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 · 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 $= 1.0 \times 10^5$ 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	$\frac{2}{5}MR^2$

Put Answers on Scantron

PHYSICS TEST

Time—1 hour 30 minutes

35 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.

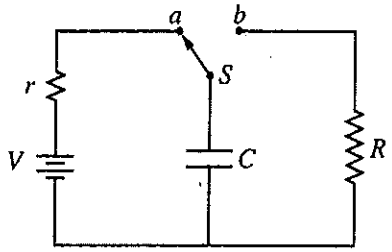


Figure 1

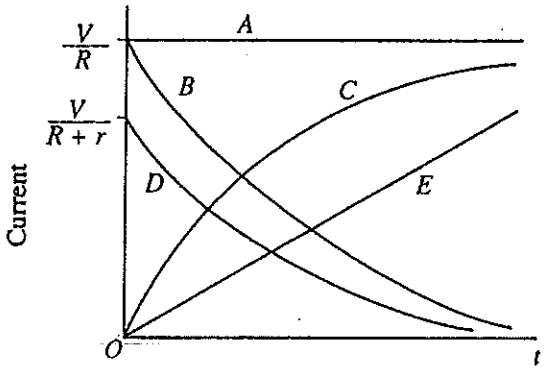
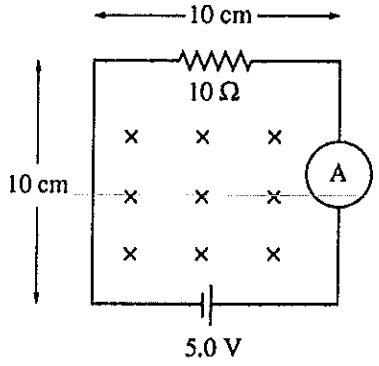


Figure 2

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

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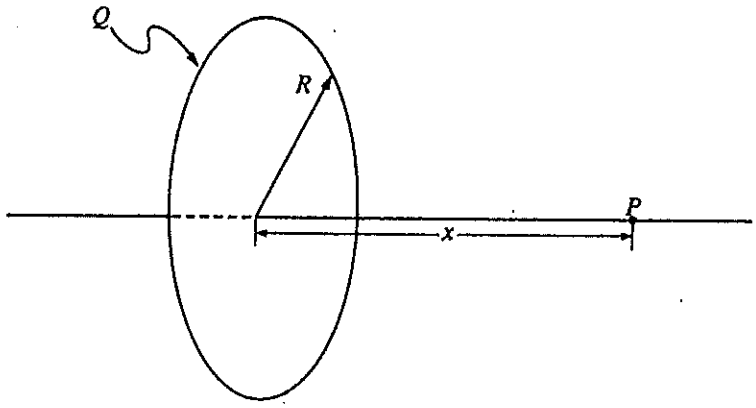
SCRATCHWORK

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) $\frac{Q}{4\pi\varepsilon_0 x}$

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

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

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

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

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) $\sqrt{\frac{qQ}{4\pi\varepsilon_0 mR^3}}$

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

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

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

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

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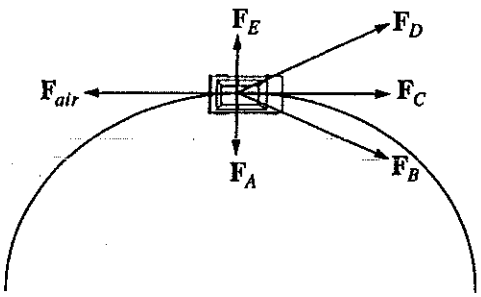
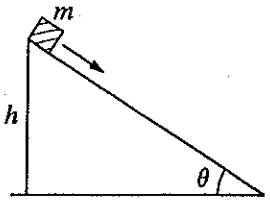
SCRATCHWORK



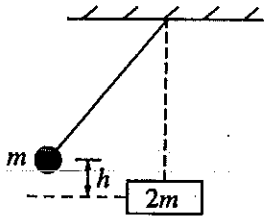
5. A car travels with constant speed on a circular road on level ground. In the diagram above, F_{air} is the force of air resistance on the car. Which of the other forces shown best represents the horizontal force of the road on the car's tires?

(A) F_A
(B) F_B
(C) F_C
(D) F_D
(E) 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

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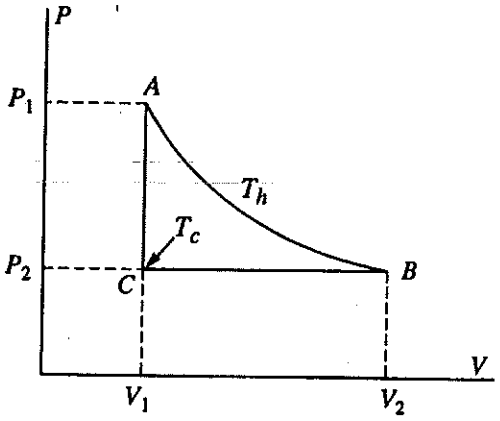
SCRATCHWORK



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

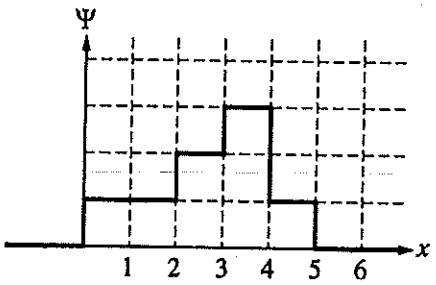
(A) 10^{-4} m

(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

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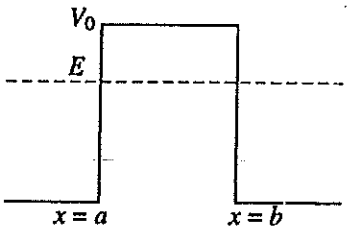
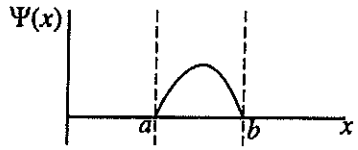
SCRATCHWORK

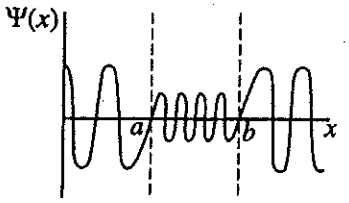


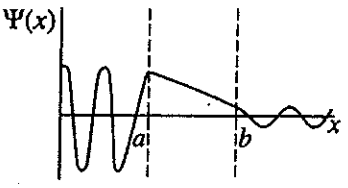
18. Consider a potential of the form

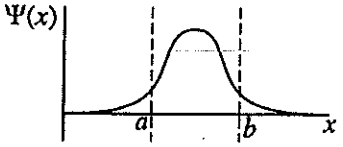
$$V(x) = 0, \ x \le a$$
$$V(x) = V_0, \ a < x < b$$
$$V(x) = 0, \ x \ge b$$

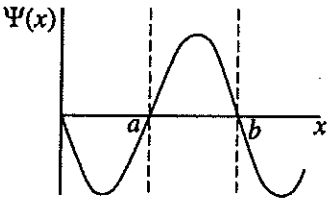
as shown in the figure above. Which of the following wave functions is possible for a particle incident from the left with energy $E < V_0$?

(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?

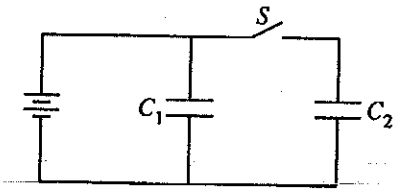
(A) 0.9 km/s
(B) 1.8 km/s
(C) 3.6 km/s
(D) 4.5 km/s
(E) 5.4 km/s

23. Suppose that the gravitational force law between two massive objects were $\mathbf{F}_{12} = \hat{\mathbf{r}}_{12} G m_1 m_2 / r_{12}^{2+\epsilon}$, 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?

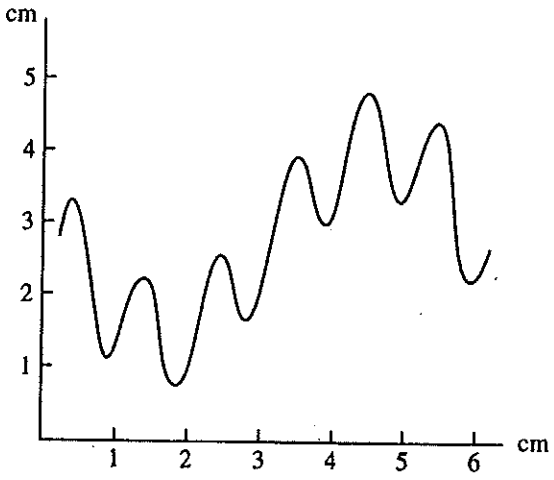
(A) 200 pF
(B) 50 pF
(C) 1 pF
(D) 0.2 pF
(E) 0.02 pF

GO ON TO THE NEXT PAGE.

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



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

GO ON TO THE NEXT PAGE.

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?

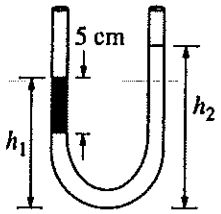
(A) $G\hbar c$

(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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