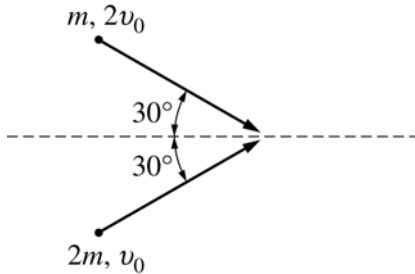


## MAJOR FIELD TEST IN PHYSICS SAMPLE QUESTIONS

The following questions illustrate the range of the test in terms of the abilities measured, the disciplines covered, and the difficulty of the questions posed. They should not, however, be considered representative of the entire scope of the test in either content or difficulty. An answer key follows the questions.



- The figure above shows two objects with masses and velocities as indicated. The objects are moving on a horizontal, frictionless surface. When they collide, the objects stick together. Their speed after the collision is most nearly

(A)  $0.67 v_0$   
 (B)  $0.87 v_0$   
 (C)  $v_0$   
 (D)  $1.15 v_0$   
 (E)  $1.73 v_0$
- Ball 1 is dropped from height  $h$  and ball 2 is dropped from height  $h/2$ . Which of the following gives the ratio of the speed of ball 1 to that of ball 2 just before impact? (Assume that air resistance is negligible.)

(A) 2  
 (B)  $\sqrt{2}$   
 (C) 1  
 (D)  $\frac{1}{\sqrt{2}}$   
 (E)  $\frac{1}{2}$
- Two planets of masses  $m$  and  $M$ , respectively, have a center-to-center separation of  $R$ . At what distance from the center of the planet of mass  $M$  do the gravitational forces of the planets cancel each other?

(A)  $\left(\frac{m}{M}\right)R$   
 (B)  $\left(1 + \frac{m}{M}\right)R$   
 (C)  $\sqrt{\frac{m}{M}}R$   
 (D)  $\left(1 + \sqrt{\frac{m}{M}}\right)R$   
 (E)  $\frac{R}{1 + \sqrt{\frac{m}{M}}}$
- A metal block is suspended in an empty tank from a scale indicating a weight of  $W$ . The tank is then filled with water until the block is covered. If the density of the metal is three times the density of water, what apparent weight of the block does the scale now read?

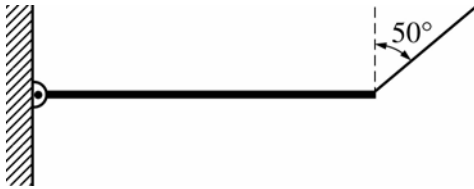
(A)  $\frac{1}{2}W$   
 (B)  $\frac{2}{3}W$   
 (C)  $W$   
 (D)  $\frac{3}{2}W$   
 (E)  $3W$

5. A 1-kilogram particle is attached to a spring and exhibits one-dimensional simple harmonic motion. The particle's distance from its equilibrium position is given by the expression

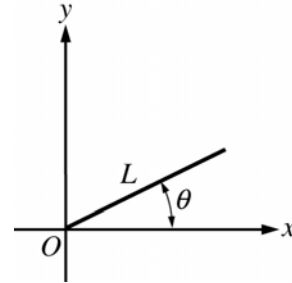
$$y(t) = A \sin\left(\omega t + \frac{\pi}{2}\right),$$

where  $A = 1$  meter and  $\omega = 0.5$  radian per second. If the potential energy of the particle at its equilibrium position is null, which of the following gives the total energy of the particle?

- (A) 2 J  
 (B) 1 J  
 (C)  $\frac{1}{2}$  J  
 (D)  $\frac{1}{8}$  J  
 (E) 0



6. The figure above shows a uniform rod of mass 4 kilograms that is pivoted at one end and supported by a string at the other end. If the rod is at rest, the tension in the string is most nearly
- (A) 20 N  
 (B) 26 N  
 (C) 31 N  
 (D) 40 N  
 (E) 62 N

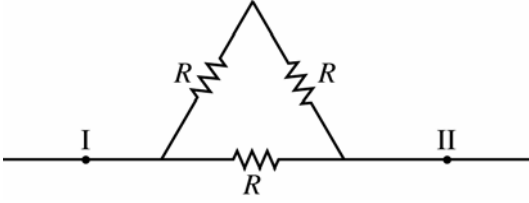


7. A stick of length  $L$  lies in the  $xy$  plane as shown above. An observer moving with velocity  $0.8c$  in the  $x$  direction measures the length of the stick. Which of the following gives the components of the length as measured by the observer?

$L_x$	$L_y$
(A) $L \cos \theta$	$0.60 L \sin \theta$
(B) $0.60 L \cos \theta$	$0.60 L \sin \theta$
(C) $0.60 L \cos \theta$	$L \sin \theta$
(D) $0.64 L \cos \theta$	$0.64 L \sin \theta$
(E) $0.78 L \cos \theta$	$0.78 L \sin \theta$

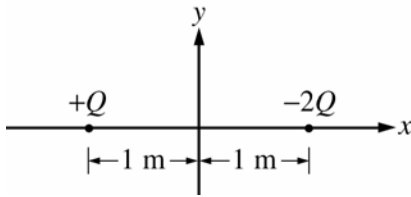


8. A capacitor of capacitance 125 microfarads is initially charged such that the voltage across the plates of the capacitor is found to be 100 volts. If the capacitor is then connected in series to a pure inductor of inductance 0.2 henry, what is the maximum value of the current that is observed in the inductor?
- (A) 1.0 A  
 (B) 2.5 A  
 (C) 4.5 A  
 (D) 5.0 A  
 (E) 10.0 A



9. If  $V$  is the potential difference between points **I** and **II** in the diagram above and all three resistors have the same resistance  $R$ , what is the total current between **I** and **II**?

- (A)  $\frac{V}{3R}$   
 (B)  $3VR$   
 (C)  $\frac{2V}{3R}$   
 (D)  $\frac{3VR}{2}$   
 (E)  $\frac{3V}{2R}$



10. A charge of  $+Q$  coulombs is placed on the  $x$ -axis at  $x = -1$  meter and a charge of  $-2Q$  coulombs is placed at  $x = +1$  meter, as shown above. At what position on the  $x$ -axis will a test charge of  $+q$  coulombs experience zero net force?

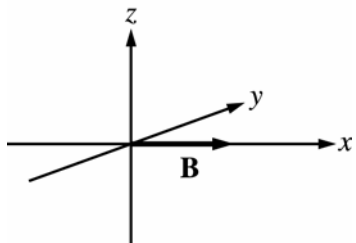
- (A)  $-(3 + \sqrt{8})$  m  
 (B)  $-\frac{1}{3}$  m  
 (C) 0 m  
 (D)  $\frac{1}{3}$  m  
 (E)  $(3 + \sqrt{8})$  m

11. An insulating sphere of radius  $R$  has a total charge  $Q$  and a uniform charge density. The electric field at a point  $\frac{R}{3}$  from the center of the sphere is given by which of the following?

- (A)  $\frac{Q}{12\pi\epsilon_0 R^2}$   
 (B)  $\frac{Q}{8\pi\epsilon_0 R^2}$   
 (C)  $\frac{Q}{6\pi\epsilon_0 R^2}$   
 (D)  $\frac{Q}{4\pi\epsilon_0 R^2}$   
 (E)  $\frac{3Q}{4\pi\epsilon_0 R^2}$

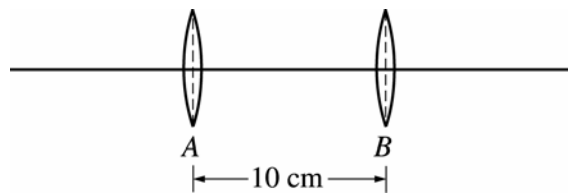
12. Four meters of wire form a square that is placed perpendicular to a uniform magnetic field of strength 0.10 tesla. The wire is reduced in length by 4.0 centimeters per second while still maintaining its square shape. Which of the following gives the initial induced emf across the ends of the wire?

- (A) 1 mV  
 (B) 2 mV  
 (C) 4 mV  
 (D) 8 mV  
 (E) 16 mV

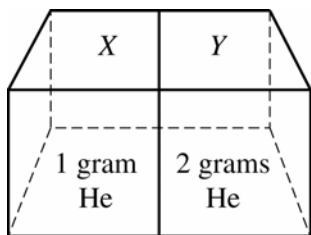


13. A linearly polarized electromagnetic plane wave carries energy in the positive  $z$ -direction. At some position  $\mathbf{r}$  and time  $t$ , the magnetic field points along the positive  $x$ -axis, as shown in the figure above. At that position and time, the electric field points along the
- (A) positive  $y$ -axis  
 (B) negative  $y$ -axis  
 (C) positive  $z$ -axis  
 (D) negative  $z$ -axis  
 (E) negative  $x$ -axis

14. An observer looks through a slit of width  $5 \times 10^{-4}$  meter at two lanterns a distance of 1 kilometer from the slit. The lanterns emit light of wavelength  $5 \times 10^{-7}$  meter. The minimum separation of the lanterns at which the observer can resolve the lantern lights is most nearly
- (A) 0.01 m  
 (B) 0.1 m  
 (C) 1 m  
 (D) 10 m  
 (E) 100m



15. Two thin converging lenses  $A$  and  $B$ , each having a focal length of 6 centimeters, are placed 10 centimeters apart, as shown in the figure above. If an object is placed 10 centimeters to the left of lens  $A$ , the final image is
- (A) 30 cm to the right of lens  $B$   
 (B)  $\frac{30}{11}$  cm to the right of lens  $B$   
 (C)  $\frac{30}{10}$  cm to the right of lens  $B$   
 (D)  $\frac{30}{11}$  cm to the left of lens  $B$   
 (E)  $\frac{30}{10}$  cm to the left of lens  $B$
16. Two identical sinusoidal waves travel in opposite directions in a wire 15 meters long and produce a standing wave in the wire. The traveling waves have a speed of 12 meters per second and the standing wave has 6 nodes, including those at the two ends. Which of the following gives the wavelength and frequency of the standing wave?
- |     | <u>Wavelength</u> | <u>Frequency</u> |
|-----|-------------------|------------------|
| (A) | 3 m               | 2 Hz             |
| (B) | 3 m               | 4 Hz             |
| (C) | 6 m               | 2 Hz             |
| (D) | 6 m               | 3 Hz             |
| (E) | 12 m              | 2 Hz             |



17. Cubical tanks  $X$  and  $Y$  have the same volumes and share a common wall. There is 1 gram of helium in tank  $X$  and 2 grams of helium in tank  $Y$ , and both samples are at the same temperature. Which of the following is the same for both samples?

- (A) The number of molecular collisions per second on the common wall
- (B) The average speed of the molecules
- (C) The pressure exerted by the helium
- (D) The density of the helium
- (E) The mean free path of the molecules

18. If one mole of an ideal gas doubles its volume as it undergoes an isothermal expansion, its pressure is

- (A) quadrupled
- (B) doubled
- (C) unchanged
- (D) halved
- (E) quartered

19. A power plant takes in steam at  $527^\circ\text{C}$  to power turbines and then exhausts the steam at  $127^\circ\text{C}$ . In any given time, it consumes 100 megawatts of heat energy from the steam. The maximum possible power output of the power plant is

- (A) 10 MW
- (B) 20 MW
- (C) 50 MW
- (D) 75 MW
- (E) 100 MW

20. For which of the following elements is the ionization energy of a neutral atom the lowest? ( $Z$  is the atomic number.)

- (A) Oxygen ( $Z = 8$ )
- (B) Fluorine ( $Z = 9$ )
- (C) Neon ( $Z = 10$ )
- (D) Sodium ( $Z = 11$ )
- (E) Magnesium ( $Z = 12$ )

21. The Paschen series for hydrogen corresponds to electronic transitions that end in the state of quantum number  $n = 3$ . The shortest wavelength line in the Paschen series is closest to which of the following? (The ionization energy of hydrogen is  $13.6\text{ eV}$  and  $hc = 1,200\text{ eV}\cdot\text{nm}$ .)

- (A) 125 nm
- (B) 250 nm
- (C) 400 nm
- (D) 800 nm
- (E) 1,800 nm

22. Which of the following describes the effect of doubling the absolute temperature of a blackbody on its power output per square meter and on the wavelength where the radiation distribution is a maximum?

- (A) The power output is increased by a factor of 16 and the maximum of the distribution shifts to twice its original wavelength.
- (B) The power output is increased by a factor of 16 and the maximum of the distribution shifts to half its original wavelength.
- (C) The power output is increased by a factor of 8 and the maximum of the distribution shifts to twice its original wavelength.
- (D) The power output is increased by a factor of 8 and the maximum of the distribution shifts to half its original wavelength.
- (E) The power output is increased by a factor of 2 and the maximum of the distribution shifts to four times its original wavelength.

23. Let  $H$  denote an Hermitian operator and suppose that  $H|\psi\rangle = a|\psi\rangle$ , where  $|\psi\rangle$  is an eigenvector of  $H$ . Which of the following is true of the eigenvalue  $a$ ? (The symbols  $\text{Re}$  and  $\text{Im}$  denote the real and imaginary parts, respectively.)

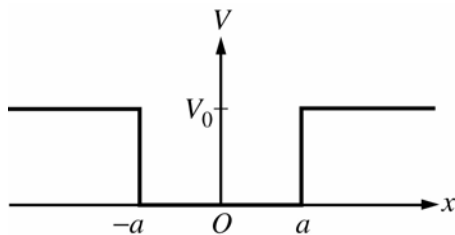
- (A)  $\text{Re}(a) = \text{Im}(a)$
- (B)  $\text{Re}(a) = -\text{Im}(a)$
- (C)  $\text{Re}(a) = 0$
- (D)  $\text{Im}(a) = 0$
- (E)  $H = a$

24. The quantum numbers used to label the radial wave function solutions to the Schrödinger equation for the hydrogen atom are the principal quantum number  $n$  and the angular momentum quantum number  $l$ . If the principal quantum number is  $n = 2$ , which of the following gives the possible values for the angular momentum quantum number  $l$ ?

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

25. The three operators  $(L_x, L_y, L_z)$  for the components of angular momentum commute with the Hamiltonian of a particular particle. Therefore, the angular momentum of the particle is

- (A) equal to zero  
 (B) equal to the energy in magnitude  
 (C) always equal to  $L_z$   
 (D) a unit vector  
 (E) a constant of the motion



26. A particle of energy  $E$  is in an eigenstate of the square well potential shown above, with wave function  $\psi(x)$ . Which of the following is a correct expression for the expectation value of  $x^2$  for this particle?

- (A)  $\int_{-a}^a x^2 \psi(x) dx$   
 (B)  $\int_{-\infty}^{\infty} x^2 \psi(x) dx$   
 (C)  $\int_{-\infty}^{\infty} \psi^*(x) x \psi(x) dx$   
 (D)  $\int_{-a}^a \psi^*(x) x^2 \psi(x) dx$   
 (E)  $\int_{-\infty}^{\infty} \psi^*(x) x^2 \psi(x) dx$

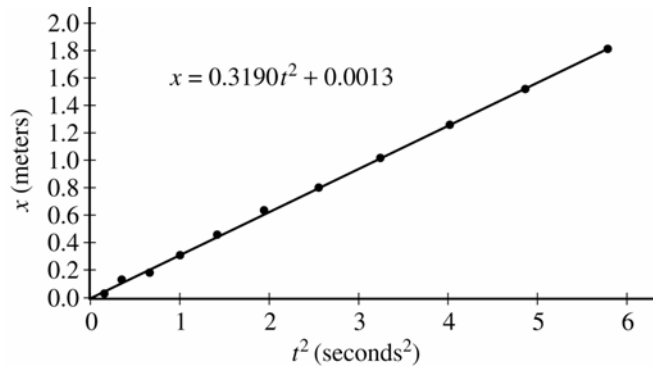
$$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad \sigma_y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \quad \sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

27. Given the Pauli spin matrices shown above and the operators defined by  $\sigma_+ \equiv \sigma_x + i\sigma_y$  and  $\sigma_- \equiv \sigma_x - i\sigma_y$ , which of the following is NOT correct?

- (A)  $\sigma_+ \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$   
 (B)  $\sigma_+ \begin{pmatrix} 0 \\ 1 \end{pmatrix} = 2 \begin{pmatrix} 1 \\ 0 \end{pmatrix}$   
 (C)  $\sigma_- \begin{pmatrix} 1 \\ 0 \end{pmatrix} = -2 \begin{pmatrix} 0 \\ 1 \end{pmatrix}$   
 (D)  $\sigma_z \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$   
 (E)  $\sigma_z \begin{pmatrix} 0 \\ 1 \end{pmatrix} = - \begin{pmatrix} 0 \\ 1 \end{pmatrix}$

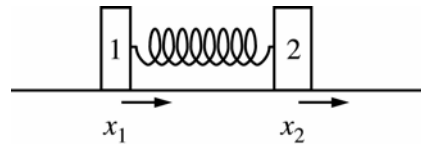
28. An experimenter measures the counting rate from a radioactive source as 10,150 counts in 100 minutes. Without changing any of the conditions, the experimenter counts for one minute. There is a probability of about 15 percent that the number of counts recorded will be fewer than

- (A) 50  
 (B) 70  
 (C) 90  
 (D) 100  
 (E) 110



29. A motion sensor is used to measure position  $x$  versus time  $t$  for a cart traveling down a ramp. A spreadsheet program is then used to make a linear fit to a plot of  $x$  versus  $t^2$ , as shown in the graph above. The equation of the best-fit line appears on the graph. Which of the following gives the acceleration of the cart?

- (A)  $0.0013 \text{ m/s}^2$   
 (B)  $0.16 \text{ m/s}^2$   
 (C)  $0.32 \text{ m/s}^2$   
 (D)  $0.64 \text{ m/s}^2$   
 (E)  $3.1 \text{ m/s}^2$



30. Two masses  $m_1$  and  $m_2$  on a horizontal, straight frictionless track are connected by a spring of spring constant  $k$ , as shown in the figure above. The spring is initially at its equilibrium length. If  $x_1$  and  $x_2$  give the displacements of the masses from their initial positions, the Lagrangian  $L$  for the system is given by which of the following? (The dot denotes differentiation with respect to time.)

- (A)  $L = \frac{1}{2} [m_1 \dot{x}_1^2 + m_2 \dot{x}_2^2] - \frac{1}{2} kx_1^2 - \frac{1}{2} kx_2^2$   
 (B)  $L = \frac{1}{2} [m_1 \dot{x}_1^2 + m_2 \dot{x}_2^2] - \frac{1}{2} k(x_2 - x_1)^2$   
 (C)  $L = \frac{1}{2} [m_1 \dot{x}_1^2 + m_2 \dot{x}_2^2] + \frac{1}{2} k(x_2 - x_1)^2$   
 (D)  $L = \frac{1}{2} [m_1 \dot{x}_1^2 + m_2 \dot{x}_2^2] + \frac{1}{2} kx_1^2 + \frac{1}{2} kx_2^2$   
 (E)  $L = \frac{1}{2} \left[ \frac{m_1 m_2}{m_1 + m_2} (\dot{x}_2 - \dot{x}_1)^2 \right] + \frac{1}{2} k(x_2 - x_1)^2$

31. Thorium, with atomic mass 228, decays by alpha emission to a daughter nucleus, which also decays by alpha emission to radon. Which of the following is true of the decay product, radon? (The atomic number of thorium is 90.)

	<u>Atomic Mass</u>	<u>Atomic Number</u>
(A)	220	82
(B)	220	86
(C)	224	82
(D)	224	88
(E)	228	91

32. Which of the following decays is possible in a vacuum?

(A)  $\pi^+ \rightarrow \mu^- + \nu_\mu$

(B)  $\pi^- \rightarrow \pi^+ + e^- + e^-$

(C)  $\pi^0 \rightarrow e^- + p$

(D)  $p \rightarrow n + e^+ + \nu_e$

(E)  $n \rightarrow p + e^- + \bar{\nu}_e$

33. For atoms in a simple cubic lattice structure, the maximum percentage of the total available volume that can be occupied by the atoms is approximately

(A) 30%

(B) 40%

(C) 50%

(D) 60%

(E) 70%

34. Which of the following gives the distance in light-years to Andromeda (M31), the spiral galaxy nearest to the Milky Way?

(A)  $2 \times 10^0$

(B)  $2 \times 10^2$

(C)  $2 \times 10^4$

(D)  $2 \times 10^6$

(E)  $2 \times 10^8$

35. Which of the following gives the derivative with respect to  $x$  of the function  $x^2 \cos(3x^4 + 1)$ ?

(A)  $-2x \sin(3x^4 + 1)$

(B)  $2x \cos(3x^4 + 1) + x^2 \sin(3x^4 + 1)$

(C)  $2x \cos(3x^4 + 1) - 12x^5 \sin(3x^4 + 1)$

(D)  $-x^2 \sin(3x^4 + 1) + (3x^4 + 1)$

(E)  $-x^2 \sin(3x^4 + 1) - \cos(3x^4 + 1) + 12x^3$

Answer Key

1. D	19. C
2. B	20. D
3. E	21. D
4. B	22. B
5. D	23. D
6. C	24. A
7. C	25. E
8. B	26. E
9. E	27. C
10. A	28. C
11. A	29. D
12. B	30. B
13. B	31. B
14. C	32. E
15. B	33. C
16. C	34. D
17. B	35. C
18. D	





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