PHYSICS B

SECTION I

Time—56 minutes

70 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 oval on the answer sheet.

Note: To simplify calculations, you may use $g = 10\ \text{m/s}^2$ in all problems.

1. A solid metal ball and a hollow plastic ball of the same external radius are released from rest in a large vacuum chamber. When each has fallen 1 m, they both have the same

   (A) inertia
   (B) speed
   (C) momentum
   (D) kinetic energy
   (E) change in potential energy

2. A student weighing 700 N climbs at constant speed to the top of an 8 m vertical rope in 10 s. The average power expended by the student to overcome gravity is most nearly

   (A) 1.1 W
   (B) 87.5 W
   (C) 560 W
   (D) 875 W
   (E) 5,600 W

3. A railroad car of mass m is moving at speed v when it collides with a second railroad car of mass M which is at rest. The two cars lock together instantaneously and move along the track. What is the speed of the cars immediately after the collision?

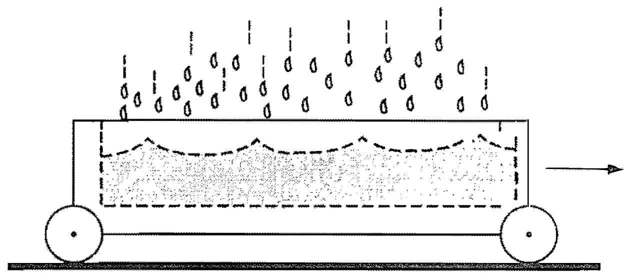
   (A) $\frac{v}{2}$

   (B) $\frac{mv}{M}$

   (C) $\frac{Mv}{m}$

   (D) $\frac{(m+M)v}{m}$

   (E) $\frac{mv}{m+M}$



4. An open cart on a level surface is rolling without frictional loss through a vertical downpour of rain, as shown above. As the cart rolls, an appreciable amount of rainwater accumulates in the cart. The speed of the cart will

   (A) increase because of conservation of momentum
   (B) increase because of conservation of mechanical energy
   (C) decrease because of conservation of momentum
   (D) decrease because of conservation of mechanical energy
   (E) remain the same because the raindrops are falling perpendicular to the direction of the cart's motion

5. Units of power include which of the following?

   I. Watt
   II. Joule per second
   III. Kilowatt-hour

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

6. A 2 kg object moves in a circle of radius 4 m at a constant speed of 3 m/s. A net force of 4.5 N acts on the object. What is the angular momentum of the object with respect to an axis perpendicular to the circle and through its center?

(A) $9\,\frac{\text{N}\cdot\text{m}}{\text{kg}}$

(B) $12\,\frac{\text{m}^2}{\text{s}}$

(C) $13.5\,\frac{\text{kg}\cdot\text{m}^2}{\text{s}^2}$

(D) $18\,\frac{\text{N}\cdot\text{m}}{\text{kg}}$

(E) $24\,\frac{\text{kg}\cdot\text{m}^2}{\text{s}}$

7. Three forces act on an object. If the object is in translational equilibrium, which of the following must be true?

I. The vector sum of the three forces must equal zero.
II. The magnitudes of the three forces must be equal.
III. All three forces must be parallel.

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

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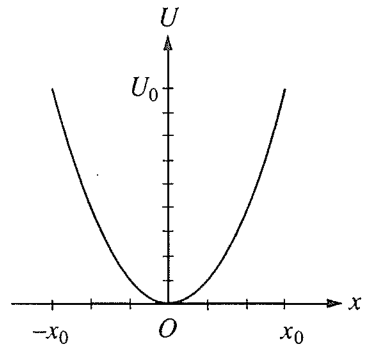
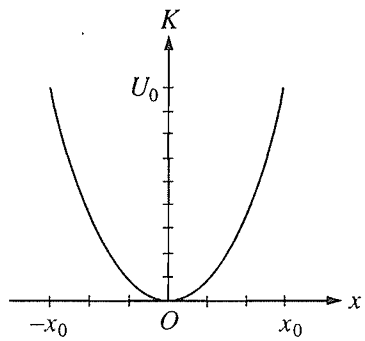
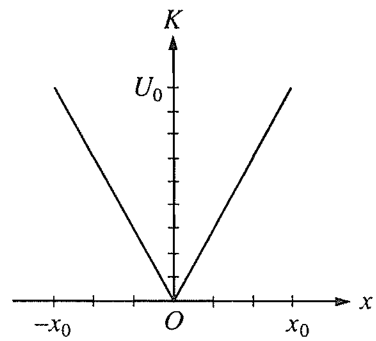


8. The graph above represents the potential energy U as a function of displacement x for an object on the end of a spring oscillating in simple harmonic motion with amplitude x_0. Which of the following graphs represents the kinetic energy K of the object as a function of displacement x ?

(A)



(B)



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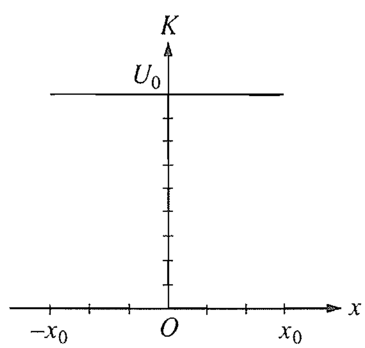

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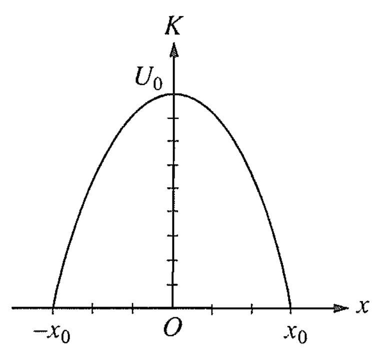
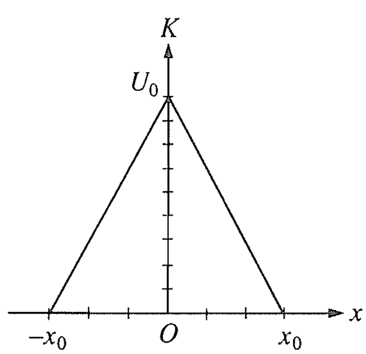


(E)



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9. A child pushes horizontally on a box of mass m which moves with constant speed v across a horizontal floor. The coefficient of friction between the box and the floor is μ. At what rate does the child do work on the box?

(A) μmgv
(B) mgv
(C) $v/\mu mg$
(D) $\mu mg/v$
(E) μmv^2

10. Quantum transitions that result in the characteristic sharp lines of the X-ray spectrum always involve

(A) the inner electron shells
(B) electron energy levels that have the same principal quantum number
(C) emission of beta particles from the nucleus
(D) neutrons within the nucleus
(E) protons within the nucleus

11. Which of the following experiments provided evidence that electrons exhibit wave properties?

I. Millikan oil-drop experiment
II. Davisson-Germer electron-diffraction experiment
III. J. J. Thomson's measurement of the charge-to-mass ratio of electrons

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

12. Quantities that are conserved in all nuclear reactions include which of the following?

I. Electric charge
II. Number of nuclei
III. Number of protons

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

13. Which of the following is true about the net force on an uncharged conducting sphere in a uniform electric field?

(A) It is zero.
(B) It is in the direction of the field.
(C) It is in the direction opposite to the field.
(D) It produces a torque on the sphere about the direction of the field.
(E) It causes the sphere to oscillate about an equilibrium position.

14. Two parallel conducting plates are connected to a constant voltage source. The magnitude of the electric field between the plates is 2,000 N/C. If the voltage is doubled and the distance between the plates is reduced to 1/5 the original distance, the magnitude of the new electric field is

(A) 800 N/C
(B) 1,600 N/C
(C) 2,400 N/C
(D) 5,000 N/C
(E) 20,000 N/C

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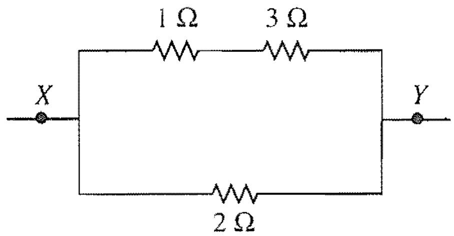
Questions 15-16 refer to the following diagram that shows part of a closed electrical circuit.



15. The electrical resistance of the part of the circuit shown between point X and point Y is

    (A) $1\frac{1}{3}\ \Omega$

    (B) $2\ \Omega$

    (C) $2\frac{3}{4}\ \Omega$

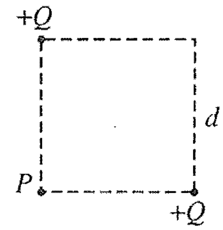
    (D) $4\ \Omega$

    (E) $6\ \Omega$

16. When there is a steady current in the circuit, the amount of charge passing a point per unit of time is

    (A) the same everywhere in the circuit
    (B) greater at point X than at point Y
    (C) greater in the 1 Ω resistor than in the 2 Ω resistor
    (D) greater in the 1 Ω resistor than in the 3 Ω resistor
    (E) greater in the 2 Ω resistor than in the 3 Ω resistor

Questions 17-18



The figure above shows two particles, each with a charge of $+Q$, that are located at the opposite corners of a square of side d.

17. What is the direction of the net electric field at point P ?

    (A) ↖

    (B) ↗

    (C) ↙

    (D) ↘

    (E) ↓

18. What is the potential energy of a particle of charge $+q$ that is held at point P ?

    (A) Zero

    (B) $\frac{\sqrt{2}}{4\pi\epsilon_0}\frac{qQ}{d}$

    (C) $\frac{1}{4\pi\epsilon_0}\frac{qQ}{d}$

    (D) $\frac{2}{4\pi\epsilon_0}\frac{qQ}{d}$

    (E) $\frac{2\sqrt{2}}{4\pi\epsilon_0}\frac{qQ}{d}$

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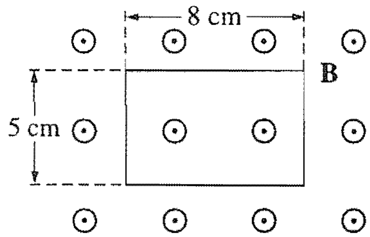
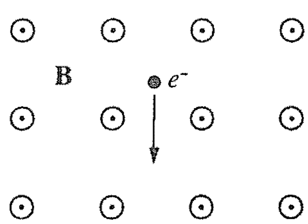


19. A rectangular wire loop is at rest in a uniform magnetic field **B** of magnitude 2 T that is directed out of the page. The loop measures 5 cm by 8 cm, and the plane of the loop is perpendicular to the field, as shown above. The total magnetic flux through the loop is

    (A) zero
    (B) 2×10^{-3} T·m^2
    (C) 8×10^{-3} T·m^2
    (D) 2×10^{-1} T·m^2
    (E) 8×10^{-1} T·m^2

20. A certain coffeepot draws 4.0 A of current when it is operated on 120 V household lines. If electrical energy costs 10 cents per kilowatt-hour, how much does it cost to operate the coffeepot for 2 hours?

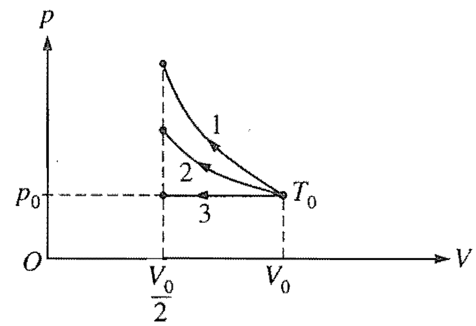
    (A) 2.4 cents
    (B) 4.8 cents
    (C) 8.0 cents
    (D) 9.6 cents
    (E) 16 cents



21. An electron is in a uniform magnetic field **B** that is directed out of the plane of the page, as shown above. When the electron is moving in the plane of the page in the direction indicated by the arrow, the force on the electron is directed

    (A) toward the right
    (B) out of the page
    (C) into the page
    (D) toward the top of the page
    (E) toward the bottom of the page

Questions 22-23



A certain quantity of an ideal gas initially at temperature T_0, pressure p_0, and volume V_0 is compressed to one-half its initial volume. As shown above, the process may be adiabatic (process 1), isothermal (process 2), or isobaric (process 3).

22. Which of the following is true of the mechanical work done on the gas?

    (A) It is greatest for process 1.
    (B) It is greatest for process 3.
    (C) It is the same for processes 1 and 2 and less for process 3.
    (D) It is the same for processes 2 and 3 and less for process 1.
    (E) It is the same for all three processes.

23. Which of the following is true of the final temperature of this gas?

    (A) It is greatest for process 1.
    (B) It is greatest for process 2.
    (C) It is greatest for process 3.
    (D) It is the same for processes 1 and 2.
    (E) It is the same for processes 1 and 3.

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24. In a certain process, 400 J of heat is added to a system and the system simultaneously does 100 J of work. The change in internal energy of the system is

(A) 500 J
(B) 400 J
(C) 300 J
(D) −100 J
(E) −300 J

25. An ice cube of mass m and specific heat c_i is initially at temperature T_1, where $T_1 < 273$ K. If L is the latent heat of fusion of water, and the specific heat of water is c_w, how much energy is required to convert the ice cube to water at temperature T_2, where $273\text{ K} < T_2 < 373\text{ K}$?

(A) $m[c_i(273 - T_1) + L + c_w(373 - T_2)]$

(B) $m[c_i(273 - T_1) + L + c_w(T_2 - 273)]$

(C) $c_i(273 - T_1) + c_w(T_2 - 273)$

(D) $mL + c_w(T_2 - T_1)$

(E) $mL + \left(\frac{c_w + c_i}{2}\right)(T_2 - T_1)$

26. A concave mirror with a radius of curvature of 1.0 m is used to collect light from a distant star. The distance between the mirror and the image of the star is most nearly

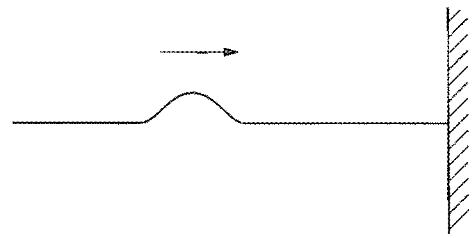
(A) 0.25 m
(B) 0.50 m
(C) 0.75 m
(D) 1.0 m
(E) 2.0 m

27. When light passes from air into water, the frequency of the light remains the same. What happens to the speed and the wavelength of light as it crosses the boundary in going from air into water?

	Speed	Wavelength
(A)	Increases	Remains the same
(B)	Remains the same	Decreases
(C)	Remains the same	Remains the same
(D)	Decreases	Increases
(E)	Decreases	Decreases

28. A physics student places an object 6.0 cm from a converging lens of focal length 9.0 cm. What is the magnitude of the magnification of the image produced?

(A) 0.6
(B) 1.5
(C) 2.0
(D) 3.0
(E) 3.6



29. One end of a horizontal string is fixed to a wall. A transverse wave pulse is generated at the other end, moves toward the wall as shown above, and is reflected at the wall. Properties of the reflected pulse include which of the following?

I. It has a greater speed than that of the incident pulse.
II. It has a greater amplitude than that of the incident pulse.
III. It is on the opposite side of the string from the incident pulse.

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

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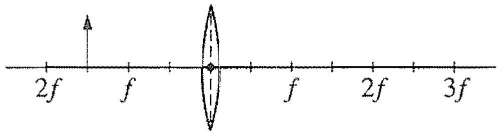
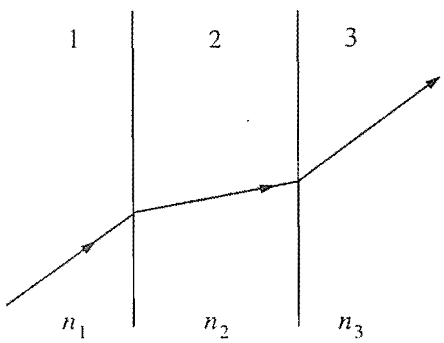


30. An object is placed at a distance of $1.5f$ from a converging lens of focal length f, as shown above. What type of image is formed and what is its size relative to the object?

	Type	Size
(A)	Virtual	Larger
(B)	Virtual	Same size
(C)	Virtual	Smaller
(D)	Real	Larger
(E)	Real	Smaller



31. A light ray passes through substances 1, 2, and 3, as shown above. The indices of refraction for these three substances are n_1, n_2, and n_3, respectively. Ray segments in 1 and in 3 are parallel. From the directions of the ray, one can conclude that

(A) n_3 must be the same as n_1
(B) n_2 must be less than n_1
(C) n_2 must be less than n_3
(D) n_1 must be equal to 1.00
(E) all three indices must be the same

32. At noon a radioactive sample decays at a rate of 4,000 counts per minute. At 12:30 P.M. the decay rate has decreased to 2,000 counts per minute. The predicted decay rate at 1:30 P.M. is

(A) 0 counts per minute
(B) 500 counts per minute
(C) 667 counts per minute
(D) 1,000 counts per minute
(E) 1,333 counts per minute

33. A negative beta particle and a gamma ray are emitted during the radioactive decay of a nucleus of ${}^{214}_{82}\text{Pb}$. Which of the following is the resulting nucleus?

(A) ${}^{210}_{80}\text{Hg}$

(B) ${}^{214}_{81}\text{Tl}$

(C) ${}^{213}_{83}\text{Bi}$

(D) ${}^{214}_{83}\text{Bi}$

(E) ${}^{218}_{84}\text{Po}$

34. If the momentum of an electron doubles, its de Broglie wavelength is multiplied by a factor of

(A) $\frac{1}{4}$

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

(C) 1

(D) 2

(E) 4

35. Quantum concepts are critical in explaining all of the following EXCEPT

(A) Rutherford's scattering experiments
(B) Bohr's theory of the hydrogen atom
(C) Compton scattering
(D) the blackbody spectrum
(E) the photoelectric effect

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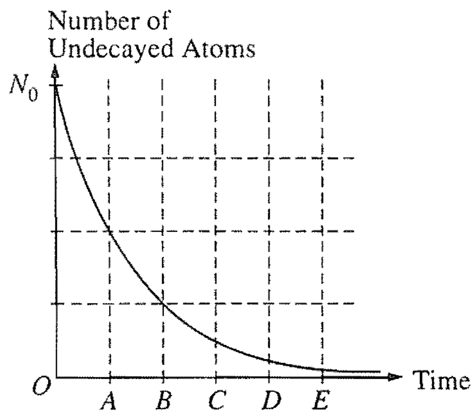


36. The graph above shows the decay of a sample of carbon 14 that initially contained N_0 atoms. Which of the lettered points on the time axis could represent the half-life of carbon 14 ?

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

37. If photons of light of frequency f have momentum p, photons of light of frequency $2f$ will have a momentum of

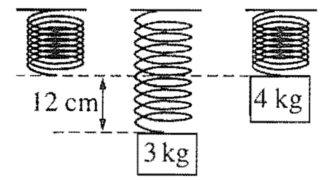
(A) $2p$

(B) $\sqrt{2}p$

(C) p

(D) $\frac{p}{\sqrt{2}}$

(E) $\frac{1}{2}p$



38. A block of mass 3.0 kg is hung from a spring, causing it to stretch 12 cm at equilibrium, as shown above. The 3.0 kg block is then replaced by a 4.0 kg block, and the new block is released from the position shown above, at which the spring is unstretched. How far will the 4.0 kg block fall before its direction is reversed?

(A) 9 cm
(B) 18 cm
(C) 24 cm
(D) 32 cm
(E) 48 cm

39. An object has a weight W when it is on the surface of a planet of radius R. What will be the gravitational force on the object after it has been moved to a distance of $4R$ from the center of the planet?

(A) $16W$

(B) $4W$

(C) W

(D) $\frac{1}{4}W$

(E) $\frac{1}{16}W$

40. What is the kinetic energy of a satellite of mass m that orbits the Earth, of mass M, in a circular orbit of radius R ?

(A) Zero

(B) $\frac{1}{2}\frac{GMm}{R}$

(C) $\frac{1}{4}\frac{GMm}{R}$

(D) $\frac{1}{2}\frac{GMm}{R^2}$

(E) $\frac{GMm}{R^2}$

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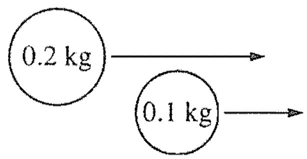
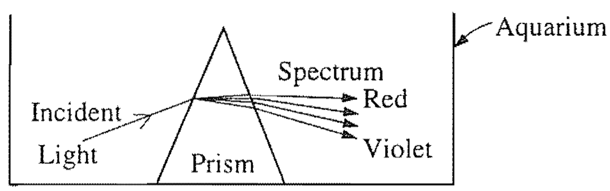


41. Two objects of mass 0.2 kg and 0.1 kg, respectively, move parallel to the x-axis, as shown above. The 0.2 kg object overtakes and collides with the 0.1 kg object. Immediately after the collision, the y-component of the velocity of the 0.2 kg object is 1 m/s upward. What is the y-component of the velocity of the 0.1 kg object immediately after the collision?

(A) 2 m/s downward
(B) 0.5 m/s downward
(C) 0 m/s
(D) 0.5 m/s upward
(E) 2 m/s upward

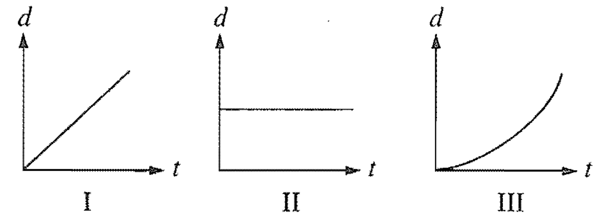


42. A beam of white light is incident on a triangular glass prism with an index of refraction of about 1.5 for visible light, producing a spectrum. Initially, the prism is in a glass aquarium filled with air, as shown above. If the aquarium is filled with water with an index of refraction of 1.3, which of the following is true?

(A) No spectrum is produced.
(B) A spectrum is produced, but the deviation of the beam is opposite to that in air.
(C) The positions of red and violet are reversed in the spectrum.
(D) The spectrum produced has greater separation between red and violet than that produced in air.
(E) The spectrum produced has less separation between red and violet than that produced in air.

Questions 43-44

Three objects can only move along a straight, level path. The graphs below show the position d of each of the objects plotted as a function of time t.



43. The magnitude of the momentum of the object is increasing in which of the cases?

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

44. The sum of the forces on the object is zero in which of the cases?

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

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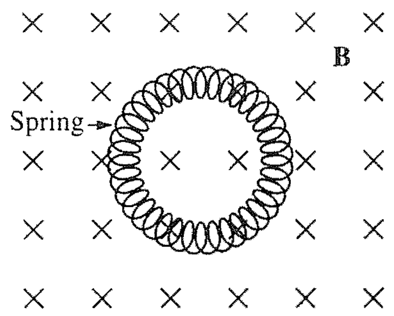

45. A metal spring has its ends attached so that it forms a circle. It is placed in a uniform magnetic field, as shown above. Which of the following will NOT cause a current to be induced in the spring?

(A) Changing the magnitude of the magnetic field
(B) Increasing the diameter of the circle by stretching the spring
(C) Rotating the spring about a diameter
(D) Moving the spring parallel to the magnetic field
(E) Moving the spring in and out of the magnetic field

Questions 46-47

A magnetic field of 0.1 T forces a proton beam of 1.5 mA to move in a circle of radius 0.1 m. The plane of the circle is perpendicular to the magnetic field.

46. Of the following, which is the best estimate of the work done by the magnetic field on the protons during one complete orbit of the circle?

(A) 0 J
(B) 10^{-22} J
(C) 10^{-5} J
(D) 10^{2} J
(E) 10^{20} J

47. Of the following, which is the best estimate of the speed of a proton in the beam as it moves in the circle?

(A) 10^{-2} m/s
(B) 10^{3} m/s
(C) 10^{6} m/s
(D) 10^{8} m/s
(E) 10^{15} m/s

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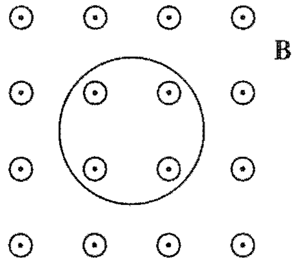
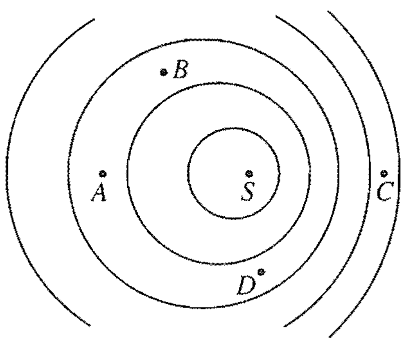


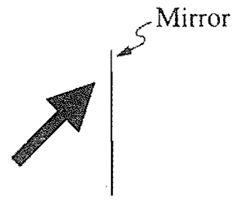
48. A single circular loop of wire in the plane of the page is perpendicular to a uniform magnetic field **B** directed out of the page, as shown above. If the magnitude of the magnetic field is decreasing, then the induced current in the wire is

(A) directed upward out of the paper
(B) directed downward into the paper
(C) clockwise around the loop
(D) counterclockwise around the loop
(E) zero (no current is induced)



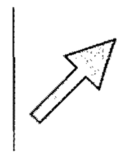
49. A small vibrating object on the surface of a ripple tank is the source of waves of frequency 20 Hz and speed 60 cm/s. If the source S is moving to the right, as shown above, with speed 20 cm/s, at which of the labeled points will the frequency measured by a stationary observer be greatest?

(A) A
(B) B
(C) C
(D) D
(E) It will be the same at all four points.

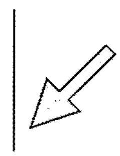


50. An object, slanted at an angle of 45°, is placed in front of a vertical plane mirror, as shown above. Which of the following shows the apparent position and orientation of the object's image?

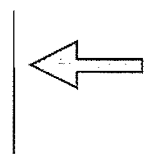
(A)



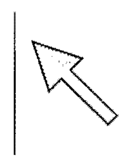
(B)



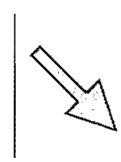
(C)

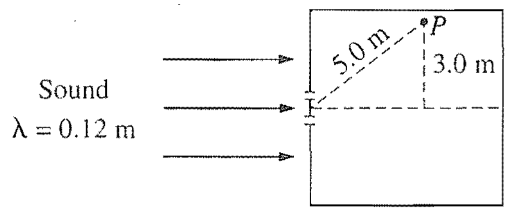


(D)



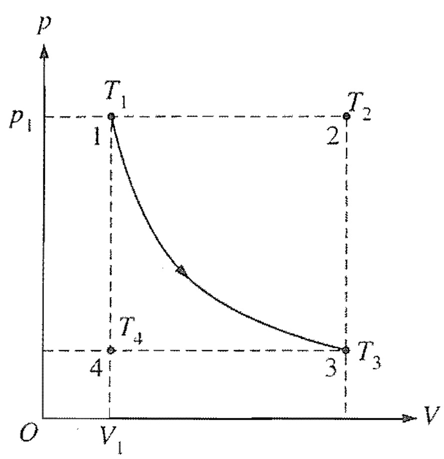
(E)





51. Plane sound waves of wavelength 0.12 m are incident on two narrow slits in a box with nonreflecting walls, as shown above. At a distance of 5.0 m from the center of the slits, a first-order maximum occurs at point P, which is 3.0 m from the central maximum. The distance between the slits is most nearly

(A) 0.07 m
(B) 0.09 m
(C) 0.16 m
(D) 0.20 m
(E) 0.24 m



52. An ideal gas is initially in a state that corresponds to point 1 on the graph above, where it has pressure p_1, volume V_1, and temperature T_1. The gas undergoes an isothermal process represented by the curve shown, which takes it to a final state 3 at temperature T_3. If T_2 and T_4 are the temperatures the gas would have at points 2 and 4, respectively, which of the following relationships is true?

(A) $T_1 < T_3$
(B) $T_1 < T_2$
(C) $T_1 < T_4$
(D) $T_1 = T_2$
(E) $T_1 = T_4$

53. The absolute temperature of a sample of monatomic ideal gas is doubled at constant volume. What effect, if any, does this have on the pressure and density of the sample of gas?

	Pressure	Density
(A)	Remains the same	Remains the same
(B)	Remains the same	Doubles
(C)	Doubles	Remains the same
(D)	Doubles	Is multiplied by a factor of 4
(E)	Is multiplied by a factor of 4	Doubles

54. The disk-shaped head of a pin is 1.0 mm in diameter. Which of the following is the best estimate of the number of atoms in the layer of atoms on the top surface of the pinhead?

(A) 10^4
(B) 10^{14}
(C) 10^{24}
(D) 10^{34}
(E) 10^{50}

55. In an experiment, light of a particular wavelength is incident on a metal surface, and electrons are emitted from the surface as a result. To produce more electrons per unit time but with less kinetic energy per electron, the experimenter should do which of the following?

(A) Increase the intensity and decrease the wavelength of the light.
(B) Increase the intensity and the wavelength of the light.
(C) Decrease the intensity and the wavelength of the light.
(D) Decrease the intensity and increase the wavelength of the light.
(E) None of the above would produce the desired result.

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56. An object moves up and down the y-axis with an acceleration given as a function of time t by the expression $a = A \sin \omega t$, where A and ω are constants. What is the period of this motion?

(A) ω

(B) $2\pi\omega$

(C) $\omega^2 A$

(D) $\frac{2\pi}{\omega}$

(E) $\frac{\omega}{2\pi}$

57. A ball of mass 0.4 kg is initially at rest on the ground. It is kicked and leaves the kicker's foot with a speed of 5.0 m/s in a direction 60° above the horizontal. The magnitude of the impulse imparted by the ball to the foot is most nearly

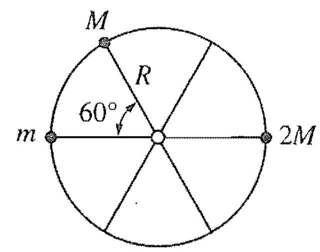
(A) 1 N·s

(B) $\sqrt{3}$ N·s

(C) 2 N·s

(D) $\frac{2}{\sqrt{3}}$ N·s

(E) 4 N·s



58. A wheel of radius R and negligible mass is mounted on a horizontal frictionless axle so that the wheel is in a vertical plane. Three small objects having masses m, M, and $2M$, respectively, are mounted on the rim of the wheel, as shown above. If the system is in static equilibrium, what is the value of m in terms of M ?

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

(B) M

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

(D) $2M$

(E) $\frac{5M}{2}$

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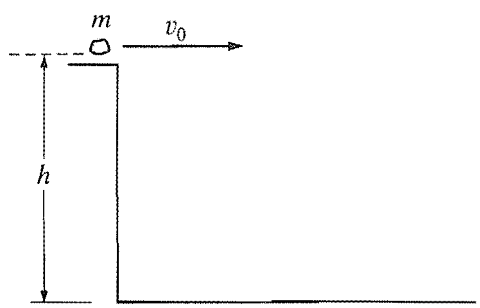
Questions 59-60



A rock of mass m is thrown horizontally off a building from a height h, as shown above. The speed of the rock as it leaves the thrower's hand at the edge of the building is v_0.

59. How much time does it take the rock to travel from the edge of the building to the ground?

(A) $\sqrt{hv_0}$

(B) h/v_0

(C) hv_0/g

(D) $2h/g$

(E) $\sqrt{2h/g}$

60. What is the kinetic energy of the rock just before it hits the ground?

(A) mgh

(B) $\frac{1}{2}mv_0^2$

(C) $\frac{1}{2}mv_0^2 - mgh$

(D) $\frac{1}{2}mv_0^2 + mgh$

(E) $mgh - \frac{1}{2}mv_0^2$

61. Which of the following statements is NOT a correct assumption of the classical model of an ideal gas?

(A) The molecules are in random motion.
(B) The volume of the molecules is negligible compared with the volume occupied by the gas.
(C) The molecules obey Newton's laws of motion.
(D) The collisions between molecules are inelastic.
(E) The only appreciable forces on the molecules are those that occur during collisions.

62. A sample of an ideal gas is in a tank of constant volume. The sample absorbs heat energy so that its temperature changes from 300 K to 600 K. If v_1 is the average speed of the gas molecules before the absorption of heat and v_2 is their average speed after the absorption of heat, what is the ratio v_2/v_1 ?

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

(B) 1

(C) $\sqrt{2}$

(D) 2

(E) 4

63. Two people of unequal mass are initially standing still on ice with negligible friction. They then simultaneously push each other horizontally. Afterward, which of the following is true?

(A) The kinetic energies of the two people are equal.
(B) The speeds of the two people are equal.
(C) The momenta of the two people are of equal magnitude.
(D) The center of mass of the two-person system moves in the direction of the less massive person.
(E) The less massive person has a smaller initial acceleration than the more massive person.

64. Two parallel conducting plates, separated by a distance d, are connected to a battery of emf $\mathcal{E}$. Which of the following is correct if the plate separation is doubled while the battery remains connected?

(A) The electric charge on the plates is doubled.
(B) The electric charge on the plates is halved.
(C) The potential difference between the plates is doubled.
(D) The potential difference between the plates is halved.
(E) The capacitance is unchanged.

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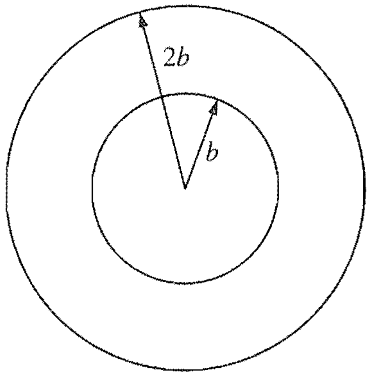
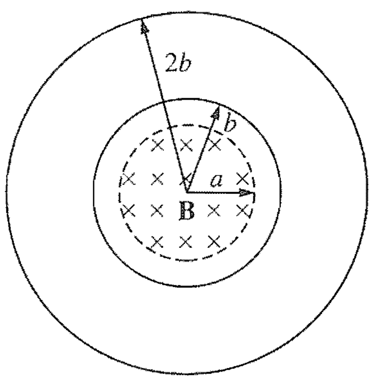
Questions 65-66



Two concentric circular loops of radii b and $2b$, made of the same type of wire, lie in the plane of the page, as shown above.

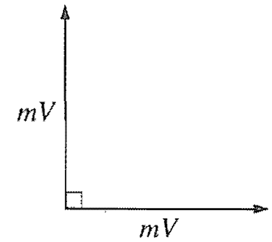
65. The total resistance of the wire loop of radius b is R. What is the resistance of the wire loop of radius $2b$?

(A) $R/4$
(B) $R/2$
(C) R
(D) $2R$
(E) $4R$



66. A uniform magnetic field $\mathbf{B}$ that is perpendicular to the plane of the page now passes through the loops, as shown above. The field is confined to a region of radius a, where $a < b$, and is changing at a constant rate. The induced emf in the wire loop of radius b is $\mathcal{E}$. What is the induced emf in the wire loop of radius $2b$?

(A) Zero
(B) $\mathcal{E}/2$
(C) $\mathcal{E}$
(D) $2\mathcal{E}$
(E) $4\mathcal{E}$



67. A stationary object explodes, breaking into three pieces of masses m, m, and $3m$. The two pieces of mass m move off at right angles to each other with the same magnitude of momentum mV, as shown in the diagram above. What are the magnitude and direction of the velocity of the piece having mass $3m$?

	Magnitude	Direction
(A)	$\frac{V}{\sqrt{3}}$	
(B)	$\frac{V}{\sqrt{3}}$	
(C)	$\frac{\sqrt{2}\,V}{3}$	
(D)	$\frac{\sqrt{2}\,V}{3}$	
(E)	$\sqrt{2}\,V$	

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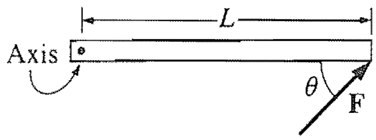


View from Above

68. A rod on a horizontal tabletop is pivoted at one end and is free to rotate without friction about a vertical axis, as shown above. A force **F** is applied at the other end, at an angle θ to the rod. If **F** were to be applied perpendicular to the rod, at what distance from the axis should it be applied in order to produce the same torque?

(A) $L \sin \theta$
(B) $L \cos \theta$
(C) L
(D) $L \tan \theta$
(E) $\sqrt{2}\, L$

69. Which of the following imposes a limit on the number of electrons in an energy state of an atom?

(A) The Heisenberg uncertainty principle
(B) The Pauli exclusion principle
(C) The Bohr model of the hydrogen atom
(D) The theory of relativity
(E) The law of conservation of energy

70. A 4 μF capacitor is charged to a potential difference of 100 V. The electrical energy stored in the capacitor is

(A) 2×10^{-10} J
(B) 2×10^{-8} J
(C) 2×10^{-6} J
(D) 2×10^{-4} J
(E) 2×10^{-2} J

S T O P

END OF SECTION I

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

DO NOT GO ON TO SECTION II UNTIL YOU ARE TOLD TO DO SO.

Answers with explanation

1. B. The vacuum chamber removes air resistance. All objects fall with the same acceleration in the absence of air resistance, so at the end of one meter, each object has attained the same speed, according to Galileo IV: $2a(x - x_o) = v^2 - v_o^2$.

2. C. Power = Work/time = mgh/t = (700 nt)(8 m)/10 sec = 560 W. Note: 700 nt = mg, not just m. (Observe that the mean ol' examiners expected people to use 700 for m, and multiply by a factor of g = 10 m/sec^2; that's why they put the answer 5600 Watts in for choice E. Nasty. The examiners are *not* your friends.

3. E. Conservation of momentum: mv = (m + M)V, or V = mv/(m + M).

4. C. The rain has no horizontal velocity before it lands in the cart. Once it lands in the cart, it gains horizontal velocity, so this must come from the horizontal velocity that the cart had before the rain fell in. The cart with its increased mass must slow down.

5. C. A Watt is a Joule/sec, so both are power. Kilowatt-hours are units of power times time; this is energy. (For the record, one kilowatt-hour is 3.6 megajoules, as you should convince yourself.)

6. E. The formula for angular momentum is mvr or mvr sin θ where θ is the angle between the velocity vector **v** and the radius vector **r**. Since it is moving in a circle at a constant speed, we know **v** is perpendicular to **r**. Then the angle is 90°, and mvr = (2 kg) (3 m/sec) (4 m) = 24 kg-m/sec. The net force of 4.5 nt has *nothing* to do with the angular momentum; it is there merely to confuse you. The examiners are *not* your friends.

7. A. "Translational equilibrium" means that the net forces add up to zero (so, if the object is moving, its velocity must be constant. It doesn't *have* to be motionless!)

8. D. Recall that the potential energy and kinetic energy graphs are reflections of each other about the line $E = {}^{1}/2\ E_o$, where E_o is the total energy of the system. Also, at the endpoints, the kinetic energy must be zero, and at the midpoint, the kinetic energy must be a maximum. E is a possibility, but the graph isn't linear.

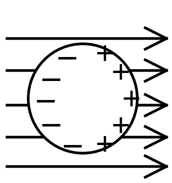
9. A. There are several things you have to put together for this problem. First, the speed is constant. That means the net force on the box is zero. Thus the child's force horizontally must be exactly equal to the friction. Next, we are told that the kid pushes horizontally. The normal force is just mg. (If the kid pushed down, we'd have N > mg; if the kid pushed up, we'd have N < mg.) Then the friction f = μN = μmg. Finally, a somewhat obscure formula for power is P = Fv cos θ = Fv since the kid is pushing horizontally. That is, the power is $F_{kid}v$ = fv = μmgv.

10. A. X–rays are of course very energetic. That means that electrons must fall a long way, from some distant orbit to an orbit very near the nucleus. Transitions in the nucleus, whether involving protons or neutrons, give rise to gamma rays, even more energetic than x–rays.

11. B. Electrons were thought to be particles from the time they were discovered (in 1896, by J.J. Thomson when he measured the q/m ratio) till about 1927, when Davisson and Germer at Bell Labs diffracted them through metal foils. It was the diffraction that established, Young-like, the wave properties of electrons. (By the way, this was Bell Labs' first Nobel Prize.) Millikan's oil-drop experiment to measure the size of the charge of the electron established by serendipity (good luck) the amazing fact that all charges are whole number multiples of the electron's charge.

12. A. Protons can turn into neutrons and vice versa, but electric charge must be conserved. It is true that the grand total of protons and neutrons, generically called nucleons, must be conserved; but it is not true that the number of *nuclei* (plural of *nucleus*) must be the same. For example, in nuclear fission, the number of nuclei usually increases. (The plural of *nucleon* is *nucleons*.)

13. A.



It has to be zero. The conducting sphere, placed in a field, will wind up becoming polarized as shown; but the net force on the sphere in a uniform field will be zero; there will be as much pull on one side as there is on the other; the net force cancels.

14. E. The formula for the electric field of a capacitor ("two parallel conducting plates") is $E = V/d$. If we double the voltage and at the same time decrease the plate separation by a factor of 5, this results in a net increase of $2/(^1/5)$ = 10 times.

15. A. Imagine connecting a battery's terminals to the two dark circles at X and Y. Then we need to find the net resistance between X and Y. The 1 Ω and 3 Ω resistors are in series; they act as a single 4 Ω resistor. Then this 4 Ω is in parallel with the 2 Ω resistor, so $^1/R_{net} = {}^1/4 + {}^1/2 = {}^3/4$ so $R_{net} = {}^4/3\ \Omega = 1^1/3\ \Omega$.

16. E. "Amount of charge passing a point per unit of time" = Current, I. Current is the same in the 1 Ω and 3 Ω resistors, and less than in the 2 Ω resistor.

17. C. The charge at the upper left leads to a field pointing straight down at point P; the charge at the lower right leads to a field pointing left at point P; the net effect is down and to the left. (Fields add as vectors.)

18. D. The electric potential $\varphi = \Sigma\ kq/R = kQ/d + kQ/d = 2kQ/d$; and $U = q\varphi = 2kQq/d$. Recall that $k = 1/4\pi\varepsilon_o$, so we can rewrite U as $U = (2/4\pi\varepsilon_o)Qq/d$.

19. C. Magnetic flux, Φ_B, is given by $\Phi_B = BA \cos\theta$ which in this case is (2 T)(0.05 m)(0.08 m) cos 0 = 0.008 T-m^2.

20. D. We need to find the power needed, P = IV, and multiply by the time, 2 hours. That is, P = (4 A)(120 V) = 480 W. Then for two hours, the energy is 480 W * 2 hrs = 960 Watt-hours = 0.96 kW-hours. If the energy costs 10¢ per kW-hr, this will be 9.6¢. (The symbol ¢ stands for "cents".)

21. A. You need to be careful about the negative charge. Were this a positive charge, you'd use your right hand to find (index finger in the direction down, middle finger out of the page of the paper, and thumb to the left) the force on a positive charge would be to the left. Therefore, the force on a negative charge will be to the right.

22. A. The work done is the area under the curve. The area under curve 1 is greater than under curve 2 or curve 3.

23. A. Use the ideal gas law, PV = nRT. Since T is proportional to PV, we need the highest product of P and V to give the highest temperature. But, the endpoints of all three processes have the same final volume, $V_o/2$. So, the highest temperature corresponds to the highest value of P. This occurs for process 1.

24. C. Use the First Law of Thermodynamics: $\Delta E = Q - W$. In this case, Q = + 400 J and W = + 100 J, so ΔE = 300 J.

25. B. (This problem is more trouble than it is worth.) We have to get the ice from T_1 to T_2 = 273 K; we have to melt the ice at 273 K to water at 273 K; we have to get the water from 273 K to T_2. The good news is that T_2 is less than boiling.

Q for ice from T_1 to 273 K = $MC_{ice}(273 - T_1)$

Q to melt the ice = ML

Q to heat water from 273 K to T_2 = $MC_{water}(T_2 - 273)$

Net Q = $M\ [C_{ice}(273 - T_1) + L + C_{water}(T_2 - 273)]$ (factoring out the common M.)

26. B. First, you need to remember that the focal length for a spherical mirror (and we are invited to take this one as spherical, since they speak of the radius of curvature) is half the radius; so f = 0.5 m. Next, a "distant" star is supposed to be taken as infinitely far away. Now use the ol' lens equation, $1/f = 1/d_o + 1/d_i$. Then

$1/d_i = 1/0.5 + 1/\infty$ or $d_i = 0.5$ m.

(General rule: images of very distant objects wind up at the focus for a converging thing, lens or mirror.)

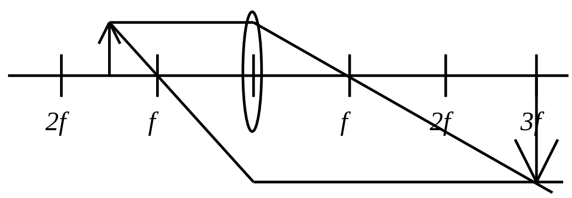
27. E. It's amazing that they actually told you that the frequency of the wave stays the same. Since $v = \lambda f$, if f doesn't change, then whatever happens to v happens to λ. You are supposed to know that v_{light} is less in water than in air, so both v and λ decrease.

28. D. The definition of magnification $m = -h_i/h_o = -d_i/d_o$. They don't want you messed up by the sign, so they ask only for the magnitude. So find d_i ;

$$1/9 = 1/6 + 1/d_i \text{ and } d_i = -18 \text{ cm (a virtual image), and } m = -(-18 \text{ cm}/6 \text{ cm}) = 3.$$

29. B. If energy is conserved, the amplitude must be the same, and the speed of the wave depends only on the tension in the string and the density of the string, which presumably are not changed by the wave's reflection. But the phase is flipped, since the density of the wall is much greater than the density of the string.

30. D. The rule is that if $d_o > 2f$, the image is smaller; if $d_o = 2f$, the image is the same size; and if $d_o < 2f$, the image is larger. (If $d_o < f$, the image is virtual, but it is still larger.) If worse comes to worst, draw the relevant ray diagram:



31. A. Since the rays in the first and the third medium are parallel, the n's in those two media must be the same. It is also true that the index of refraction in medium 2 is greater than in either medium 1 or medium 3 (since the light bends towards the normal in the more optically dense medium.) That rules out B., C. and E. We have no way of knowing what n_1 is equal to, and it certainly does not have to be equal to 1.

32. B. The halflife of the material is thirty minutes (since we go from 4000 decays a minute at noon to 2000 decays a minute at 12:30.) At 1:00 the count will be 1000 a minute, and at 1:30 at 500 counts a minute.

33. D. The negative beta particle is of course an electron. This means that a neutron has been converted into a proton, and both an electron and an (anti)neutrino are ejected. The resulting nucleus has the top, mass number A unchanged (the top number remains at 214) and the bottom, atomic number Z increases from 82 to 83.

34. B. The de Broglie wavelength $\lambda_{dB} = h/p$, where h = Planck's constant and p = the momentum of the particle. If the momentum doubles, the de Broglie wavelength is cut in half.

35. A. Rutherford's scattering of alpha particles can be understood in terms of Newtonian physics and Coulomb's Law. All the other experiments require Planck's constant.

36. A. At point A, half of the original number of atoms is still present, so the time at point A represents the half life.

37. A. The momentum of light, p_{light} , = E/c. Since E = hf, we can say p_{light} = hf/c. So p is directly proportional to f.

38. D. This is a deliberately misleading question, because they are asking you to compare the distance stretched at equilibrium of one mass, the 3 kg, with the furthest distance a second mass, the 4 kg mass, would fall if dropped. But as you may be able to convince yourself, the distance the spring falls when dropped before it begins to return is equal to *twice* the amplitude. Let's see how this comes about.

Suppose we hang a mass m on a vertical spring, and gently lower the mass until it no longer falls. At this point it hangs motionless; it is at equilibrium, and the net force on it is zero. Say the spring is now stretched a distance x. Then we must have

$$F_{net} = kx - mg = 0, \text{ or } x_{equilib} = mg/k.$$

Now lift the mass to the original unstretched length, and drop it suddenly. At the lowest point, we have that the kinetic energy equals zero. Call the initial position x = 0, and the total energy at this point is

$$E_{top} = K + U_{grav} + U_{spring} = 0 + mg{*}0 + {}^{1}/2\, k{*}(0)^2$$

At the bottom point, say at a distance of h below the starting point, once again we have v = 0, so K = 0, and

38., continued

$$E_{bottom} = K + U_{grav} + U_{spring} = 0 + mg*(-h) + {}^{1}/2\ k*(-h)^{2}$$

But this must be equal to E_{top}, which is zero. That is,

$$0 = -\ mgh + {}^{1}/2\ kh^{2} = h({}^{1}/2\ kh - mg);$$

either h = 0 (which is just at the top) or h = 2mg/k, which is *twice* the equilibrium distance, QED.

Now we answer the question. If 3 kg stretches the spring 12 cm, then (as F = kx = mg) 4 kg will stretch it 16 cm, and the distance the mass will fall if dropped will be 2*16 = 32 cm. Not too surprisingly, only 15% of the students taking the test got this one right. In my opinion, it wasn't the physics that stumped people, but the tricky way the question was asked.

39. E. F_{grav} is proportional to the inverse square of R, so if R is increased by 4 times, the weight is decreased by 16 times.

40. B. For a stable circular orbit, we have to have $F_{net} = mv^2/R = GMm/R^2$, or $v^2 = GM/R$. Then the kinetic energy is

$$K = {}^{1}/2\ mv^{2} = {}^{1}/2\ m\ GM/R = {}^{1}/2\ GMm/R$$

Note that the *total* energy of a satellite in circular orbit is given by

$$E = K + U = {}^{1}/2\ mGM/R - GMm/R = -{}^{1}/2\ GMm/R.$$

The negative indicates that the satellite is *captured*; its motion is bounded by energy.

41. A. Before the collision, there is no net momentum in the y direction. After the collision, by conservation of momentum, there must be no net momentum in the y direction. That means $(0.2)(0.1) + (0.1)(v_y) = 0$, or $v_y = -\ 2$ m/sec.

42. E. The effective index of refraction of the prism will now be in the ratio of 1.5:1.3 = 1.15. The violet will still be bent the most, however, and the red the least; but the separation will be less since the index of refraction will be effectively less.

43. B. Graph I indicates a constant, nonzero velocity. Graph II represents a constant, but zero, velocity. Graph III indicates acceleration. It alone will have momentum increasing.

44. C. A famous trick question. If the forces add up to zero, it does not mean that the object has to be at rest; it means only that the object is not accelerating. Graph I and Graph II both describe constant velocity (and no acceleration), o both of them describe a net force equalling zero.

45. D. Faraday's Law. We will get an induced voltage, and hence an induced current, if the flux changes. Either B needs to change, or A needs to change, or the orientation of A with respect to B needs to change. All of the possible answers, except for D, will do one of these things.

46. A. Another famous trick question. Recall that Work = $F\Delta x \cos\theta$. But in uniform circular motion, the F is always directed towards the center of the circle, at right angles to the velocity (which is tangent to the circle.) That means that *a magnetic field cannot do work on a free charge.*

47. C. Setting $F_{mag} = F_{centrip}$, we have $qvB = mv^2/R$, or $v = qBR/m$. You need to look up the sizes of m and q for the proton, and you find the following:

$$v = (1.6 \times 10^{-19}\ \text{coul})(0.1\ \text{T})(0.1\ \text{m})/(1.67 \times 10^{-27}\ \text{kg})$$

Calculators are no longer allowed on the multiple choice part, so we have to say 1.6/1.67 ≈ 1. Then

$v \approx 10^{-21}/10^{-27} \approx 10^{6}$ m/sec. (Note that answer E. is impossible, as relativity forbids it!)

48. D. Lenz' Law. If we are taking away O's, the current tries to make up for the loss. That it does by choosing a counter-clockwise direction.

49. C. The frequency will be the greatest where the waves are most closely bunched up together. At point D, the frequency will be nearly the same as normal; at points B and A, it will be lower than normal.

50. D. Just imagine folding over the paper at the mirror.

51. D. Young's patterns, but for sound. Use the formula d sin $\theta = j\lambda$. For a "first order" maximum, j = 1, and they are asking for d. Then

$$d = 1(0.12 \text{ m})/(3/5) = 0.12/0.6 = 0.2 \text{ m}.$$

52. B. Since the curve is isothermal, we know that $T_1 = T_3$. From the ideal gas law, PV = nRT. That means T_2, at a higher pressure but the same volume as T_3, is greater than T_3 and also T_1 (since these are the same). By the same argument, T_4 is less than T_1 and hence also than T_3. In order, then, we have

$$T_2 > T_1 = T_3 > T_4.$$

53. C. Ideal Gas Law: PV = nRT. If the volume stays the same, and the temperature is doubled, then the pressure must double. The density is the mass divided by the volume. We aren't changing either, so the density must stay the same.

54. B. The average radius of an atom is on the order of an Ångstrom (0.1 nanometer). If we assume no distance between the atoms, we would say that we'd need $0.5 \times 10^{-3} / 0.1 \times 10^{-9} = 5 \times 10^6$ atoms across for the radius. And as the area goes as the radius squared, we'd estimate that the area would need $\pi(5 \times 10^6)^2$ or about 75×10^{12}, call it 10^{14} atoms. (Not too surprisingly, only 14% of the students got this right.)

55. B. The number of electrons is proportional to the intensity of the light; the energy of the electrons is proportional to the frequency of the light (and therefore inversely proportional to the wavelength of the light.)

56. D. The angular frequency ω is the same for position, velocity and acceleration. But by definition $T = 2\pi/\omega$.

57. C. Impulse is just another word for Δp. We don't need the angle here (it is just put in to confuse you.) The change in momentum is just $m\Delta v$ = (0.4 kg)(5 m/sec – 0 m/sec) = 2 kg–m/sec = 2 nt–sec.

58. C. For rotational equilibrium, we have to have the net torque equal to zero. The clockwise torque is 2MgR.The counter-clockwise torques are mgR and MgR cos 60 = $^1/_2$ MgR. That is, we need

$$2MgR = mgR + \tfrac{1}{2} MgR \text{ , or } m = \tfrac{3}{2} M.$$

59. E. Since the original velocity is horizontal, it has no effect on the time needed for the object to drop. Merely set $h = \frac{1}{2} gt^2$ (Galileo I.) and solve for t; $t = \sqrt{2h/g}$.

60. D. Conservation of Energy! When the object is thrown, its total energy is $mgh + \frac{1}{2} mv_o^2$. Just as it hits the ground, its energy is entirely kinetic, and must be equal to this initial energy. (It is astonishing to me that only 30% of the students got this one correctly!)

61. D. The assumption is that the collisions are elastic.

62. C. Recall that $\langle E \rangle = \frac{3}{2} k_B T$ where k_B is Boltzmann's constant. But the average energy $\langle E \rangle$ is just kinetic energy, which means that $\langle v^2 \rangle$ is proportional to T. So, if the temperature is doubled, then the velocity increases by $\sqrt{2}$.

63. C. Conservation of momentum! The lighter guy speeds up more than the heavier guy, and his kinetic energy will likewise be greater. That rules out A. and B. The center of mass will not move, which rules out D. Finally, the less massive person will accelerate more than the heavier person.

64. B. Capacitance is directly proportional to the area of the plates, and inversely proportional to the plate separation. That means that if the plates are pulled apart with the battery still connected, the voltage will remain the same but C will decrease. Since $q = CV$, we have both C and q getting smaller, while V stays the same. (The relevant formula is $C = A/4\pi kd$.)

65. D. A companion to 64. The formula for resistance is $R = \rho L/A$, where $\rho L/A$, is the resistivity of the metal, L the length of the wire, and A the cross-sectional area. The circumference of the larger circle is twice that of the smaller circle, and all else is the same, so R for the larger circle is twice that of the smaller circle.

66. C. The changing flux contained within the inner circle is exactly the same as that contained within the outer circle. (Recall that the flux is the overlap of the magnetic field and the area.) Therefore, the induced voltages are the same in both wires. (This seems to have been the hardest problem on the test; only 9% got it right.)

67. D. Conservation of momentum. We have before the explosion that $\mathbf{p}_{total} = 0$, so we must have after the explosion

$$\mathbf{p}_1 + \mathbf{p}_2 + \mathbf{p}_3 = 0 \text{ or } \mathbf{p}_3 = -(\mathbf{p}_1 + \mathbf{p}_2) = -(m(0, V) + m(V, 0)) = -(mV, mV).$$

but $\mathbf{p}_3 = 3m(v_x, v_y)$, so we have $3m(v_x, v_y) = -(mV, mV)$, or

$$3v_x = -V \text{ and } 3v_y = -V. \quad \text{Then } \boldsymbol{v} = (-V/3, -V/3) \text{ and by Pythagoras, } v = V\sqrt{2}/3.$$

68. A. By definition, torque $\tau = rF \sin\theta$, so in the present case, $\tau = LF \sin\theta$. Were the force to be applied perpendicular at a distance x, we'd have $\tau = xF$. If this is to equal $LF \sin\theta$, we have to have $x = L \sin\theta$.

69. B. Pauli's principle forbids more than two electrons in the same orbital.

70. E. Energy of a capacitor = $\frac{1}{2} CV^2 = \frac{1}{2} (4 \times 10^{-6}\text{ F})(10^2\text{ V})^2 = 2 \times 10^{-2}$ J.

Here's the breakdown by topic:

Unit	*Problems on test*	*Actual %*	*Target %*
Mechanics	1–9, 38–41, 43, 44, 56–60, 63, 67, 68	23/70 = 32.8%	35%
Heat & Thermodynamics	22–25, 52, 53, 61, 62	8/70 = 11.4%	10%
Electricity & Magnetism	13–21, 45–48, 64–66, 70	17/70 = 24.3%	25%
Optics, Waves & Sound	26–31, 42, 49–51	10/70 = 14.3%	15%
Modern Physics	10–12, 32–37, 54, 55, 69	12/70 = 17.1%	15%