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GRE®

Graduate Record Examinations®

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.

ETS®
Educational Testing Service

Visit GRE Online at **www.gre.org**

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

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 are 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 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.

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. In each category, the subtopics are listed roughly in order of decreasing importance for inclusion in the test. 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 range 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	75	71	60-61
800	61	57	45
700	47	43-44	33
600	33-34	29-30	22
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 47 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
47	47	0	53	100
47	52	20	28	100
47	57	40	3	100

Practice Test

To become familiar with how the administration will be conducted at the test center, first remove the answer sheet (pages 77 and 78). Then go to the back cover of the test book (page 72) 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 GR9677

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GRE®

THE GRADUATE RECORD EXAMINATIONS®

PHYSICS TEST

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

The contents of this test are confidential. Disclosure or reproduction of any portion of it is prohibited.

THIS TEST BOOK MUST NOT BE TAKEN FROM THE ROOM.

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	$N_0 = 6.02 \times 10^{23}$ per mole
Universal gas constant	$R = 8.31$ joules/(mole $\cdot$ 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 $\cdot$ second $= 4.14 \times 10^{-15}$ eV $\cdot$ second
	$\hbar = h/2\pi$
Vacuum permittivity	$\epsilon_0 = 8.85 \times 10^{-12}$ coulomb^2/(newton $\cdot$ meter^2)
Vacuum permeability	$\mu_0 = 4\pi \times 10^{-7}$ weber/(ampere $\cdot$ meter)
Universal gravitational constant	$G = 6.67 \times 10^{-11}$ meter^3/(kilogram $\cdot$ second^2)
Acceleration due to gravity	$g = 9.80$ m/s^2 $= 980$ cm/s^2
1 atmosphere pressure	1 atm $= 1.0 \times 10^{5}$ newton/meter^2 $= 1.0 \times 10^{5}$ pascals (Pa)
1 angstrom	1 Å $= 1 \times 10^{-10}$ 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.

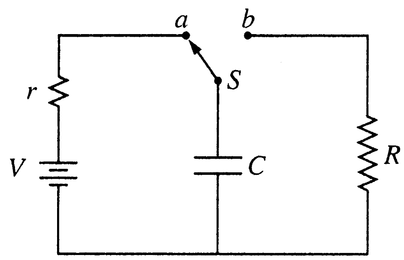


Figure 1

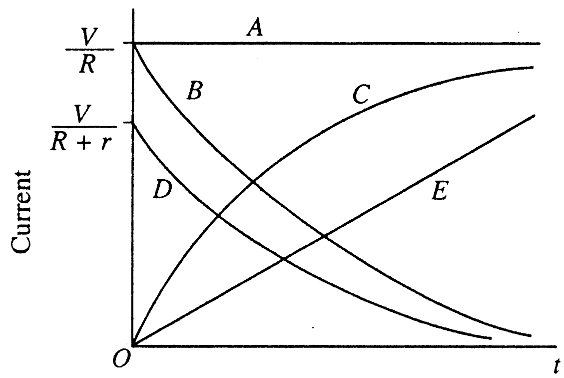
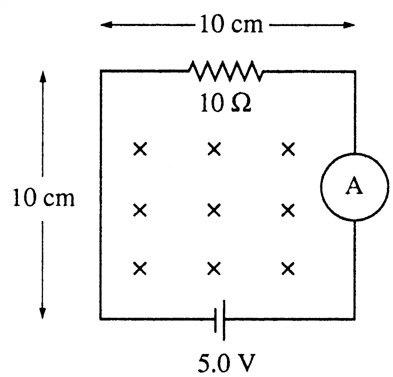


Figure 2

1. The capacitor shown in Figure 1 above is charged by connecting switch S to contact a. If switch S is thrown to contact b at time $t = 0$, which of the curves in Figure 2 above represents the magnitude of the current through the resistor R as a function of time?

(A) A
(B) B
(C) C
(D) D
(E) E



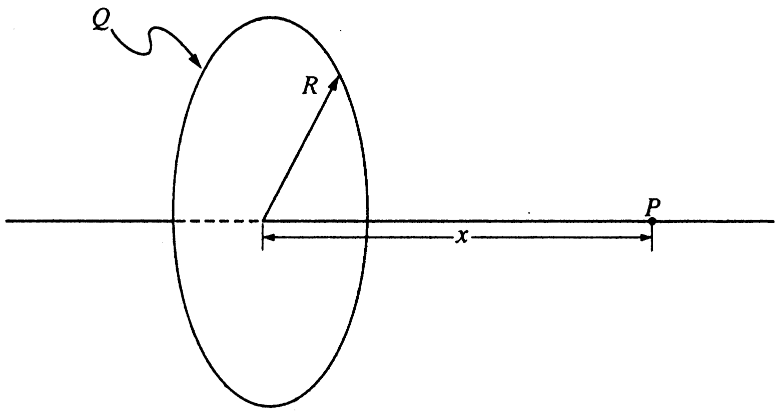
2. The circuit shown above is in a uniform magnetic field that is into the page and is decreasing in magnitude at the rate of 150 tesla/second. The ammeter reads

(A) 0.15 A
(B) 0.35 A
(C) 0.50 A
(D) 0.65 A
(E) 0.80 A

GO ON TO THE NEXT PAGE.

SCRATCHWORK

Questions 3-4 refer to a thin, nonconducting ring of radius R, as shown below, which has a charge Q uniformly spread out on it.



3. The electric potential at a point P, which is located on the axis of symmetry a distance x from the center of the ring, is given by

(A) $\dfrac{Q}{4\pi\varepsilon_0 x}$

(B) $\dfrac{Q}{4\pi\varepsilon_0\sqrt{R^2 + x^2}}$

(C) $\dfrac{Qx}{4\pi\varepsilon_0(R^2 + x^2)}$

(D) $\dfrac{Qx}{4\pi\varepsilon_0(R^2 + x^2)^{3/2}}$

(E) $\dfrac{QR}{4\pi\varepsilon_0(R^2 + x^2)}$

4. A small particle of mass m and charge $-q$ is placed at point P and released. If $R >> x$, the particle will undergo oscillations along the axis of symmetry with an angular frequency that is equal to

(A) $\sqrt{\dfrac{qQ}{4\pi\varepsilon_0 mR^3}}$

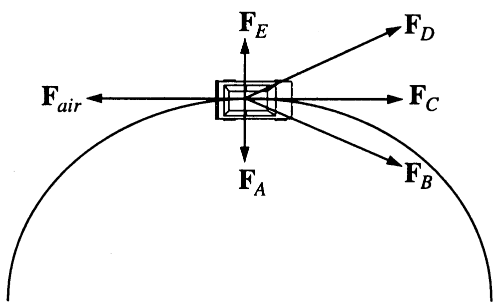
(B) $\sqrt{\dfrac{qQx}{4\pi\varepsilon_0 mR^4}}$

(C) $\dfrac{qQ}{4\pi\varepsilon_0 mR^3}$

(D) $\dfrac{qQx}{4\pi\varepsilon_0 mR^4}$

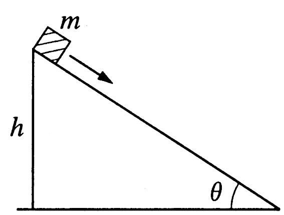
(E) $\sqrt{\dfrac{qQx}{4\pi\varepsilon_0 m}}\dfrac{1}{R^2 + x^2}$

SCRATCHWORK



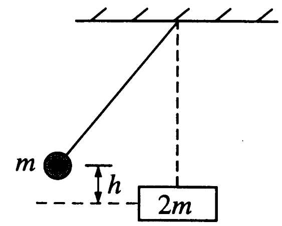
5. A car travels with constant speed on a circular road on level ground. In the diagram above, $\mathbf{F}_{air}$ is the force of air resistance on the car. Which of the other forces shown best represents the horizontal force of the road on the car's tires?

(A) $\mathbf{F}_A$
(B) $\mathbf{F}_B$
(C) $\mathbf{F}_C$
(D) $\mathbf{F}_D$
(E) $\mathbf{F}_E$



6. A block of mass m sliding down an incline at constant speed is initially at a height h above the ground, as shown in the figure above. The coefficient of kinetic friction between the mass and the incline is μ. If the mass continues to slide down the incline at a constant speed, how much energy is dissipated by friction by the time the mass reaches the bottom of the incline?

(A) mgh/μ
(B) mgh
(C) $\mu mgh/\sin\theta$
(D) $mgh\sin\theta$
(E) 0



7. As shown above, a ball of mass m, suspended on the end of a wire, is released from height h and collides elastically, when it is at its lowest point, with a block of mass $2m$ at rest on a frictionless surface. After the collision, the ball rises to a final height equal to

(A) 1/9 h
(B) 1/8 h
(C) 1/3 h
(D) 1/2 h
(E) 2/3 h

8. A particle of mass m undergoes harmonic oscillation with period T_0. A force f proportional to the speed v of the particle, $f = -bv$, is introduced. If the particle continues to oscillate, the period with f acting is

(A) larger than T_0
(B) smaller than T_0
(C) independent of b
(D) dependent linearly on b
(E) constantly changing

9. In the spectrum of hydrogen, what is the ratio of the longest wavelength in the Lyman series ($n_f = 1$) to the longest wavelength in the Balmer series ($n_f = 2$) ?

(A) 5/27
(B) 1/3
(C) 4/9
(D) 3/2
(E) 3

GO ON TO THE NEXT PAGE.

SCRATCHWORK

10. Internal conversion is the process whereby an excited nucleus transfers its energy directly to one of the most tightly bound atomic electrons, causing the electron to be ejected from the atom and leaving the atom in an excited state. The most probable process after an internal conversion electron is ejected from an atom with a high atomic number is that the

(A) atom returns to its ground state through inelastic collisions with other atoms
(B) atom emits one or several x-rays
(C) nucleus emits a γ-ray
(D) nucleus emits an electron
(E) nucleus emits a positron

11. A beam of neutral hydrogen atoms in their ground state is moving into the plane of this page and passes through a region of a strong inhomogeneous magnetic field that is directed upward in the plane of the page. After the beam passes through this field, a detector would find that it has been

(A) deflected upward
(B) deflected to the right
(C) undeviated
(D) split vertically into two beams
(E) split horizontally into three beams

12. The ground-state energy of positronium is most nearly equal to

(A) −27.2 eV
(B) −13.6 eV
(C) −6.8 eV
(D) −3.4 eV
(E) 13.6 eV

13. A 100-watt electric heating element is placed in a pan containing one liter of water. Although the heating element is on for a long time, the water, though close to boiling, does not boil. When the heating element is removed, approximately how long will it take the water to cool by 1° C ? (Assume that the specific heat for water is 4.2 kilojoules/kilogram °C.)

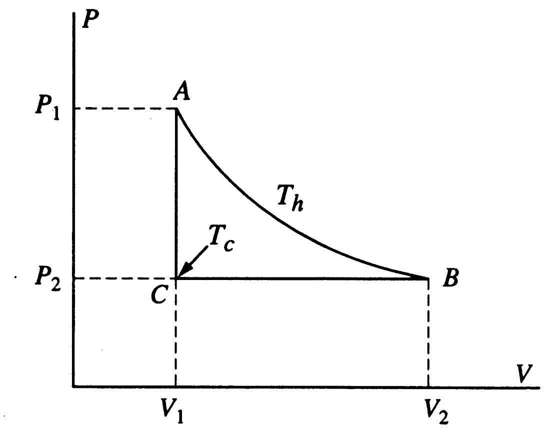
(A) 20 s
(B) 40 s
(C) 60 s
(D) 130 s
(E) 200 s

14. Two identical 1.0-kilogram blocks of copper metal, one initially at a temperature $T_1 = 0°$ C and the other initially at a temperature $T_2 = 100°$ C, are enclosed in a perfectly insulating container. The two blocks are initially separated. When the blocks are placed in contact, they come to equilibrium at a final temperature T_f. The amount of heat exchanged between the two blocks in this process is equal to which of the following? (The specific heat of copper metal is equal to 0.1 kilocalorie/kilogram °K.)

(A) 50 kcal
(B) 25 kcal
(C) 10 kcal
(D) 5 kcal
(E) 1 kcal

GO ON TO THE NEXT PAGE.

SCRATCHWORK



15. Suppose one mole of an ideal gas undergoes the reversible cycle $ABCA$ shown in the P-V diagram above, where AB is an isotherm. The molar heat capacities are C_p at constant pressure and C_v at constant volume. The net heat added to the gas during the cycle is equal to

(A) $RT_h V_2/V_1$

(B) $-C_p(T_h - T_c)$

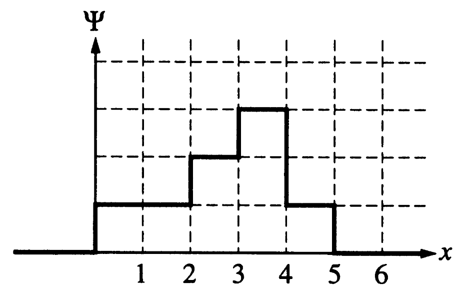
(C) $C_v(T_h - T_c)$

(D) $RT_h \ln V_2/V_1 - C_p(T_h - T_c)$

(E) $RT_h \ln V_2/V_1 - R(T_h - T_c)$

16. The mean free path for the molecules of a gas is approximately given by $\frac{1}{\eta\sigma}$, where η is the number density and σ is the collision cross section. The mean free path for air molecules at room conditions is approximately

(A) 10^{-4} m
(B) 10^{-7} m
(C) 10^{-10} m
(D) 10^{-13} m
(E) 10^{-16} m



17. The wave function for a particle constrained to move in one dimension is shown in the graph above ($\Psi = 0$ for $x \leq 0$ and $x \geq 5$). What is the probability that the particle would be found between $x = 2$ and $x = 4$?

(A) 17/64

(B) 25/64

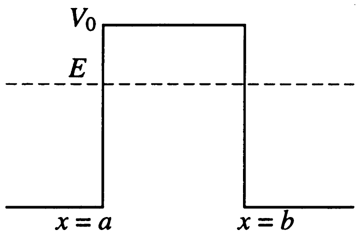
(C) 5/8

(D) $\sqrt{5/8}$

(E) 13/16

GO ON TO THE NEXT PAGE.

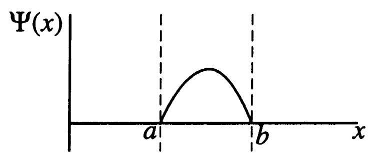
SCRATCHWORK

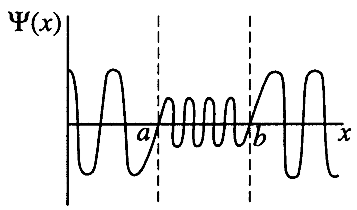


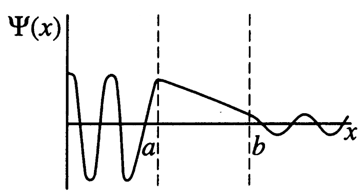
18. Consider a potential of the form

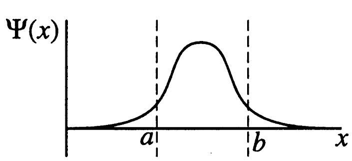
$$V(x) = 0,\ x \le a$$
$$V(x) = V_0,\ a < x < b$$
$$V(x) = 0,\ x \ge b$$

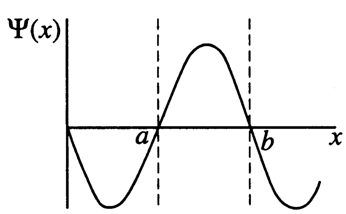
as shown in the figure above. Which of the following wave functions is possible for a particle incident from the left with energy $E < V_0$?

(A)


(B)


(C)


(D)


(E)


19. When alpha particles are directed onto atoms in a thin metal foil, some make very close collisions with the nuclei of the atoms and are scattered at large angles. If an alpha particle with an initial kinetic energy of 5 MeV happens to be scattered through an angle of 180°, which of the following must have been its distance of closest approach to the scattering nucleus? (Assume that the metal foil is made of silver, with $Z = 50$.)

(A) $1.22 \times 50^{1/3}$ fm
(B) 2.9×10^{-14} m
(C) 1.0×10^{-12} m
(D) 3.0×10^{-8} m
(E) 1.7×10^{-7} m

20. A helium atom, mass 4u, travels with nonrelativistic speed v normal to the surface of a certain material, makes an elastic collision with an (essentially free) surface atom, and leaves in the opposite direction with speed $0.6v$. The atom on the surface must be an atom of

(A) hydrogen, mass 1u
(B) helium, mass 4u
(C) carbon, mass 12u
(D) oxygen, mass 16u
(E) silicon, mass 28u

GO ON TO THE NEXT PAGE.

SCRATCHWORK

21. The period of a physical pendulum is $2\pi\sqrt{I/mgd}$, where I is the moment of inertia about the pivot point and d is the distance from the pivot to the center of mass. A circular hoop hangs from a nail on a barn wall. The mass of the hoop is 3 kilograms and its radius is 20 centimeters. If it is displaced slightly by a passing breeze, what is the period of the resulting oscillations?

(A) 0.63 s
(B) 1.0 s
(C) 1.3 s
(D) 1.8 s
(E) 2.1 s

22. The curvature of Mars is such that its surface drops a vertical distance of 2.0 meters for every 3600 meters tangent to the surface. In addition, the gravitational acceleration near its surface is 0.4 times that near the surface of Earth. What is the speed a golf ball would need to orbit Mars near the surface, ignoring the effects of air resistance?

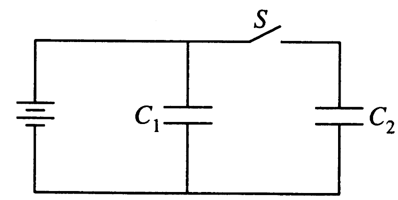
(A) 0.9 km/s
(B) 1.8 km/s
(C) 3.6 km/s
(D) 4.5 km/s
(E) 5.4 km/s

23. Suppose that the gravitational force law between two massive objects were $\mathbf{F}_{12} = \hat{\mathbf{r}}_{12}Gm_1m_2/r_{12}^{2+\epsilon}$, where ϵ is a small positive number. Which of the following statements would be FALSE?

(A) The total mechanical energy of the planet-Sun system would be conserved.
(B) The angular momentum of a single planet moving about the Sun would be conserved.
(C) The periods of planets in circular orbits would be proportional to the $(3 + \epsilon)/2$ power of their respective orbital radii.
(D) A single planet could move in a stationary noncircular elliptical orbit about the Sun.
(E) A single planet could move in a stationary circular orbit about the Sun.

24. Two identical conducting spheres, A and B, carry equal charge. They are initially separated by a distance much larger than their diameters, and the force between them is F. A third identical conducting sphere, C, is uncharged. Sphere C is first touched to A, then to B, and then removed. As a result, the force between A and B is equal to

(A) 0
(B) $F/16$
(C) $F/4$
(D) $3F/8$
(E) $F/2$



25. Two real capacitors of equal capacitance ($C_1 = C_2$) are shown in the figure above. Initially, while the switch S is open, one of the capacitors is uncharged and the other carries charge Q_0. The energy stored in the charged capacitor is U_0. Sometime after the switch is closed, the capacitors C_1 and C_2 carry charges Q_1 and Q_2, respectively; the voltages across the capacitors are V_1 and V_2; and the energies stored in the capacitors are U_1 and U_2. Which of the following statements is INCORRECT?

(A) $Q_0 = \frac{1}{2}(Q_1 + Q_2)$

(B) $Q_1 = Q_2$

(C) $V_1 = V_2$

(D) $U_1 = U_2$

(E) $U_0 = U_1 + U_2$

26. A series RLC circuit is used in a radio to tune to an FM station broadcasting at 103.7 MHz. The resistance in the circuit is 10 ohms and the inductance is 2.0 microhenries. What is the best estimate of the capacitance that should be used?

(A) 200 pF
(B) 50 pF
(C) 1 pF
(D) 0.2 pF
(E) 0.02 pF

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SCRATCHWORK

27. In laboratory experiments, graphs are employed to determine how one measured variable depends on another. These graphs generally fall into three categories: linear, semilog (logarithmic *versus* linear), and log-log. Which type of graph listed in the third column below would NOT be the best for plotting data to test the relationship given in the first and second columns?

Relation	Variables Plotted	Type of Graph
(A) $dN/dt \propto e^{-2t}$	Activity *vs*. time for a radioactive isotope	Semilog
(B) $eV_s = hf - W$	Stopping potential *vs*. frequency for the photoelectric effect	Linear
(C) $s \propto t^2$	Distance *vs*. time for an object undergoing constant acceleration	Log-log
(D) $V_{out}/V_{in} \propto 1/\omega$	Gain *vs*. frequency for a low-pass filter	Linear
(E) $P \propto T^4$	Power radiated *vs*. temperature for blackbody radiation	Log-log

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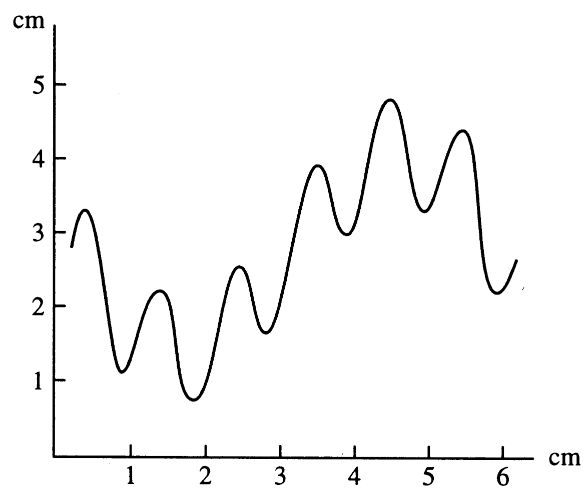

28. The figure above represents the trace on the screen of a cathode ray oscilloscope. The screen is graduated in centimeters. The spot on the screen moves horizontally with a constant speed of 0.5 centimeter/millisecond, and the vertical scale is 2 volts/centimeter. The signal is a superposition of two oscillations. Which of the following are most nearly the observed amplitude and frequency of these two oscillations?

	Oscillation 1	Oscillation 2
(A)	5V, 250Hz	2.5V, 1000Hz
(B)	1.5V, 250Hz	3V, 1500Hz
(C)	5V, 6Hz	2V, 2Hz
(D)	2.5V, 83Hz	1.25V, 500Hz
(E)	6.14V, 98Hz	1.35V, 257Hz

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SCRATCHWORK

29. The characteristic distance at which quantum gravitational effects are significant, the Planck length, can be determined from a suitable combination of the physical constants G, $\hbar$, and c. Which of the following correctly gives the Planck length?

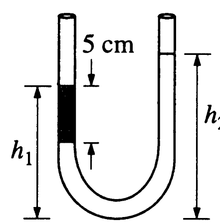
(A) $G\hbar c$

(B) $G\hbar^2 c^3$

(C) $G^2\hbar c$

(D) $G^{\frac{1}{2}}\hbar^2 c$

(E) $(G\hbar/c^3)^{\frac{1}{2}}$



30. An open-ended U-tube of uniform cross-sectional area contains water (density 1.0 gram/centimeter^3) standing initially 20 centimeters from the bottom in each arm. An immiscible liquid of density 4.0 grams/centimeter^3 is added to one arm until a layer 5 centimeters high forms, as shown in the figure above. What is the ratio h_2/h_1 of the heights of the liquid in the two arms?

(A) 3/1
(B) 5/2
(C) 2/1
(D) 3/2
(E) 1/1

31. A sphere of mass m is released from rest in a stationary viscous medium. In addition to the gravitational force of magnitude mg, the sphere experiences a retarding force of magnitude bv, where v is the speed of the sphere and b is a constant. Assume that the buoyant force is negligible. Which of the following statements about the sphere is correct?

(A) Its kinetic energy decreases due to the retarding force.
(B) Its kinetic energy increases to a maximum, then decreases to zero due to the retarding force.
(C) Its speed increases to a maximum, then decreases back to a final terminal speed.
(D) Its speed increases monotonically, approaching a terminal speed that depends on b but not on m.
(E) Its speed increases monotonically, approaching a terminal speed that depends on both b and m.

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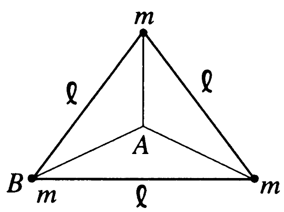
SCRATCHWORK



32. Three equal masses m are rigidly connected to each other by massless rods of length ℓ forming an equilateral triangle, as shown above. The assembly is to be given an angular velocity ω about an axis perpendicular to the triangle. For fixed ω, the ratio of the kinetic energy of the assembly for an axis through B compared with that for an axis through A is equal to

    (A) 3
    (B) 2
    (C) 1
    (D) 1/2
    (E) 1/3

33. A diatomic molecule is initially in the state $\Psi(\Theta, \Phi) = (5Y_1^{\,1} + 3Y_5^{\,1} + 2Y_5^{\,-1})/(38)^{1/2}$, where $Y_\ell^{\,m}$ is a spherical harmonic. If measurements are made of the total angular momentum quantum number ℓ and of the azimuthal angular momentum quantum number m, what is the probability of obtaining the result $\ell = 5$?

    (A) 36/1444
    (B) 9/38
    (C) 13/38
    (D) $5/(38)^{1/2}$
    (E) 34/38

34. When the beta-decay of ^{60}Co nuclei is observed at low temperatures in a magnetic field that aligns the spins of the nuclei, it is found that the electrons are emitted preferentially in a direction opposite to the ^{60}Co spin direction. Which of the following invariances is violated by this decay?

    (A) Gauge invariance
    (B) Time invariance
    (C) Translation invariance
    (D) Reflection invariance
    (E) Rotation invariance

35. The wave function for identical fermions is anti-symmetric under particle interchange. Which of the following is a consequence of this property?

    (A) Pauli exclusion principle
    (B) Bohr correspondence principle
    (C) Heisenberg uncertainty principle
    (D) Bose-Einstein condensation
    (E) Fermi's golden rule

36. A lump of clay whose rest mass is 4 kilograms is traveling at three-fifths the speed of light when it collides head-on with an identical lump going the opposite direction at the same speed. If the two lumps stick together and no energy is radiated away, what is the mass of the composite lump?

    (A) 4 kg
    (B) 6.4 kg
    (C) 8 kg
    (D) 10 kg
    (E) 13.3 kg

37. An atom moving at speed $0.3c$ emits an electron along the same direction with speed $0.6c$ in the internal rest frame of the atom. The speed of the electron in the lab frame is equal to

    (A) $0.25c$
    (B) $0.51c$
    (C) $0.66c$
    (D) $0.76c$
    (E) $0.90c$

38. What is the speed of a particle having a momentum of 5 MeV/c and a total relativistic energy of 10 MeV ?

    (A) c
    (B) $0.75\,c$
    (C) $\frac{1}{\sqrt{3}}\,c$
    (D) $\frac{1}{2}\,c$
    (E) $\frac{1}{4}\,c$

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SCRATCHWORK

39. Which of the following atoms has the lowest ionization potential?

(A) $^{2}_{4}\text{He}$

(B) $^{7}_{14}\text{N}$

(C) $^{8}_{16}\text{O}$

(D) $^{18}_{40}\text{Ar}$

(E) $^{55}_{133}\text{Cs}$

40. If a singly ionized helium atom in an $n = 4$ state emits a photon of wavelength 470 nanometers, which of the following gives the approximate final energy level, E_f, of the atom, and the n value, n_f, of this final state?

	E_f (eV)	n_f
(A)	−6.0	3
(B)	−6.0	2
(C)	−14	2
(D)	−14	1
(E)	−52	1

41. A $3p$ electron is found in the $^3P_{3/2}$ energy level of a hydrogen atom. Which of the following is true about the electron in this state?

(A) It is allowed to make an electric dipole transition to the $^2S_{1/2}$ level.
(B) It is allowed to make an electric dipole transition to the $^2P_{1/2}$ level.
(C) It has quantum numbers $\ell = 3$, $j = 3/2$, $s = 1/2$.
(D) It has quantum numbers $n = 3$, $j = \ell$, $s = 3/2$.
(E) It has exactly the same energy as it would in the $^3D_{3/2}$ level.

42. Light of wavelength 500 nanometers is incident on sodium, with work function 2.28 electron volts. What is the maximum kinetic energy of the ejected photoelectrons?

(A) 0.03 eV
(B) 0.2 eV
(C) 0.6 eV
(D) 1.3 eV
(E) 2.0 eV

43. The line integral of $\mathbf{u} = y\mathbf{i} - x\mathbf{j} + z\mathbf{k}$ around a circle of radius R in the xy-plane with center at the origin is equal to

(A) 0
(B) $2\pi R$
(C) $2\pi R^2$
(D) $\pi R^2/4$
(E) $3R^3$

44. A particle of unit mass undergoes one-dimensional motion such that its velocity varies according to

$$v(x) = \beta x^{-n},$$

where β and n are constants and x is the position of the particle. What is the acceleration of the particle as a function of x ?

(A) $-n\beta^2 x^{-2n-1}$

(B) $-n\beta^2 x^{-n-1}$

(C) $-n\beta^2 x^{-n}$

(D) $-\beta x^{-n+1}$

(E) $-\beta x^{-2n+1}$

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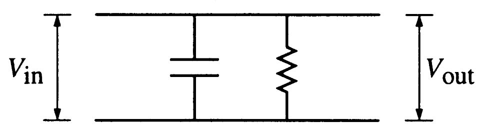
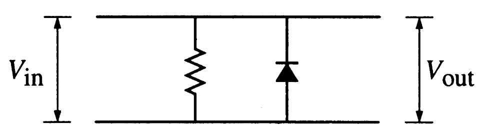
SCRATCHWORK

45. The circuits below consist of two-element combinations of capacitors, diodes, and resistors. V_{in} represents an ac-voltage with variable frequency. It is desired to build a circuit for which $V_{out} \approx V_{in}$ at high frequencies and $V_{out} \approx 0$ at low frequencies. Which of the following circuits will perform this task?

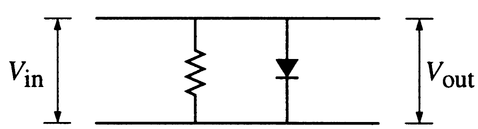
(A)



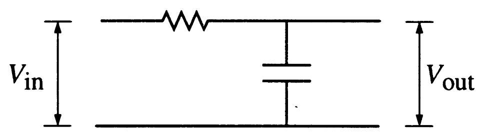
(B)



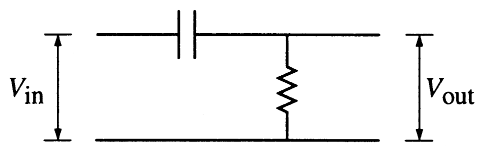
(C)

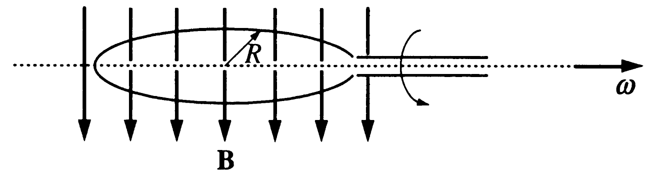


(D)



(E)





46. A circular wire loop of radius R rotates with an angular speed ω in a uniform magnetic field **B**, as shown in the figure above. If the emf $\mathcal{E}$ induced in the loop is $\mathcal{E}_0 \sin \omega t$, then the angular speed of the loop is

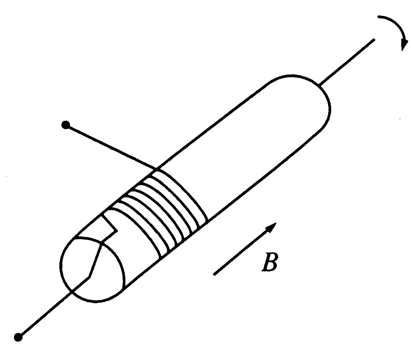
(A) $\mathcal{E}_0 R/B$

(B) $2\pi\mathcal{E}_0/R$

(C) $\mathcal{E}_0/(B\pi R^2)$

(D) $\mathcal{E}_0^2/(BR^2)$

(E) $\tan^{-1}(\mathcal{E}_0/Bc)$



47. A wire is being wound around a rotating wooden cylinder of radius R. One end of the wire is connected to the axis of the cylinder, as shown in the figure above. The cylinder is placed in a uniform magnetic field of magnitude B parallel to its axis and rotates at N revolutions per second. What is the potential difference between the open ends of the wire?

(A) 0

(B) $2\pi NBR$

(C) πNBR^2

(D) BR^2/N

(E) πNBR^3

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SCRATCHWORK

48. The half-life of a π^+ meson at rest is 2.5×10^{-8} second. A beam of π^+ mesons is generated at a point 15 meters from a detector. Only $\frac{1}{2}$ of the π^+ mesons live to reach the detector. The speed of the π^+ mesons is

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

(B) $\sqrt{\frac{2}{5}}c$

(C) $\frac{2}{\sqrt{5}}c$

(D) c

(E) $2c$

49. The infinite xy-plane is a nonconducting surface, with surface charge density σ, as measured by an observer at rest on the surface. A second observer moves with velocity $v\hat{\mathbf{x}}$ relative to the surface, at height h above it. Which of the following expressions gives the electric field measured by this second observer?

(A) $\frac{\sigma}{2\epsilon_0}\hat{\mathbf{z}}$

(B) $\frac{\sigma}{2\epsilon_0}\sqrt{1 - v^2/c^2}\,\hat{\mathbf{z}}$

(C) $\frac{\sigma}{2\epsilon_0\sqrt{1 - v^2/c^2}}\hat{\mathbf{z}}$

(D) $\frac{\sigma}{2\epsilon_0}\left(\sqrt{1 - v^2/c^2}\,\hat{\mathbf{z}} + v/c\,\hat{\mathbf{x}}\right)$

(E) $\frac{\sigma}{2\epsilon_0}\left(\sqrt{1 - v^2/c^2}\,\hat{\mathbf{z}} - v/c\,\hat{\mathbf{y}}\right)$

50. In inertial frame S, two events occur at the same instant in time and $3c \cdot$ minutes apart in space. In inertial frame S', the same events occur at $5c \cdot$ minutes apart. What is the time interval between the events in S'?

(A) 0 min
(B) 2 min
(C) 4 min
(D) 8 min
(E) 16 min

51. The solution to the Schrödinger equation for a particle bound in a one-dimensional, infinitely deep potential well, indexed by quantum number n, indicates that in the middle of the well the probability density vanishes for

(A) the ground state ($n = 1$) only
(B) states of even n ($n = 2, 4, \ldots$)
(C) states of odd n ($n = 1, 3, \ldots$)
(D) all states ($n = 1, 2, 3 \ldots$)
(E) all states except the ground state

52. At a given instant of time, a rigid rotator is in the state $\psi(\theta, \phi) = \sqrt{3/4\pi}\,\sin\theta\,\sin\phi$, where θ is the polar angle relative to the z-axis and ϕ is the azimuthal angle. Measurement will find which of the following possible values of the z-component of the angular momentum, L_z?

(A) 0
(B) $\hbar/2,\ -\hbar/2$
(C) $\hbar,\ -\hbar$
(D) $2\hbar,\ -2\hbar$
(E) $\hbar,\ 0,\ -\hbar$

53. Positronium is the bound state of an electron and a positron. Consider only the states of zero orbital angular momentum ($\ell = 0$). The most probable decay product of any such state of positronium with spin zero (singlet) is

(A) 0 photons
(B) 1 photon
(C) 2 photons
(D) 3 photons
(E) 4 photons

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SCRATCHWORK

Questions 54-55 concern a plane electromagnetic wave that is a superposition of two independent orthogonal plane waves and can be written as the real part of $\mathbf{E} = \hat{\mathbf{x}}E_1 \exp(i[kz - \omega t]) + \hat{\mathbf{y}}E_2 \exp(i[kz - \omega t + \pi])$, where k, ω, E_1, and E_2 are real.

54. If $E_2 = E_1$, the tip of the electric field vector will describe a trajectory that, as viewed along the z-axis from positive z and looking toward the origin, is a

(A) line at 45° to the $+x$-axis
(B) line at 135° to the $+x$-axis
(C) clockwise circle
(D) counterclockwise circle
(E) random path

55. If the plane wave is split and recombined on a screen after the two portions, which are polarized in the x- and y-directions, have traveled an optical path difference of $2\pi/k$, the observed average intensity will be proportional to

(A) $E_1^2 + E_2^2$
(B) $E_1^2 - E_2^2$
(C) $(E_1 + E_2)^2$
(D) $(E_1 - E_2)^2$
(E) 0

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56. A light source is at the bottom of a pool of water (the index of refraction of water is 1.33). At what minimum angle of incidence will a ray be totally reflected at the surface?

(A) 0°
(B) 25°
(C) 50°
(D) 75°
(E) 90°

57. Consider a single-slit diffraction pattern for a slit of width d. It is observed that for light of wavelength 400 nanometers, the angle between the first minimum and the central maximum is 4×10^{-3} radians. The value of d is

(A) 1×10^{-5} m
(B) 5×10^{-5} m
(C) 1×10^{-4} m
(D) 2×10^{-4} m
(E) 1×10^{-3} m

58. A collimated laser beam emerging from a commercial HeNe laser has a diameter of about 1 millimeter. In order to convert this beam into a well-collimated beam of diameter 10 millimeters, two convex lenses are to be used. The first lens is of focal length 1.5 centimeters and is to be mounted at the output of the laser. What is the focal length, f, of the second lens and how far from the first lens should it be placed?

	f	Distance
(A)	4.5 cm	6.0 cm
(B)	10 cm	10 cm
(C)	10 cm	11.5 cm
(D)	15 cm	15 cm
(E)	15 cm	16.5 cm

59. The approximate number of photons in a femtosecond (10^{-15}s) pulse of 600 nanometers wavelength light from a 10-kilowatt peak-power dye laser is

(A) 10^3
(B) 10^7
(C) 10^{11}
(D) 10^{15}
(E) 10^{18}

60. The Lyman alpha spectral line of hydrogen (λ = 122 nanometers) differs by 1.8×10^{-12} meter in spectra taken at opposite ends of the Sun's equator. What is the speed of a particle on the equator due to the Sun's rotation, in kilometers per second?

(A) 0.22
(B) 2.2
(C) 22
(D) 220
(E) 2200

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SCRATCHWORK

61. A sphere of radius R carries charge density proportional to the square of the distance from the center: $\rho = Ar^2$, where A is a positive constant. At a distance of $R/2$ from the center, the magnitude of the electric field is

(A) $A/4\pi\epsilon_0$

(B) $AR^3/40\epsilon_0$

(C) $AR^3/24\epsilon_0$

(D) $AR^3/5\epsilon_0$

(E) $AR^3/3\epsilon_0$

62. Two capacitors of capacitances 1.0 microfarad and 2.0 microfarads are each charged by being connected across a 5.0-volt battery. They are disconnected from the battery and then connected to each other with resistive wires so that plates of opposite charge are connected together. What will be the magnitude of the final voltage across the 2.0-microfarad capacitor?

(A) 0 V
(B) 0.6 V
(C) 1.7 V
(D) 3.3 V
(E) 5.0 V

63. According to the Standard Model of elementary particles, which of the following is NOT a composite object?

(A) Muon
(B) Pi-meson
(C) Neutron
(D) Deuteron
(E) Alpha particle

64. The binding energy of a heavy nucleus is about 7 million electron volts per nucleon, whereas the binding energy of a medium-weight nucleus is about 8 million electron volts per nucleon. Therefore, the total kinetic energy liberated when a heavy nucleus undergoes symmetric fission is most nearly

(A) 1876 MeV
(B) 938 MeV
(C) 200 MeV
(D) 8 MeV
(E) 7 MeV

65. A man of mass m on an initially stationary boat gets off the boat by leaping to the left in an exactly horizontal direction. Immediately after the leap, the boat, of mass M, is observed to be moving to the right at speed v. How much work did the man do during the leap (both on his own body and on the boat) ?

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

(B) $\frac{1}{2}mv^2$

(C) $\frac{1}{2}(M+m)v^2$

(D) $\frac{1}{2}\left(M+\frac{M^2}{m}\right)v^2$

(E) $\frac{1}{2}\left(\frac{Mm}{M+m}\right)v^2$

66. When it is about the same distance from the Sun as is Jupiter, a spacecraft on a mission to the outer planets has a speed that is 1.5 times the speed of Jupiter in its orbit. Which of the following describes the orbit of the spacecraft about the Sun?

(A) Spiral
(B) Circle
(C) Ellipse
(D) Parabola
(E) Hyperbola

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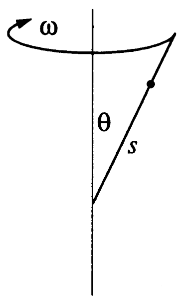
SCRATCHWORK

67. A black hole is an object whose gravitational field is so strong that even light cannot escape. To what approximate radius would Earth (mass $= 5.98 \times 10^{24}$ kilograms) have to be compressed in order to become a black hole?

(A) 1 nm
(B) 1 μm
(C) 1 cm
(D) 100 m
(E) 10 km



68. A bead is constrained to slide on a frictionless rod that is fixed at an angle θ with a vertical axis and is rotating with angular frequency ω about the axis, as shown above. Taking the distance s along the rod as the variable, the Lagrangian for the bead is equal to

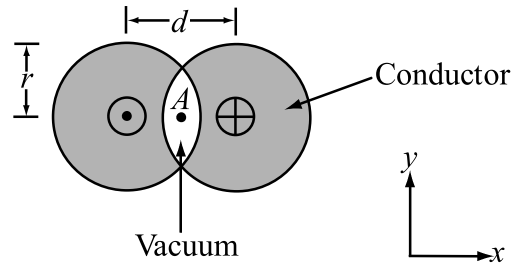
(A) $\frac{1}{2}m\dot{s}^2 - mgs\cos\theta$

(B) $\frac{1}{2}m\dot{s}^2 + \frac{1}{2}m(\omega s)^2 - mgs$

(C) $\frac{1}{2}m\dot{s}^2 + \frac{1}{2}m(\omega s\cos\theta)^2 + mgs\cos\theta$

(D) $\frac{1}{2}m(\dot{s}\sin\theta)^2 - mgs\cos\theta$

(E) $\frac{1}{2}m\dot{s}^2 + \frac{1}{2}m(\omega s\sin\theta)^2 - mgs\cos\theta$



69. Two long conductors are arranged as shown above to form overlapping cylinders, each of radius r, whose centers are separated by a distance d. Current of density J flows into the plane of the page along the shaded part of one conductor and an equal current flows out of the plane of the page along the shaded portion of the other, as shown. What are the magnitude and direction of the magnetic field at point A ?

(A) $(\mu_0/2\pi)\pi dJ$, in the $+y$-direction
(B) $(\mu_0/2\pi)d^2J/r$, in the $+y$-direction
(C) $(\mu_0/2\pi)4d^2J/r$, in the $-y$-direction
(D) $(\mu_0/2\pi)Jr^2/d$, in the $-y$-direction
(E) There is no magnetic field at A.

70. A charged particle, A, moving at a speed much less than c, decelerates uniformly. A second particle, B, has one-half the mass, twice the charge, three times the velocity, and four times the acceleration of particle A. According to classical electrodynamics, the ratio P_B/P_A of the powers radiated is

(A) 16
(B) 32
(C) 48
(D) 64
(E) 72

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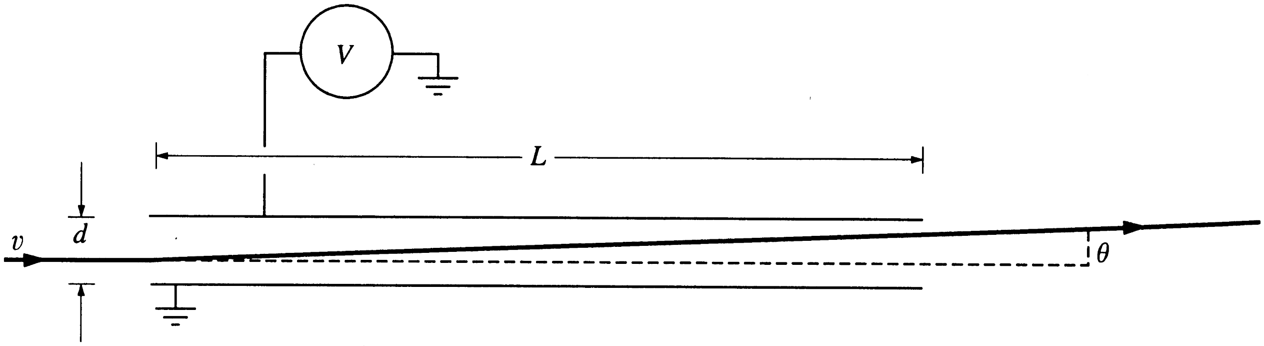
SCRATCHWORK



71. The figure above shows the trajectory of a particle that is deflected as it moves through the uniform electric field between parallel plates. There is potential difference V and distance d between the plates, and they have length L. The particle (mass m, charge q) has nonrelativistic speed v before it enters the field, and its direction at this time is perpendicular to the field. For small deflections, which of the following expressions is the best approximation to the deflection angle θ ?

(A) $\arctan\left((L/d)(Vq/mv^2) \right)$
(B) $\arctan\left((L/d)(Vq/mv^2)^2 \right)$
(C) $\arctan\left((L/d)^2(Vq/mv^2) \right)$
(D) $\arctan\left((L/d)(2Vq/mv^2)^{1/2} \right)$
(E) $\arctan\left((L/d)^{1/2}(2Vq/mv^2) \right)$

---

72. In a voltage amplifier, which of the following is NOT usually a result of introducing negative feedback?

(A) Increased amplification
(B) Increased bandwidth
(C) Increased stability
(D) Decreased distortion
(E) Decreased voltage gain

73. The adiabatic expansion of an ideal gas is described by the equation $PV^\gamma = C$, where γ and C are constants. The work done by the gas in expanding adiabatically from the state (V_i, P_i) to (V_f, P_f) is equal to

(A) $P_f V_f$

(B) $\dfrac{(P_i + P_f)}{2}(V_f - V_i)$

(C) $\dfrac{P_f V_f - P_i V_i}{1 - \gamma}$

(D) $\dfrac{P_i (V_f^{1+\gamma} - V_i^{1+\gamma})}{1 + \gamma}$

(E) $\dfrac{P_f (V_f^{1-\gamma} - V_i^{1-\gamma})}{1 + \gamma}$

74. A body of mass m with specific heat C at temperature 500 K is brought into contact with an identical body at temperature 100 K, and the two are isolated from their surroundings. The change in entropy of the system is equal to

(A) $(4/3)mC$
(B) $mC\ln(9/5)$
(C) $mC\ln(3)$
(D) $-mC\ln(5/3)$
(E) 0

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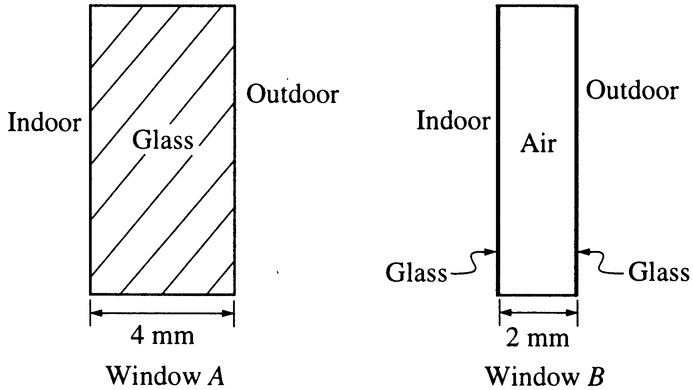
SCRATCHWORK



75. Window A is a pane of glass 4 millimeters thick, as shown above. Window B is a sandwich consisting of two extremely thin layers of glass separated by an air gap 2 millimeters thick, as shown above. If the thermal conductivities of glass and air are 0.8 watt/meter °C and 0.025 watt/meter °C, respectively, then the ratio of the heat flow through window A to the heat flow through window B is

(A) 2
(B) 4
(C) 8
(D) 16
(E) 32

---

76. A Gaussian wave packet travels through free space. Which of the following statements about the wave packet are correct for all such wave packets?

I. The average momentum of the wave packet is zero.
II. The width of the wave packet increases with time, as $t \to \infty$.
III. The amplitude of the wave packet remains constant with time.
IV. The narrower the wave packet is in momentum space, the wider it is in coordinate space.

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

GO ON TO THE NEXT PAGE.

SCRATCHWORK

77. Two ions, 1 and 2, at fixed separation, with spin angular momentum operators $\mathbf{S_1}$ and $\mathbf{S_2}$, have the interaction Hamiltonian $H = -J\,\mathbf{S_1} \cdot \mathbf{S_2}$, where $J > 0$. The values of $\mathbf{S_1}^2$ and $\mathbf{S_2}^2$ are fixed at $S_1(S_1 + 1)$ and $S_2(S_2 + 1)$, respectively. Which of the following is the energy of the ground state of the system?

(A) 0

(B) $-JS_1S_2$

(C) $-J[S_1(S_1 + 1) - S_2(S_2 + 1)]$

(D) $-(J/2)[(S_1 + S_2)(S_1 + S_2 + 1) - S_1(S_1 + 1) - S_2(S_2 + 1)]$

(E) $-\frac{J}{2}\left[\frac{S_1(S_1 + 1) + S_2(S_2 + 1)}{(S_1 + S_2)(S_1 + S_2 + 1)}\right]$

78. In an n-type semiconductor, which of the following is true of impurity atoms?

(A) They accept electrons from the filled valence band into empty energy levels just above the valence band.
(B) They accept electrons from the filled valence band into empty energy levels just below the valence band.
(C) They accept electrons from the conduction band into empty energy levels just below the conduction band.
(D) They donate electrons to the filled valence band from donor levels just above the valence band.
(E) They donate electrons to the conduction band from filled donor levels just below the conduction band.

79. For an ideal diatomic gas in thermal equilibrium, the ratio of the molar heat capacity at constant volume at very high temperatures to that at very low temperatures is equal to

(A) 1
(B) 5/3
(C) 2
(D) 7/3
(E) 3

80. A string consists of two parts attached at $x = 0$. The right part of the string ($x > 0$) has mass μ_r per unit length and the left part of the string ($x < 0$) has mass μ_ℓ per unit length. The string tension is T. If a wave of unit amplitude travels along the left part of the string, as shown in the figure above, what is the amplitude of the wave that is transmitted to the right part of the string?

(A) 1

(B) $\dfrac{2}{1 + \sqrt{\mu_\ell/\mu_r}}$

(C) $\dfrac{2\sqrt{\mu_\ell/\mu_r}}{1 + \sqrt{\mu_\ell/\mu_r}}$

(D) $\dfrac{\sqrt{\mu_\ell/\mu_r} - 1}{\sqrt{\mu_\ell/\mu_r} + 1}$

(E) 0

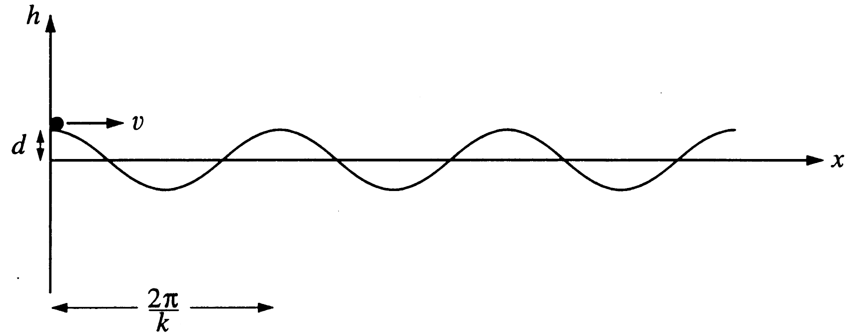
81. A piano tuner who wishes to tune the note D_2 corresponding to a frequency of 73.416 hertz has tuned A_4 to a frequency of 440.000 hertz. Which harmonic of D_2 (counting the fundamental as the first harmonic) will give the lowest number of beats per second, and approximately how many beats will this be when the two notes are tuned properly?

	Harmonic	Number of Beats
(A)	6	5
(B)	6	0.5
(C)	5	0.1
(D)	3	0.372
(E)	2	4.5

82. Consider two horizontal glass plates with a thin film of air between them. For what values of the thickness of the film of air will the film, as seen by reflected light, appear bright if it is illuminated normally from above by blue light of wavelength 488 nanometers?

(A) 0, 122 nm, 244 nm
(B) 0, 122 nm, 366 nm
(C) 0, 244 nm, 488 nm
(D) 122 nm, 244 nm, 366 nm
(E) 122 nm, 366 nm, 610 nm

SCRATCHWORK



83. Consider a particle moving without friction on a rippled surface, as shown above. Gravity acts down in the negative h direction. The elevation $h(x)$ of the surface is given by $h(x) = d \cos(kx)$. If the particle starts at $x = 0$ with a speed v in the x direction, for what values of v will the particle stay on the surface at all times?

(A) $v \leq \sqrt{gd}$

(B) $v \leq \sqrt{\frac{g}{k}}$

(C) $v \leq \sqrt{gkd^2}$

(D) $v \leq \sqrt{\frac{g}{k^2 d}}$

(E) $v > 0$

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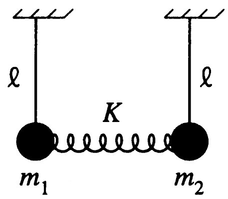
SCRATCHWORK



84. Two pendulums are attached to a massless spring, as shown above. The arms of the pendulums are of identical lengths ℓ, but the pendulum balls have unequal masses m_1 and m_2. The initial distance between the masses is the equilibrium length of the spring, which has spring constant K. What is the highest normal mode frequency of this system?

(A) $\sqrt{g/\ell}$

(B) $\sqrt{\dfrac{K}{m_1 + m_2}}$

(C) $\sqrt{\dfrac{K}{m_1} + \dfrac{K}{m_2}}$

(D) $\sqrt{\dfrac{g}{\ell} + \dfrac{K}{m_1} + \dfrac{K}{m_2}}$

(E) $\sqrt{\dfrac{2g}{\ell} + \dfrac{K}{m_1 + m_2}}$

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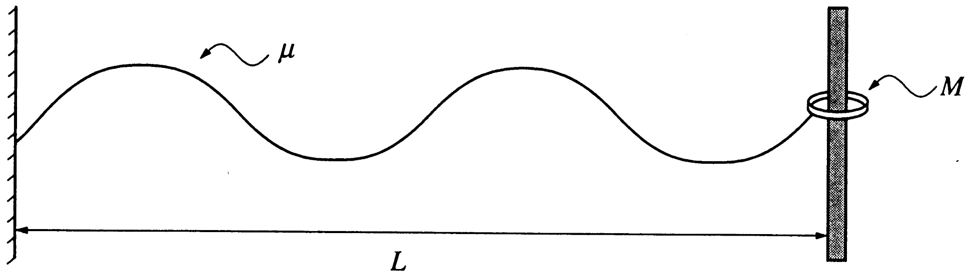
SCRATCHWORK



85. Small-amplitude standing waves of wavelength λ occur on a string with tension T, mass per unit length μ, and length L. One end of the string is fixed and the other end is attached to a ring of mass M that slides on a frictionless rod, as shown in the figure above. When gravity is neglected, which of the following conditions correctly determines the wavelength? (You might want to consider the limiting cases $M \to 0$ and $M \to \infty$.)

(A) $\mu/M = \frac{2\pi}{\lambda} \cot \frac{2\pi L}{\lambda}$

(B) $\mu/M = \frac{2\pi}{\lambda} \tan \frac{2\pi L}{\lambda}$

(C) $\mu/M = \frac{2\pi}{\lambda} \sin \frac{2\pi L}{\lambda}$

(D) $\lambda = 2L/n,\ n = 1, 2, 3, \ldots$

(E) $\lambda = 2L/(n + \frac{1}{2}),\ n = 1, 2, 3, \ldots$

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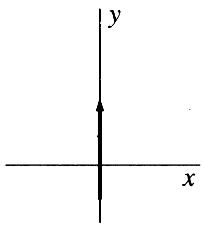
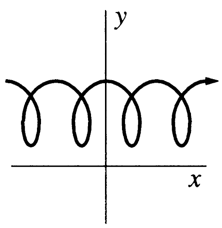
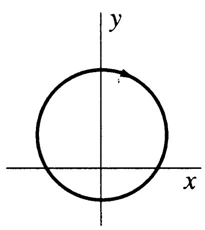
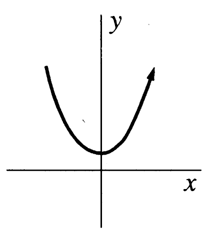
SCRATCHWORK

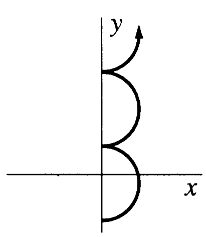
86. A positively charged particle is moving in the xy-plane in a region where there is a non-zero uniform magnetic field B in the $+z$-direction and a non-zero uniform electric field E in the $+y$-direction. Which of the following is a possible trajectory for the particle?

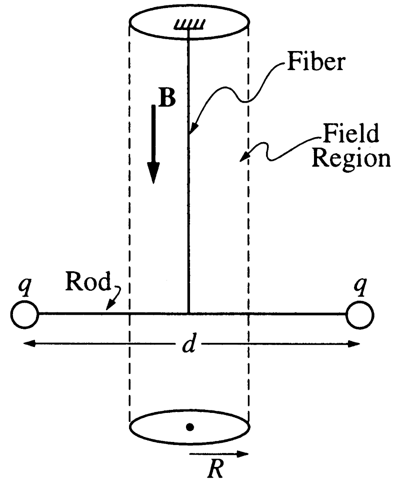
(A)


(B)


(C)


(D)


(E)




87. Two small pith balls, each carrying a charge q, are attached to the ends of a light rod of length d, which is suspended from the ceiling by a thin torsion-free fiber, as shown in the figure above. There is a uniform magnetic field **B**, pointing straight down, in the cylindrical region of radius R around the fiber. The system is initially at rest. If the magnetic field is turned off, which of the following describes what happens to the system?

(A) It rotates with angular momentum qBR^2.

(B) It rotates with angular momentum $\frac{1}{4}qBd^2$.

(C) It rotates with angular momentum $\frac{1}{2}qBRd$.

(D) It does not rotate because to do so would violate conservation of angular momentum.

(E) It does not move because magnetic forces do no work.

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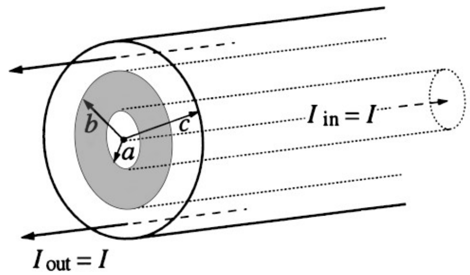
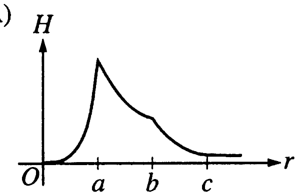
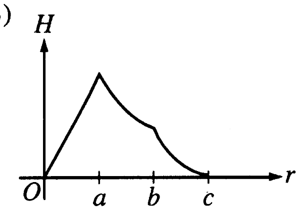
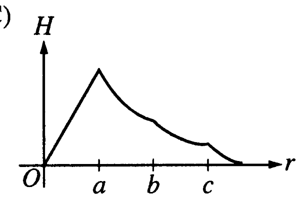
SCRATCHWORK

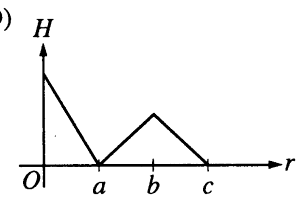


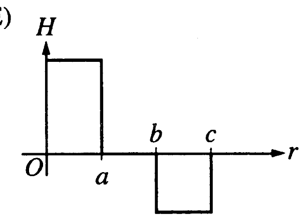
88. A coaxial cable has the cross section shown in the figure above. The shaded region is insulated. The regions in which $r < a$ and $b < r < c$ are conducting. A uniform dc current density of total current I flows along the inner part of the cable ($r < a$) and returns along the outer part of the cable ($b < r < c$) in the directions shown. The radial dependence of the magnitude of the magnetic field, H, is shown by which of the following?

(A) 

(B) 

(C) 

(D) 

(E) 

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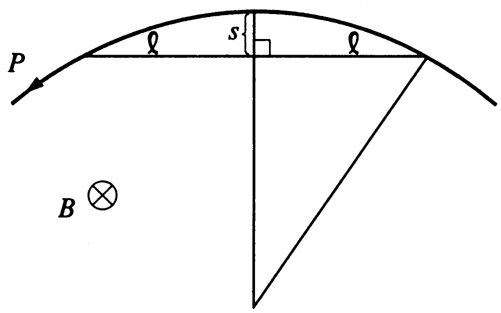
SCRATCHWORK



89. A particle with charge q and momentum p is moving in the horizontal plane under the action of a uniform vertical magnetic field of magnitude B. Measurements are made of the particle's trajectory to determine the "sagitta" s and half-chord length ℓ, as shown in the figure above. Which of the following expressions gives the particle's momentum in terms of q, B, s, and ℓ? (Assume $s << \ell$.)

(A) $qBs^2/2\ell$

(B) qBs^2/ℓ

(C) $qB\ell/s$

(D) $qB\ell^2/2s$

(E) $qB\ell^2/8s$

90. **THIS ITEM WAS NOT SCORED.**

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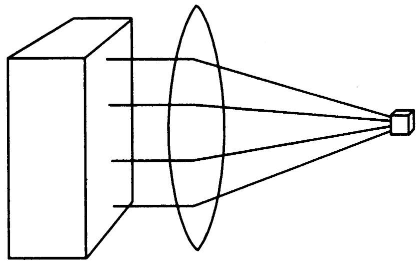
SCRATCHWORK



91. An experimenter needs to heat a small sample to 900 K, but the only available oven has a maximum temperature of 600 K. Could the experimenter heat the sample to 900 K by using a large lens to concentrate the radiation from the oven onto the sample, as shown above?

(A) Yes, if the volume of the oven is at least 3/2 the volume of the sample.
(B) Yes, if the area of the front of the oven is at least 3/2 the area of the front of the sample.
(C) Yes, if the sample is placed at the focal point of the lens.
(D) No, because it would violate conservation of energy.
(E) No, because it would violate the second law of thermodynamics.

---

92. A particle of mass m moves in a one-dimensional potential $V(x) = -ax^2 + bx^4$, where a and b are positive constants. The angular frequency of small oscillations about the minima of the potential is equal to

(A) $\pi(a/2b)^{1/2}$
(B) $\pi(a/m)^{1/2}$
(C) $(a/mb)^{1/2}$
(D) $2(a/m)^{1/2}$
(E) $(a/2m)^{1/2}$

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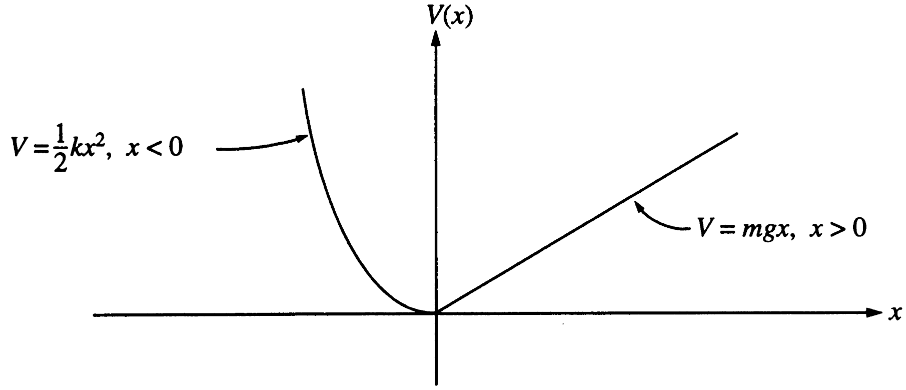
SCRATCHWORK



93. A particle of mass m moves in the potential shown above. The period of the motion when the particle has energy E is

(A) $\sqrt{k/m}$

(B) $2\pi\sqrt{m/k}$

(C) $2\sqrt{2E/mg^2}$

(D) $\pi\sqrt{m/k} + 2\sqrt{2E/mg^2}$

(E) $2\pi\sqrt{m/k} + 4\sqrt{2E/mg^2}$

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SCRATCHWORK

94. A system consists of N weakly interacting subsystems, each with two internal quantum states with energies 0 and ϵ. The internal energy for this system at absolute temperature T is equal to

(A) $N\epsilon$

(B) $\frac{3}{2}NkT$

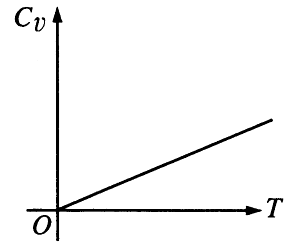
(C) $N\epsilon e^{-\epsilon/kT}$

(D) $\frac{N\epsilon}{(e^{\epsilon/kT} + 1)}$

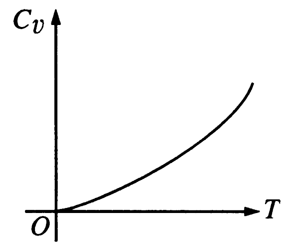
(E) $\frac{N\epsilon}{(1 + e^{-\epsilon/kT})}$

95. Which of the following curves is characteristic of the specific heat C_V of a metal such as lead, tin, or aluminum in the temperature region where it becomes superconducting?

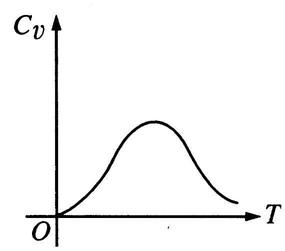
(A)



(B)



(C)



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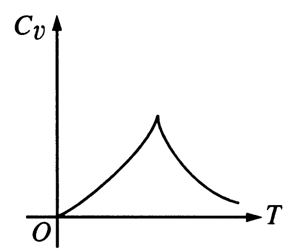

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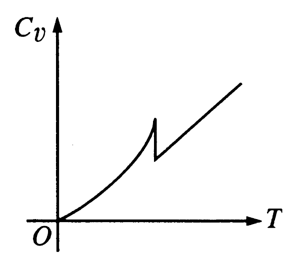

SCRATCHWORK

96. Which of the following reasons explains why a photon cannot decay to an electron and a positron ($\gamma \rightarrow e^+ + e^-$) in free space?

(A) Linear momentum and energy are not both conserved.
(B) Linear momentum and angular momentum are not both conserved.
(C) Angular momentum and parity are not both conserved.
(D) Parity and strangeness are not both conserved.
(E) Charge and lepton number are not both conserved.

97. A particle of mass m has the wave function $\psi(x, t) = e^{i\omega t}[\alpha \cos(kx) + \beta \sin(kx)]$, where α and β are complex constants and ω and k are real constants. The probability current density is equal to which of the following? (Note: α^* denotes the complex conjugate of α, and $|\alpha|^2 = \alpha^* \alpha$.)

(A) 0

(B) $\hbar k/m$

(C) $\frac{\hbar k}{2m}(|\alpha|^2 + |\beta|^2)$

(D) $\frac{\hbar k}{m}(|\alpha|^2 - |\beta|^2)$

(E) $\frac{\hbar k}{2mi}(\alpha^* \beta - \beta^* \alpha)$

98. A particle of mass m is acted on by a harmonic force with potential energy function $V(x) = m\omega^2 x^2/2$ (a one-dimensional simple harmonic oscillator). If there is a wall at $x = 0$ so that $V = \infty$ for $x < 0$, then the energy levels are equal to

(A) $0, \hbar\omega, 2\hbar\omega, \ldots$

(B) $0, \frac{\hbar\omega}{2}, \hbar\omega, \ldots$

(C) $\frac{\hbar\omega}{2}, \frac{3\hbar\omega}{2}, \frac{5\hbar\omega}{2}, \ldots$

(D) $\frac{3\hbar\omega}{2}, \frac{7\hbar\omega}{2}, \frac{11\hbar\omega}{2}, \ldots$

(E) $0, \frac{3\hbar\omega}{2}, \frac{5\hbar\omega}{2}, \ldots$

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SCRATCHWORK

99. The electronic energy levels of atoms of a certain gas are given by $E_n = E_1 n^2$, where $n = 1, 2, 3, \ldots$. Assume that transitions are allowed between all levels. If one wanted to construct a laser from this gas by pumping the $n = 1 \rightarrow n = 3$ transition, which energy level or levels would have to be metastable?

(A) $n = 1$ only

(B) $n = 2$ only

(C) $n = 1$ and $n = 3$ only

(D) $n = 1$, $n = 2$, and $n = 3$

(E) None

100. The operator $\hat{a} = \sqrt{\frac{m\omega_0}{2\hbar}}(\hat{x} + i\frac{\hat{p}}{m\omega_0})$, when operating on a harmonic energy eigenstate ψ_n with energy E_n, produces another energy eigenstate whose energy is $E_n - \hbar\omega_0$. Which of the following is true?

I. $\hat{a}$ commutes with the Hamiltonian.
II. $\hat{a}$ is a Hermitian operator and therefore an observable.
III. The adjoint operator $\hat{a}^\dagger \neq \hat{a}$.

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

IF YOU FINISH BEFORE TIME IS CALLED, YOU MAY CHECK YOUR WORK ON THIS TEST.

SCRATCHWORK

I

NOTE: To ensure prompt processing of test results, it is important that you fill in the blanks exactly as directed.

SUBJECT TEST

A. Print and sign your full name in this box:

PRINT: ____
(LAST) (FIRST) (MIDDLE)

SIGN: ____

Copy this code in box 6 on your answer sheet. Then fill in the corresponding ovals exactly as shown.

6. TITLE CODE				
7	7	7	1	2
0	0	0	0	0
1	1	1	●	1
2	2	2	2	●
3	3	3	3	3
4	4	4	4	4
5	5	5	5	5
6	6	6	6	6
●	●	●	7	7
8	8	8	8	8
9	9	9	9	9

Copy the Test Name and Form Code in box 7 on your answer sheet.

TEST NAME Physics

FORM CODE GR9677

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.

Scoring Your Subject Test

Physics Test scores typically range from 400 to 990. 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 75 shows the score range for this edition of the test only.**

The worksheet on page 74 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 740.

Worksheet for the Physics Test, Form GR9677 Answer Key and Percentage* of Examinees Answering Each Question Correctly

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

Correct (**C**) ____________________

Incorrect (**I**) ____________________

Total Score:

C – I/4 = ____________

Scaled Score (SS) = ____________

* The P+ column indicates the percentage of Physics Test examinees that answered each question correctly; it is based on a sample of December 1996 examinees selected to represent all Physics Test examinees tested between October 1, 1993, and September 30, 1996.

** Item 90 was not scored when this form of the test was originally administered.

Score Conversions and Percents Below* for GRE Physics Test, Form GR9677

TOTAL SCORE					
Raw Score	Scaled Score	%	Raw Score	Scaled Score	%
67-99	990	97	30-31	690	59
65-66	980	96	29	680	57
64	970	96	28	670	55
63	960	95	27	660	53
62	950	95	26	650	50
61	940	94	24-25	640	48
59-60	930	93	23	630	45
58	920	92	22	620	43
57	910	91	21	610	40
56	900	91	19-20	600	38
54-55	890	90	18	590	35
53	880	89	17	580	32
52	870	88	16	570	29
51	860	86	15	560	27
50	850	85	13-14	550	25
48-49	840	84	12	540	23
47	830	83	11	530	20
46	820	82	10	520	18
45	810	81	9	510	15
44	800	79	7-8	500	13
42-43	790	77	6	490	11
41	780	76	5	480	9
40	770	74	4	470	7
39	760	73	3	460	6
38	750	71	1-2	450	4
36-37	740	69	0	440	3
35	730	67			
34	720	65			
33	710	63			
32	700	61			

*Percentage scoring below the scaled score is based on the performance of 11,322 examinees who took the Physics Test between October 1, 1993, and September 30, 1996.

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 74 and the table on page 75 use performance data from GRE Physics Test examinees.

The data in the worksheet on page 74 are based on the performance of a sample of the examinees who took this test in December 1996. This sample was selected to represent the total population of GRE Physics Test examinees tested between October 1993 and September 1996. 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 individual test questions.

The table on page 75 contains, for each scaled score, the percentage of examinees tested between October 1993 and September 1996 who received lower scores. Interpretive data based on the scores earned by examinees tested in this three-year period were used by admissions officers in the 1997-98 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 53. This means that 53 percent of the GRE Physics Test examinees tested between October 1993 and September 1996 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 have also changed. To obtain current percentile rank information, visit the GRE Web site at www.gre.org/codelst.html, or contact 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

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: ______________________

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.

3. DATE OF BIRTH

Month: Jan., Feb., Mar., April, May, June, July, Aug., Sept., Oct., Nov., Dec. | Day | Year

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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