Raw Score	Scaled Score	%
85-100	990	98	43	690	57
84	980	97	41-42	680	54
82-83	970	97	40	670	53
81	960	96	38-39	660	50
80	950	95	37	650	48
78-79	940	95	35-36	640	45
77	930	94	34	630	44
75-76	920	92	33	620	41
74	910	91	31-32	610	39
73	900	90	30	600	37
71-72	890	89	28-29	590	34
70	880	88	27	580	32
68-69	870	87	26	570	29
67	860	86	24-25	560	27
65-66	850	84	23	550	25
64	840	83	21-22	540	22
63	830	82	20	530	20
61-62	820	81	18-19	520	18
60	810	79	17	510	16
58-59	800	78	16	500	13
57	790	76	14-15	490	11
55-56	780	74	13	480	10
54	770	72	11-12	470	7
53	760	71	10	460	6
51-52	750	69	8-9	450	5
50	740	67	7	440	4
48-49	730	65	6	430	3
47	720	63	4-5	420	1
45-46	710	61	3	410	1
44	700	59	1-2	400	1
			0	390	1

*The percent scoring below the scaled score is based on the performance of 10,947 examinees who took the Physics Test between July 1, 2000, and June 30, 2003.

Evaluating Your Performance

Now that you have scored your test, you may wish to compare your performance with the performance of others who took this test. Both the worksheet on page 72 and the table on page 73 use performance data from GRE Physics Test examinees.

The data in the worksheet on page 72 are based on the performance of a sample of the examinees who took this test in November 2001. This sample was selected to represent the total population of GRE Physics Test examinees tested between July 1, 2000, and June 30, 2003. The numbers in the column labeled "P+" on the worksheet indicate the percentages of examinees in this sample who answered the questions correctly. You may use these numbers as a guide for evaluating your performance on each test question.

The table on page 73 contains, for each scaled score, the percentage of examinees tested between July 1, 2000, and June 30, 2003 who received lower scores. Interpretive data based on the scores earned by examinees tested in this three-year period will be used by admissions officers in the 2004-05 testing year. These percentages appear in the score conversion table in a column to the right of the scaled scores. For example, in the percentage column opposite the scaled score of 660 is the number 50. This means that 50 percent of the GRE Physics Test examinees tested between July 1, 2000, and June 30, 2003 scored lower than 660. To compare yourself with this population, look at the percentage next to the scaled score you earned on the practice test. Note: due to changes in the test-taking population, the percentile rank data changes over time. Percentile rank information is kept current on the GRE Web site and may be obtained by visiting the GRE Web site at www.gre.org/codelst.html, or by contacting the GRE Program.

It is important to realize that the conditions under which you tested yourself were not exactly the same as those you will encounter at a test center. It is impossible to predict how different test-taking conditions will affect test performance, and this is only one factor that may account for differences between your practice test scores and your actual test scores. By comparing your performance on this practice test with the performance of other GRE Physics Test examinees, however, you will be able to determine your strengths and weaknesses and can then plan a program of study to prepare yourself for taking the GRE Physics Test under standard conditions.

DO NOT USE INK

Use only a pencil with soft, black lead (No. 2 or HB) to complete this answer sheet.
Be sure to fill in completely the space that corresponds to your answer choice.
Completely erase any errors or stray marks.

GRADUATE RECORD EXAMINATIONS® - GRE® - SUBJECT TEST

SIDE 1

1. NAME

Enter your last name, first name initial (given name), and middle initial if you have one. Omit spaces, apostrophes, Jr., II., etc.

Last Name only (Family or Surname) - first 15 letters | First Name Initial | Middle Initial

(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) (-)

BE SURE EACH MARK IS DARK AND COMPLETELY FILLS THE INTENDED SPACE AS ILLUSTRATED HERE: ●.
YOU MAY FIND MORE RESPONSE SPACES THAN YOU NEED. IF SO, PLEASE LEAVE THEM BLANK.

1 (A) (B) (C) (D) (E)	39 (A) (B) (C) (D) (E)	77 (A) (B) (C) (D) (E)
2 (A) (B) (C) (D) (E)	40 (A) (B) (C) (D) (E)	78 (A) (B) (C) (D) (E)
3 (A) (B) (C) (D) (E)	41 (A) (B) (C) (D) (E)	79 (A) (B) (C) (D) (E)
4 (A) (B) (C) (D) (E)	42 (A) (B) (C) (D) (E)	80 (A) (B) (C) (D) (E)
5 (A) (B) (C) (D) (E)	43 (A) (B) (C) (D) (E)	81 (A) (B) (C) (D) (E)
6 (A) (B) (C) (D) (E)	44 (A) (B) (C) (D) (E)	82 (A) (B) (C) (D) (E)
7 (A) (B) (C) (D) (E)	45 (A) (B) (C) (D) (E)	83 (A) (B) (C) (D) (E)
8 (A) (B) (C) (D) (E)	46 (A) (B) (C) (D) (E)	84 (A) (B) (C) (D) (E)
9 (A) (B) (C) (D) (E)	47 (A) (B) (C) (D) (E)	85 (A) (B) (C) (D) (E)
10 (A) (B) (C) (D) (E)	48 (A) (B) (C) (D) (E)	86 (A) (B) (C) (D) (E)
11 (A) (B) (C) (D) (E)	49 (A) (B) (C) (D) (E)	87 (A) (B) (C) (D) (E)
12 (A) (B) (C) (D) (E)	50 (A) (B) (C) (D) (E)	88 (A) (B) (C) (D) (E)
13 (A) (B) (C) (D) (E)	51 (A) (B) (C) (D) (E)	89 (A) (B) (C) (D) (E)
14 (A) (B) (C) (D) (E)	52 (A) (B) (C) (D) (E)	90 (A) (B) (C) (D) (E)
15 (A) (B) (C) (D) (E)	53 (A) (B) (C) (D) (E)	91 (A) (B) (C) (D) (E)
16 (A) (B) (C) (D) (E)	54 (A) (B) (C) (D) (E)	92 (A) (B) (C) (D) (E)
17 (A) (B) (C) (D) (E)	55 (A) (B) (C) (D) (E)	93 (A) (B) (C) (D) (E)
18 (A) (B) (C) (D) (E)	56 (A) (B) (C) (D) (E)	94 (A) (B) (C) (D) (E)
19 (A) (B) (C) (D) (E)	57 (A) (B) (C) (D) (E)	95 (A) (B) (C) (D) (E)
20 (A) (B) (C) (D) (E)	58 (A) (B) (C) (D) (E)	96 (A) (B) (C) (D) (E)
21 (A) (B) (C) (D) (E)	59 (A) (B) (C) (D) (E)	97 (A) (B) (C) (D) (E)
22 (A) (B) (C) (D) (E)	60 (A) (B) (C) (D) (E)	98 (A) (B) (C) (D) (E)
23 (A) (B) (C) (D) (E)	61 (A) (B) (C) (D) (E)	99 (A) (B) (C) (D) (E)
24 (A) (B) (C) (D) (E)	62 (A) (B) (C) (D) (E)	100 (A) (B) (C) (D) (E)
25 (A) (B) (C) (D) (E)	63 (A) (B) (C) (D) (E)	101 (A) (B) (C) (D) (E)
26 (A) (B) (C) (D) (E)	64 (A) (B) (C) (D) (E)	102 (A) (B) (C) (D) (E)
27 (A) (B) (C) (D) (E)	65 (A) (B) (C) (D) (E)	103 (A) (B) (C) (D) (E)
28 (A) (B) (C) (D) (E)	66 (A) (B) (C) (D) (E)	104 (A) (B) (C) (D) (E)
29 (A) (B) (C) (D) (E)	67 (A) (B) (C) (D) (E)	105 (A) (B) (C) (D) (E)
30 (A) (B) (C) (D) (E)	68 (A) (B) (C) (D) (E)	106 (A) (B) (C) (D) (E)
31 (A) (B) (C) (D) (E)	69 (A) (B) (C) (D) (E)	107 (A) (B) (C) (D) (E)
32 (A) (B) (C) (D) (E)	70 (A) (B) (C) (D) (E)	108 (A) (B) (C) (D) (E)
33 (A) (B) (C) (D) (E)	71 (A) (B) (C) (D) (E)	109 (A) (B) (C) (D) (E)
34 (A) (B) (C) (D) (E)	72 (A) (B) (C) (D) (E)	110 (A) (B) (C) (D) (E)
35 (A) (B) (C) (D) (E)	73 (A) (B) (C) (D) (E)	111 (A) (B) (C) (D) (E)
36 (A) (B) (C) (D) (E)	74 (A) (B) (C) (D) (E)	112 (A) (B) (C) (D) (E)
37 (A) (B) (C) (D) (E)	75 (A) (B) (C) (D) (E)	113 (A) (B) (C) (D) (E)
38 (A) (B) (C) (D) (E)	76 (A) (B) (C) (D) (E)	114 (A) (B) (C) (D) (E)

Item responses continued on reverse side.

2.

YOUR NAME: ____________________
(Print) Last Name (Family or Surname) First Name (Given) M.I.

MAILING ADDRESS: ____________________
(Print) P.O. Box or Street Address

City State or Province

Country Zip or Postal Code

CENTER: ____________________
City State or Province

Country Center Number Room Number

SIGNATURE: ____________________

3. DATE OF BIRTH

Month	Day	Year
Jan.		
Feb.		
Mar.	0 0	0 0
April	1 1	1 1
May	2 2	2 2
June	3 3	3 3
July	4	4 4
Aug.	5	5 5
Sept.	6	6 6
Oct.	7	7 7
Nov.	8	8 8
Dec.	9	9

4. SOCIAL SECURITY NUMBER
(U.S.A. only)

5. REGISTRATION NUMBER
(from your admission ticket)

6. TITLE CODE
(on back cover of your test book)

7. TEST NAME (on back cover of your test book)

FORM CODE (on back cover of your test book)

8. TEST BOOK SERIAL NUMBER
(red number in upper right corner of front cover of your test book)

SHADED AREA FOR ETS USE ONLY

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SIDE 2

SUBJECT TEST

COMPLETE THE CERTIFICATION STATEMENT, THEN TURN ANSWER SHEET OVER TO SIDE 1.

CERTIFICATION STATEMENT

Please write the following statement below, DO NOT PRINT.
"I certify that I am the person whose name appears on this answer sheet. I also agree not to disclose the contents of the test I am taking today to anyone."
Sign and date where indicated.

____

____

____

____

____

SIGNATURE: ______________________________ DATE: ____/____/____
Month Day Year

BE SURE EACH MARK IS DARK AND COMPLETELY FILLS THE INTENDED SPACE AS ILLUSTRATED HERE: ●.
YOU MAY FIND MORE RESPONSE SPACES THAN YOU NEED. IF SO, PLEASE LEAVE THEM BLANK.

115	A	B	C	D	E	147	A	B	C	D	E	179	A	B	C	D	E	211	A	B	C	D	E
116	A	B	C	D	E	148	A	B	C	D	E	180	A	B	C	D	E	212	A	B	C	D	E
117	A	B	C	D	E	149	A	B	C	D	E	181	A	B	C	D	E	213	A	B	C	D	E
118	A	B	C	D	E	150	A	B	C	D	E	182	A	B	C	D	E	214	A	B	C	D	E
119	A	B	C	D	E	151	A	B	C	D	E	183	A	B	C	D	E	215	A	B	C	D	E
120	A	B	C	D	E	152	A	B	C	D	E	184	A	B	C	D	E	216	A	B	C	D	E
121	A	B	C	D	E	153	A	B	C	D	E	185	A	B	C	D	E	217	A	B	C	D	E
122	A	B	C	D	E	154	A	B	C	D	E	186	A	B	C	D	E	218	A	B	C	D	E
123	A	B	C	D	E	155	A	B	C	D	E	187	A	B	C	D	E	219	A	B	C	D	E
124	A	B	C	D	E	156	A	B	C	D	E	188	A	B	C	D	E	220	A	B	C	D	E
125	A	B	C	D	E	157	A	B	C	D	E	189	A	B	C	D	E	221	A	B	C	D	E
126	A	B	C	D	E	158	A	B	C	D	E	190	A	B	C	D	E	222	A	B	C	D	E
127	A	B	C	D	E	159	A	B	C	D	E	191	A	B	C	D	E	223	A	B	C	D	E
128	A	B	C	D	E	160	A	B	C	D	E	192	A	B	C	D	E	224	A	B	C	D	E
129	A	B	C	D	E	161	A	B	C	D	E	193	A	B	C	D	E	225	A	B	C	D	E
130	A	B	C	D	E	162	A	B	C	D	E	194	A	B	C	D	E	226	A	B	C	D	E
131	A	B	C	D	E	163	A	B	C	D	E	195	A	B	C	D	E	227	A	B	C	D	E
132	A	B	C	D	E	164	A	B	C	D	E	196	A	B	C	D	E	228	A	B	C	D	E
133	A	B	C	D	E	165	A	B	C	D	E	197	A	B	C	D	E	229	A	B	C	D	E
134	A	B	C	D	E	166	A	B	C	D	E	198	A	B	C	D	E	230	A	B	C	D	E
135	A	B	C	D	E	167	A	B	C	D	E	199	A	B	C	D	E	231	A	B	C	D	E
136	A	B	C	D	E	168	A	B	C	D	E	200	A	B	C	D	E	232	A	B	C	D	E
137	A	B	C	D	E	169	A	B	C	D	E	201	A	B	C	D	E	233	A	B	C	D	E
138	A	B	C	D	E	170	A	B	C	D	E	202	A	B	C	D	E	234	A	B	C	D	E
139	A	B	C	D	E	171	A	B	C	D	E	203	A	B	C	D	E	235	A	B	C	D	E
140	A	B	C	D	E	172	A	B	C	D	E	204	A	B	C	D	E	236	A	B	C	D	E
141	A	B	C	D	E	173	A	B	C	D	E	205	A	B	C	D	E	237	A	B	C	D	E
142	A	B	C	D	E	174	A	B	C	D	E	206	A	B	C	D	E	238	A	B	C	D	E
143	A	B	C	D	E	175	A	B	C	D	E	207	A	B	C	D	E	239	A	B	C	D	E
144	A	B	C	D	E	176	A	B	C	D	E	208	A	B	C	D	E	240	A	B	C	D	E
145	A	B	C	D	E	177	A	B	C	D	E	209	A	B	C	D	E	241	A	B	C	D	E
146	A	B	C	D	E	178	A	B	C	D	E	210	A	B	C	D	E	242	A	B	C	D	E

TR	TW	TFS	TCS	1R	1W	1FS	1CS	2R	2W	2FS	2CS
FOR ETS USE ONLY				3R	3W	3FS	3CS	4R	4W	4FS	4CS
				5R	5W	5FS	5CS	6R	6W	6FS	6CS

IF YOU DO NOT WANT THIS ANSWER SHEET TO BE SCORED

If you want to cancel your scores from this administration, complete A and B below. You will not receive scores for this test; however, you will receive confirmation of this cancellation. No record of this test or the cancellation will be sent to the recipients you indicated, and there will be no scores for this test on your GRE file. Once a score is canceled, it cannot be reinstated.

To cancel your scores from this test administration, you must:

A. fill in both ovals here . . . ◯ – ◯ B. sign your full name here: ______________

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