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## MULTIPLE-CHOICE QUESTION ANALYSES

1. Which of the following is the primary goal of scientific inquiry?
A. finding technological solutions to human problems
B. discovering the fundamental principles that govern nature
C. developing mathematical techniques for solving problems
D. investigating fundamental principles that transcend the material world

Correct Response: B. The primary goal of scientific inquiry is to discover the fundamental principles that govern nature. This is the essence of science. Finding technological solutions to human problems, A, is the primary goal of engineering. Developing mathematical techniques for solving problems, C, can be applied to a wider variety of situations and areas (e.g., finance, social sciences) and is not the primary goal of scientific inquiry. Investigating fundamental principles that transcend the material world, D, is related to religion or philosophy and is not the primary goal of scientific inquiry.
2. Which of the following is the best example of a testable hypothesis?
A. Why do both Coulomb's law and Newton's law of gravitation obey an inverse square relationship?
B. Will an incandescent lamp last longer if it is left on continuously or rapidly turned on and off?
C. When is it most important to apply the laws of quantum physics in place of those of classical physics?
D. Why does light refract as it moves from one optical medium to another?

Correct Response: B. "Will an incandescent lamp last longer if it is left on continuously or rapidly turned on and off?" is the only question that seeks to establish a relationship between a dependent variable (duration of the lamp) and an independent variable (switched on and off or run continuously) that can be verified by an experiment. A relationship between the independent and dependent variables can readily be derived from this question, and the relationship can be tested using experimental methods. None of the other answer choices (A, C, or D) are concerned with the relationship between an independent and a dependent variable, so no hypothesis is implied by any of them.
3. A student is investigating factors that affect the strength of an electromagnet. The student proposes the following design.

Factors: Voltage, number of turns of wire.
Process: Set voltage to 2.0 V , wrap 50 turns of wire around an iron coil. Measure how many paper clips the magnet can pick up. Set voltage to 4.0 V and wrap 30 more turns of wire. Again measure the number of paper clips. Repeat several times.

Which of the following is the most significant problem with this experimental design?
A. not accounting for the resistance of the additional length of wire
B. using paper clips to measure the strength of the electromagnet
C. using increments of 2.0 V instead of 1.0 V
D. changing the values of two factors at the same time

Correct Response: D. Changing the values of two factors at the same time is the most significant problem with this experimental design. Limiting the change to one variable at a time is important because it isolates the effect of each variable. Not accounting for the resistance of the additional length of wire (A) would most likely not present a problem for this experiment, since the field strength would increase as the number of turns increases, even though the resistance of the coil also increases. Using paper clips to measure the strength of the electromagnet (B) is not a problem, since a stronger magnetic field can lift more paper clips than can a weaker magnetic field. Using increments of 2.0 V instead of $1.0 \mathrm{~V}(\mathbf{C})$ does not present a problem as long as the wire can withstand the higher currents and as long as the voltage is manipulated while the number of turns and any other variables are held constant.
4. Which of the following guidelines should be followed when keeping a laboratory notebook?
A. Reorganize the notebook by cleaning up data, notes, and records before each new lab.
B. Round all data values to two significant figures before recording.
C. Date and record all procedures, events, and original data in ink to prevent erasures.
D. Keep a separate notebook to record calculations and sketches.

Correct Response: C. Dating and recording all procedures, events, and original data in ink to prevent erasures is important for protection and retention of all recorded information. Reorganizing the notebook by cleaning up data, notes, and records before each new lab (A) is not considered a good practice. Organization of the notebook should be accomplished prior to the lab. All notes should be written directly into the notebook in ink, and all data should be kept, not "cleaned up." Mistakes should be corrected by crossing out the mistake and entering the correction next to the mistake. Rounding all data values to two significant figures before recording (B) would be arbitrary and is incorrect. Rounding of data should be based on the level of precision of the measurements being recorded. Keeping a separate notebook in which to record calculations and sketches (D) is incorrect, because all calculations and sketches should be entered directly into the laboratory notebook.
5. Which of the following calculations can be used for curve fitting?
A. the chi-square distribution
B. least-squares regression
C. the correlation coefficient
D. the standard deviation of a sample

Correct Response: B. Least-squares regression is a method that is commonly used for curve fitting data to linear and nonlinear functions. None of the other answer choices is used for curve fitting. The chi-square distribution (A) is a probability distribution commonly used for goodness-of-fit testing in statistics. The correlation coefficient (C) is used to measure the linear relationship between two variables. It is normally used when curve fitting with least-squares linear regression to express how strongly the two variables are related and whether the relationship is negative or positive. The standard deviation of a sample ( $\mathbf{D}$ ) is a statistic used in order to estimate the standard deviation of the associated population.
6. The dimensions of a rectangular solid block are given below.

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length = 1.55 cm
width = 4.2 cm
height = 0.87 cm
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Which of the following values expresses the volume of the block using the correct number of significant figures?
A. $\quad 5.7 \mathrm{~cm}^{3}$
B. $\quad 5.66 \mathrm{~cm}^{3}$
C. $\quad 5.67 \mathrm{~cm}^{3}$
D. $\quad 5.664 \mathrm{~cm}^{3}$

Correct Response: A. When multiplying two or more measured quantities, the product should contain the same number of significant figures as the factor with the minimum number of significant figures. In this case, the answer should contain two significant figures, because the factors 4.2 and 0.87 each contain the minimum number of two significant figures. Answer choice $\mathbf{B}$ is rounded to 3 significant figures. This is the number of significant figures contained by the factor with the maximum number of significant figures. Answer choice $\mathbf{C}$ is incorrectly rounded down and has three significant figures. This is the number of significant figures contained by the factor with the maximum number of significant figures. Answer choice $\mathbf{D}$ is rounded to four significant figures, but four significant figures are not warranted, since this is greater than the number of significant figures contained by any of the factors.
7. Students in a physics class are learning how to solder electronic components onto a printed circuit board. In addition to working in a well-ventilated area, the students should also wear:
A. leather gloves.
B. safety glasses.
C. rubber shoes.
D. an antistatic wrist strap.

Correct Response: B. Safety glasses must be worn during all laboratory activities. In this case, they protect the eyes from splashed molten solder, hot vapors, and from the possibility of being struck by pieces of wire that are projected when trimming excess wire from soldered joints. Leather gloves (A) serve no useful purpose and would actually get in the way when soldering electronic components. Rubber shoes (C) are necessary when working with high voltages, but most printed circuit boards operate at low voltages and should be completely disconnected from any power source while being soldered. An antistatic wrist strap (D) is sometimes required when working on some circuit boards to protect delicate circuit components from electrostatic discharge, but is not necessary in all cases.
8. A student would like to measure the electric power used by a laptop computer when placed in the low-power mode. Which of the following pairs of meters should be selected for this measurement?
A. galvanometer and ammeter
B. galvanometer and ohmmeter
C. voltmeter and ammeter
D. ohmmeter and voltmeter

Correct Response: C. Electric power is calculated by multiplying voltage by current. A voltmeter and an ammeter should be selected to determine the power used since they measure voltage and current, respectively. The galvanometer and ammeter (A) should not be chosen. A galvanometer is essentially a sensitive ammeter, and while it can be converted to a voltmeter by adding a suitable resistor, that information is not included in the response. The galvanometer and ohmmeter (B) will not measure voltage and current since an ohmmeter is used for measuring resistance. The ohmmeter and voltmeter (D) will measure voltage and resistance, respectively.
9. Students in a physics class have been creating electrochemical cells using various chemical solutions. Which of the following would be the best source of information for properly storing and disposing of the chemicals?
A. reference guide of physics and chemistry data and formulas
B. laboratory manual for introductory physics
C. National Science Teachers Association (NSTA)
D. Material Safety Data Sheets (MSDS)

Correct Response: D. Material Safety Data Sheets (MSDS) are the best source of information for properly storing and disposing of chemicals. MSDS documents are produced by the chemical manufacturer for each given chemical. They contain information about each chemical's characteristics, including known hazards and procedures for proper storage and disposal. A reference guide of physics and chemistry data and formulas (A) may or may not include some of this information, but the MSDS would definitely have the information by design. A laboratory manual for introductory physics (B) would probably not contain this information, and it may or may not refer the reader to the pertinent MSDS for a given lab, as applicable. The National Science Teachers Association (NSTA) (C) does publish general information on classroom safety, including chemical safety, but the MSDS for any given chemical is specifically designed to contain the detailed information on that chemical, including proper storage and disposal.
10. Which of the following experiments led most directly to the quantum theory of light?
A. Michelson's and Morley's effort to detect the luminiferous ether
B. Röntgen's discovery of the emission of X-rays from a vacuum tube
C. Planck's analysis of the spectrum emitted by a blackbody
D. Hertz's detection of electromagnetic radiation

Correct Response: C. In the late $19^{\text {th }}$ century, classical physics predicted that at short wavelengths, a black body in thermal equilibrium would emit an infinite amount of energy, a situation sometimes referred to as the ultraviolet catastrophe. Planck's analysis of the spectrum emitted by a blackbody showed that the situation could be resolved by postulating that light is quantized. Einstein applied this postulate to explain the photoelectric effect, setting the stage for further acceptance of the idea of quantization. Michelson's and Morley's effort (A) to detect the luminiferous ether influenced the development of the theory of relativity. Röntgen's discovery of the emission of X-rays from a vacuum tube (B) represented the discovery of a new type of radiation in the form of electromagnetic waves. This was very significant, but it did not directly lead to the quantum theory of light. Hertz's detection of electromagnetic radiation (D) demonstrated the existence of electromagnetic waves, lending support to Maxwell's electrodynamic theory. This led to the understanding of light as a wave, but not as a photon, which is the electromagnetic particle associated with the quantum theory of light.
11. In chemistry, the enthalpy is defined as the heat energy change of a reaction. It is most closely related to which of the following concepts in physics?
A. the area under a force versus displacement graph
B. the slope of the line tangent to a velocity versus time graph
C. the area under a force versus time graph
D. the slope of the line tangent to a momentum versus time graph

Correct Response: A. The area under a force versus displacement graph for a moving object is equal to the work done by the force on the object if the force is parallel to the displacement. This is a measure of the change in energy of the system. The slope of the line tangent to a velocity versus time graph (B) is acceleration, which equals the rate of change in velocity, not energy. The area under a force versus time graph (C) equals impulse, which also equals the change in momentum, not energy. The slope of the line tangent to a momentum versus time graph (D) equals the rate of change in momentum, which equals force, not energy.
12. Several students in a physics class are planning to design a wind power system that can generate enough electricity to perform hydrolysis of water in a 500 mL beaker. According to the engineering design process, which of the following should the students do first?
A. make an expanded sketch of the major parts of the system
B. build a small, working prototype of the system
C. define the problem that needs to be solved
D. brainstorm several alternative designs for the system

Correct Response: C. Defining the problem that needs to be solved must be the first step. All of the other steps listed must then be accomplished in the following order: "brainstorm several alternative designs for the system" (D), followed by "make an expanded sketch of the major parts of the system" (A), followed by "build a small, working prototype of the system" (B). Attempting to accomplish any of the other steps without first defining the problem would very likely result in time wasted developing a solution that does not completely address the problem, if it addresses it at all.
13. Newton's laws, when applied in a particular situation, give the following equations.

$$
\begin{aligned}
F_{n}+F \sin \theta-m g & =0 \\
F \cos \theta-\mu F_{n} & =m a
\end{aligned}
$$

Which of the following equations correctly expresses $\mu$ ?
A. $\mu=\frac{m a-F \cos \theta}{-F \sin \theta-m g}$
B. $\quad \mu=\frac{m a+F \cos \theta}{F \sin \theta-m g}$
C. $\quad \mu=\frac{-m a+F \cos \theta}{-F \sin \theta+m g}$
D. $\mu=\frac{-m a+F \cos \theta}{F \sin \theta-m g}$

Correct Response: C. Solving the first equation for $F_{n}$ : $F_{n}=-F \sin \theta+m g$. Solving the second equation for $\mu: \mu=(-m a+F \cos \theta) / F_{n}$. Substituting $F_{n}$ in the second equation with $-F \sin \theta+m g$ from the first equation produces the correct answer. Answer choice $\mathbf{A}$ is obtained by using the correct denominator and the negative of the numerator of the correct answer. Answer choice $\mathbf{B}$ is obtained by using the negative of the correct denominator and the negative of the first term in the correct numerator. Answer choice $\mathbf{D}$ is obtained by using the correct numerator and the negative of the correct denominator.
14. Use the diagram below to answer the question that follows.


What is the sum of the three vectors shown above, expressed using the unit vectors $\mathbf{i}$ and $\mathbf{j}$ ?
A. $-1 \mathbf{i}+-1 \mathbf{j}$
B. $\mathbf{1 i}+-1 \mathbf{j}$
C. $-1 \mathbf{i}+1 \mathbf{j}$
D. $1 \mathbf{i}+1 \mathbf{j}$

Correct Response: A. The sum of the vectors equals the resultant, $\mathbf{V}_{r}$. The $x$-component of the resultant equals the sum of the $x$-components of the vectors being added, so $\mathbf{V}_{r, x}=\mathbf{V}_{1, x}+\mathbf{V}_{2, x}+\mathbf{V}_{3, \mathrm{x}}=$ $4 \hat{\mathbf{i}}-2 \hat{\mathbf{i}}-3 \hat{\mathbf{i}}=-1 \hat{\mathbf{i}}$. The $y$-component of the resultant equals the sum of the $y$-components of the vectors being added, so $\mathbf{V}_{r, y}=\mathbf{V}_{1, y}+\mathbf{V}_{2, y}+\mathbf{V}_{3, y}=2 \hat{\boldsymbol{j}}+1 \hat{\mathbf{j}}-4 \hat{\boldsymbol{j}}=-1 \hat{\boldsymbol{j}}$, and $\mathbf{V}_{\mathrm{r}}=-1 \hat{\mathbf{i}}-1 \hat{\boldsymbol{j}}$. Answer choice B has the correct $y$-component, but its $x$-component is the negative of the $x$-component of the correct answer. Answer choice $\mathbf{C}$ has the correct $x$-component, but its $y$-component is the negative of the $y$-component of the correct answer. Answer choice $\mathbf{D}$ has the negative of the $x$-component and the negative of the $y$-component of the correct answer.
15. The acceleration of a particle is given by the following equation.
$a(t)=6 t^{2}$
Given that $\mathrm{v}(0)=4 \mathrm{~m} / \mathrm{s}$, what is the velocity of the particle at $t=3 \mathrm{~s}$ ?
A. $\quad 36 \mathrm{~m} / \mathrm{s}$
B. $50 \mathrm{~m} / \mathrm{s}$
C. $54 \mathrm{~m} / \mathrm{s}$
D. $58 \mathrm{~m} / \mathrm{s}$

Correct Response: D. The velocity at $t=3 \mathrm{~s}$ can be determined with the equation $v=v_{0}+\Delta v$, where $v$ is the velocity of the particle at $t=3 \mathrm{~s}, v_{0}$ is the initial velocity, and $\Delta v$ is the change in the velocity of the particle due to its acceleration. Since the initial velocity is provided, the equation can be written as $v$ $=4 \mathrm{~m} / \mathrm{s}+\Delta v$. The change in velocity can be calculated by integrating the acceleration function from $t=$ 0 to $t=3 \mathrm{~s}: \Delta v=\int_{0}^{3} a(t) d t=\int_{0}^{3} 6 t^{2} d t=\left[2 t^{3}\right]_{0}^{3}=54-0=54 \mathrm{~m} / \mathrm{s}$. So $v=4 \mathrm{~m} / \mathrm{s}+54 \mathrm{~m} / \mathrm{s}=58 \mathrm{~m} / \mathrm{s}$.
Answer choice A can be obtained by multiplying the initial velocity by the time squared $(4)\left(3^{2}\right)=36$. Answer choice $\mathbf{B}$ can be obtained by subtracting the initial velocity from the change in velocity ( $54-4=50$ ). Answer choice $\mathbf{C}$ is numerically equal to both the change in velocity and to the acceleration at $t=3 \mathrm{~s}$.
16. Use the graph below to answer the question that follows.


The graph above shows the velocity of a particle moving in a straight line. At $t=0$, the particle is located at $x=0$. Which of the following graphs shows the position of the particle with respect to time, $\mathrm{x}(\mathrm{t})$ ?
A.

C.

B.

D.


Correct Response: C. The graph gives $v$ as a function of $t$. Since $\frac{d x}{d t}=v$, then $d x=v d t$ and the displacement of the particle is given by the area under the curve. During the first second, the particle moves at a constant positive velocity of $2 \mathrm{~m} / \mathrm{s}$, starting from position $x=0$. This means the position-versus-time graph must start at $(0,0)$ and increase with a constant slope until the end of the first second, when $t=1 \mathrm{~s}$ and $x=(2 \mathrm{~m} / \mathrm{s})(1 \mathrm{~s})=2 \mathrm{~m}$. Note the area under the graph for this interval is the area of a rectangle of height $=2.0 \mathrm{~m} / \mathrm{s}$ and width $=1.0 \mathrm{~s}$. The graphs of answer choices $\mathbf{B}$ and $\mathbf{C}$ both satisfy these initial conditions for the first second. During the next 2 seconds (from $t=1 \mathrm{~s}$ to $t=3 \mathrm{~s}$ ), the particle accelerates at a constant rate from $2 \mathrm{~m} / \mathrm{s}$ to $-2 \mathrm{~m} / \mathrm{s}$. It momentarily comes to rest at $t=2 \mathrm{~s}$ as it reverses direction from positive to negative. The position-versus-time graph between $t=1 \mathrm{~s}$ and $t=3 \mathrm{~s}$ must therefore be initially increasing, peaking at $t=2 \mathrm{~s}$, and then decreasing as the particle travels in the negative direction between $t=2 \mathrm{~s}$ and $t=3 \mathrm{~s}$. More specifically, the shape of the position-versustime curve between 1 and 3 seconds must be parabolic, concave downward, and with its vertex at $t=2$ s , making answer choice $\mathbf{C}$ the correct answer while eliminating answer choice $\mathbf{B}$. Note that the slope of the line tangent to the graph also matches the graph given in the question. Answer choice A looks similar to the velocity-versus-time graph. It is incorrect because it does not begin at the origin. In addition, it incorrectly indicates the particle is at rest for the first second, and it incorrectly indicates that the position of the particle is continuously decreasing between $t=1 \mathrm{~s}$ and $t=3 \mathrm{~s}$. Answer choice $\mathbf{D}$ looks like the correct answer, $\mathbf{C}$, but is inverted and translated. It is incorrect because it does not begin at the origin, incorrectly indicates that the particle is moving in the negative direction for the first 2 seconds, and incorrectly indicates that the position of the particle is increasing between $t=2 \mathrm{~s}$ and $t=3 \mathrm{~s}$.
17. Use the diagram below to answer the question that follows.


A boat that moves in still water with a speed of $2.5 \mathrm{~m} / \mathrm{s}$ now heads north across a river that has a current of $1.5 \mathrm{~m} / \mathrm{s}$ east, as shown in the diagram above. What is the boat's velocity relative to an observer on the shore?
A. $\quad 2.9 \mathrm{~m} / \mathrm{s}$ at $31^{\circ}$ north of east
B. $\quad 2.9 \mathrm{~m} / \mathrm{s}$ at $59^{\circ}$ north of east
C. $\quad 4.0 \mathrm{~m} / \mathrm{s}$ at $31^{\circ}$ north of east
D. $\quad 4.0 \mathrm{~m} / \mathrm{s}$ at $59^{\circ}$ north of east

Correct Response: B. The velocity of the boat relative to the shore ( $\mathbf{v}_{\mathrm{b}, \mathrm{s}}$ ) equals the vector sum of the velocity of boat relative to the water ( $\mathbf{v}_{\mathrm{b}, \mathrm{w}}$ ) + velocity of water relative to shore ( $\mathbf{v}_{\mathrm{w}, \mathrm{s}}$ ). Since the vectors being added form a right angle, the Pythagorean Theorem can be used to calculate the magnitude of the resultant. The magnitude of $\mathbf{v}_{\mathrm{b}, \mathrm{s}}$ is $\left[(2.5 \mathrm{~m} / \mathrm{s})^{2}+(1.5 \mathrm{~m} / \mathrm{s})^{2}\right]^{1 / 2}=2.9 \mathrm{~m} / \mathrm{s}$, and its direction relative to the east, $\theta=\operatorname{Tan}^{-1}(2.5 / 1.5)=59^{\circ}$ north of east, so $\mathbf{V}_{\mathrm{b}, \mathrm{s}}=2.9 \mathrm{~m} / \mathrm{s}, 59^{\circ}$ north of east. Answer choice $\mathbf{A}$ has the right magnitude, but its direction is the complement of $\theta$. This direction can be obtained by making the mistake of using $\theta=\operatorname{Tan}^{-1}(1.5 / 2.5)$ rather thanTan ${ }^{-1}(2.5 / 1.5)$. Answer choice $\mathbf{C}$ has the wrong magnitude equal to the scalar sum, $v_{\mathrm{b}, \mathrm{w}}+v_{\mathrm{ws}}=2.5 \mathrm{~m} / \mathrm{s}+1.5 \mathrm{~m} / \mathrm{s}=4.0 \mathrm{~m} / \mathrm{s}$, although its direction is correct. Answer choice $\mathbf{D}$ has the wrong magnitude equal to the scalar sum, $v_{\mathrm{b}, \mathrm{w}}+v_{\mathrm{w}, \mathrm{s}}=2.5$ $\mathrm{m} / \mathrm{s}+1.5 \mathrm{~m} / \mathrm{s}=4.0 \mathrm{~m} / \mathrm{s}$, and the wrong direction, obtained using $\theta=\operatorname{Tan}^{-1}(1.5 / 2.5)$ rather than Tan${ }^{1}(2.5 / 1.5)$.
18. Use the graph below to answer the question that follows.


The graph above shows the velocity with respect to time of an object moving in a straight line. The positive direction is to the right and the negative direction is to the left. Which of the following statements best describes the motion of this object?
A. The object starts at a location to the left of the origin and travels at a constant speed toward the right.
B. The object starts at a location to the left of the origin at a slow speed and speeds up as it moves to the right.
C. The object slows down as it moves to the left, stops, and starts moving to the right.
D. The object slows down as it moves to the right, stops, and continues moving to the right.

Correct Response: C. The velocity is initially negative, so the object is initially moving to the left. As the velocity increases to zero, the speed (magnitude of velocity) of the object decreases to zero. At the $x$-intercept, the object comes to rest as it reverses direction and then continues moving to the right with increasing velocity. Answer choice A incorrectly describes the speed as being constant, when in fact the speed is continuously changing (acceleration is constant). Answer choice B incorrectly describes the speed as continuously increasing, when in fact it is initially continuously decreasing until it stops and only then begins to continuously increase. Answer choice $\mathbf{D}$ incorrectly describes the object as initially slowing down as it moves to the right when in fact it is initially slowing down as it moves to the left.
19. A car on a highway has an initial speed of $23 \mathrm{~m} / \mathrm{s}$. The car accelerates at a constant rate for 10 s to a final speed of $29 \mathrm{~m} / \mathrm{s}$. How far does the car travel during this time interval?
A. 230 m
B. 260 m
C. 275 m
D. 290 m

Correct Response: B. This problem can be solved with the formula $\Delta x=v_{\text {avg }} t=\left[\left(v_{0}+v_{f}\right) / 2\right] t=[(23$ $\mathrm{m} / \mathrm{s}+29 \mathrm{~m} / \mathrm{s}) / 2][10 \mathrm{~s}]=260 \mathrm{~m}$. Answer choice A can be obtained using the incorrect formula $\Delta x=v_{0} t=$ $23 \mathrm{~m} / \mathrm{s} \times 10 \mathrm{~s}=230 \mathrm{~m}$. Answer choice $\mathbf{C}$ can be obtained using the incorrect average speed of 27.5 $\mathrm{m} / \mathrm{s}$ in the formula $\Delta x=(27.5 \mathrm{~m} / \mathrm{s})(10 \mathrm{~s})=275 \mathrm{~m}$. Answer choice $\mathbf{D}$ can be obtained using the incorrect formula $\Delta x=v_{\mathrm{f}} t=(29 \mathrm{~m} / \mathrm{s})(10 \mathrm{~s})=290 \mathrm{~m}$.
20. A car traveling at $12 \mathrm{~m} / \mathrm{s}$ slows down and comes to a stop in 20 m . What is the acceleration of the car, assuming it is constant?
A. $\quad-7.2 \mathrm{~m} / \mathrm{s}^{2}$
B. $-3.6 \mathrm{~m} / \mathrm{s}^{2}$
C. $-0.6 \mathrm{~m} / \mathrm{s}^{2}$
D. $-0.3 \mathrm{~m} / \mathrm{s}^{2}$

Correct Response: B. This problem can be solved with the formula: $v^{2}=v_{0}{ }^{2}+2 \mathrm{a} \Delta x$, where $v=$ final velocity, $v_{0}=$ initial velocity, $a=$ acceleration, and $\Delta x$ is the displacement. Solving for $a$, the equation is rewritten as $a=\left(v^{2}-v_{0}{ }^{2}\right) /(2 \Delta x)=\left[0-(12 \mathrm{~m} / \mathrm{s})^{2}\right] /(2)(20 \mathrm{~m})=-3.6 \mathrm{~m} / \mathrm{s}^{2}$. Answer choice A would be obtained if the factor 2 were omitted from the equation. This would make the solution twice as large, since the solution includes 2 in the denominator of the fraction. Answer choice $\mathbf{C}$ would be obtained if the factor 2 were omitted from the solution and the velocities were not squared. Answer choice D would be obtained by failing to square the velocities in the solution.
21. An object moves along the $x$-axis with a constant acceleration of $6 \mathrm{~m} / \mathrm{s}^{2}$ and an initial velocity of $-24 \mathrm{~m} / \mathrm{s}$. It is located at $x=6 \mathrm{~m}$ when $t=0 \mathrm{~s}$. What is its position when its velocity is zero?
A. $\quad 6 \mathrm{~m}$
B. -42 m
C. -90 m
D. -96 m

Correct Response: B. This problem can be solved using the formula $x=x_{0}+v_{0} t+(1 / 2)$ at ${ }^{2}$, where $x$ is the position of the object at time $t, x_{0}$ is the initial position of the object, and $a$ is the acceleration of the object. In order to find the position when the velocity is zero, the time must first be determined at which the velocity is zero by setting the velocity function equal to zero and solving for time. The velocity function is the first derivative of the position function with respect to time, so $v=x \rrbracket=v_{0}+a t$. When $v=$ $0, v_{0}=-a t$, and $t=-v_{0} / a=-(-24 \mathrm{~m} / \mathrm{s}) /\left(6 \mathrm{~m} / \mathrm{s}^{2}\right)=4 \mathrm{~s}$. When $t=4 \mathrm{~s}, x=x_{0}+v_{0} t+(1 / 2) \mathrm{at}{ }^{2}=6 \mathrm{~m}+(-24$ $\mathrm{m} / \mathrm{s})(4 \mathrm{~s})+(1 / 2)\left(6 \mathrm{~m} / \mathrm{s}^{2}\right)(4 \mathrm{~s})^{2}=-42 \mathrm{~m}$. Answer choice $\mathbf{A}$ is the position of the object when $t=0$, not when $v=0$. Answer choice $\mathbf{C}$ is obtained by omitting the factor $1 / 2$ in the equation $x=x_{0}+v_{0} t+(1 / 2) a t^{2}$. Answer choice $\mathbf{D}$ is obtained by omitting the factor $1 / 2$ in the equation $x=x_{0}+v_{0} t+(1 / 2) a t^{2}$ and using $x_{0}=0$ rather than 6 m in the same equation.
22. Which of the following is an action-reaction pair for a space station containing astronauts in orbit about the earth?
A. the weight of the space station and the centripetal force on the space station
B. the weight of the astronauts and the centripetal force on the space station
C. the weight of the space station and the gravitational force of the space station on the earth
D. the weight of the astronauts and the gravitational force of the space station on the astronauts

Correct Response: C. The weight of the space station and the gravitational force of the space station on Earth is the only answer choice that represents an action-reaction pair. The weight of the space station is the force of Earth's gravity on the space station. This force is equal in magnitude and opposite in direction to the gravitational force of the space station on Earth. The weight of the space station and the centripetal force on the space station (A) are not an action-reaction pair. The weight of the space station is the force of Earth's gravity on the space station. This is the same as the centripetal force on the space station, which is also the force of Earth's gravity on the space station. The weight of the astronauts and the centripetal force on the space station (B) are not an action-reaction pair. The weight of the astronauts is the force of Earth's gravity on the astronauts. Its action-reaction pair is the gravitational force of the astronauts on Earth. It is not the centripetal force on the space station, which equals the force of Earth's gravity on the space station. The weight of the astronauts and the gravitational force of the space station on the astronauts (D) are not an action-reaction pair. The weight of the astronauts is the force of Earth's gravity on the astronauts. This is independent of the gravitational force of the space station on the astronauts.
23. A person who weighs $w$ newtons stands on a scale in an elevator that is initially at rest. The elevator accelerates upward to a constant speed and then slows to a stop. Which of the following graphs best represents the reading on the scale?
A.

B.

C.

D.


Correct Response: C. The scale reads the magnitude of the normal force ( $N$ ) of the scale on the person. From Newton's laws, $F=m a=N-m g$, so $N=m g+m a$. The value of $w$ is equal in magnitude to this force. As the elevator accelerates from rest to a constant speed ( $v$ ), the acceleration increases from zero and then decreases to zero as the speed approaches $v$. Therefore the scale reading starts at $w$ and increases to a value that is greater than $w$, before it returns to $w$ upon reaching the constant speed $v$. The acceleration remains at zero as long as the constant speed $v$ is maintained. As the speed transitions from $v$ to 0 , the acceleration starts out negative and increases to zero upon coming to rest. Answer choice C satisfies these conditions, while the other answer choices do not. Answer choice A implies that the scale reading will exceed $w$ at all times except for the points at the beginning and end of the elevator ride. It does not account for the times when the scale reading is less than w. Answer choice B fails to account for the extended period of time that the elevator moves with the constant speed, $v$, during which the scale reading would equal $w$. Answer choice $\mathbf{D}$ implies that the scale reading will exceed the weight of the person at all times except for the points at the beginning and end of the elevator ride. It does not account for the times that the scale reading is less than the person's weight, nor does it account for the extended period of time when the elevator moves with the constant speed, $v$, during which the scale reading would equal $w$.
24. Use the diagram below to answer the question that follows.


The diagram above shows the horizontal forces on a 20.0 kg mass. The forces are constant in time. If the mass starts from rest, how far has it traveled in the horizontal direction after 3.00 s ?
A. $\quad 4.50 \mathrm{~m}$
B. $\quad 6.75 \mathrm{~m}$
C. $\quad 9.00 \mathrm{~m}$
D. 25.5 m

Correct Response: B. The magnitude of the net force on the mass is $100.0 \mathrm{~N}-70.0 \mathrm{~N}=30.0 \mathrm{~N}$. Since the forces are constant, the net force and acceleration are each also constant, and the acceleration $=(30.0 \mathrm{~N}) /(20.0 \mathrm{~kg})=1.50 \mathrm{~m} / \mathrm{s}^{2}$. The distance traveled can be calculated using the equation $\Delta x=v_{0} t+(1 / 2) a t^{2}=0+(1 / 2)\left(1.5 \mathrm{~m} / \mathrm{s}^{2}\right)(3 \mathrm{~s})^{2}=6.75 \mathrm{~m}$. Answer choice A would be obtained if the factor $1.5 \mathrm{~m} / \mathrm{s}^{2}$ were omitted from the equation. Answer choice $\mathbf{C}$ would be obtained if the factor $1 / 2$ were omitted from the equation. Answer choice $\mathbf{D}$ would be obtained if the acceleration were calculated as $(100.0 \mathrm{~N}) /(20.0 \mathrm{~kg})=5 \mathrm{~m} / \mathrm{s}^{2}$ and an initial velocity of $1 \mathrm{~m} / \mathrm{s}$ were used in the equation, so that $\Delta x=$ $v_{0} t+(1 / 2) a t^{2}=(1 \mathrm{~m} / \mathrm{s})(3 \mathrm{~s})+(1 / 2)\left(5.00 \mathrm{~m} / \mathrm{s}^{2}\right)(3 \mathrm{~s})^{2}=25.5 \mathrm{~m}$.
25. Use the diagram below to answer the question that follows.


The free-body diagram above shows two forces acting on a mass. Which of the following equations represents the vector sum of the forces in newtons, in the $x$-direction?
A. $\quad \Sigma F_{x}=-4 \cos 60^{\circ}+6 \sin 40^{\circ}$
B. $\quad \Sigma F_{x}=-4 \sin 60^{\circ}+6 \sin 40^{\circ}$
C. $\Sigma F_{x}=-4 \cos 60^{\circ}+6 \cos 40^{\circ}$
D. $\quad \Sigma F_{x}=-4 \sin 60^{\circ}+6 \cos 40^{\circ}$

Correct Response: D. The $x$-component of the resultant is equal to the sum of the $x$-components of the vectors being added, so $\mathrm{F}_{\mathrm{r}, \mathrm{x}}=\Sigma \mathrm{F}_{x}=-4 \sin 60^{\circ}+6 \cos 40^{\circ}$. Answer choice $\mathbf{A}$ is obtained by interchanging the applications of the sine and cosine functions. Answer choice $\mathbf{B}$ is obtained by using $\sin 40^{\circ}$ where $\cos 40^{\circ}$ should be used. Answer choice $\mathbf{C}$ is obtained by using $\cos 60^{\circ}$ where $\sin 60^{\circ}$ should be used.
26. The gravitational force between two masses is 80.0 N . Their centers are separated by a distance of $6.40 \times 10^{6} \mathrm{~m}$. What is the force if the distance is changed to $12.8 \times 10^{6} \mathrm{~m}$ ?
A. $\quad 20.0 \mathrm{~N}$
B. $\quad 40.0 \mathrm{~N}$
C. 160 N
D. 320 N

Correct Response: A. The gravitational force is an inverse square force law. If the distance between two masses is doubled, then the force will decrease by a factor of 4 . Since the distance between the two masses doubles, then the force will be $80 \mathrm{~N} / 4=20 \mathrm{~N}$. Answer choice B would be obtained if the force were assumed to be inversely proportional to the distance, so that doubling the distance would reduce the force to half its original value. Answer choice $\mathbf{C}$ would be obtained if the force were assumed to be proportional to the distance, so that doubling the distance would double the force. Answer choice $\mathbf{D}$ would be obtained if the force were assumed to be proportional to the square of the distance, so that doubling the distance would quadruple the force.
27. A 10 kg object is acted on by a net force that makes a $50^{\circ}$ angle with the $x$-axis. The $x$ component of the force is 30 N . What is the magnitude of the acceleration of the mass?
A. $\quad 1.9 \mathrm{~m} / \mathrm{s}^{2}$
B. $\quad 2.3 \mathrm{~m} / \mathrm{s}^{2}$
C. $\quad 3.9 \mathrm{~m} / \mathrm{s}^{2}$
D. $\quad 4.7 \mathrm{~m} / \mathrm{s}^{2}$

Correct Response: D. The magnitude of the acceleration can be calculated with the equation $a=$ $F_{\text {net }} / m$, where $a$ is the acceleration of the object, $F_{\text {net }}$ is the net force on the object, and $m$ is the mass of the object. The net force can be determined from its $x$-component with the equation $F_{\text {net, }, x}=F_{\text {net }} \cos \theta$. Solving the equation for $F_{\text {net }}$ results in $F_{\text {net }}=F_{\text {net, }, ~} / \cos \theta=30 \mathrm{~N} / \cos 50^{\circ}=46.7 \mathrm{~N}$, so a $=F_{\text {net }} / m=$ $(46.7 \mathrm{~N}) /(10 \mathrm{~kg})=4.7 \mathrm{~m} / \mathrm{s}^{2}$. Answer choice $\mathbf{A}$ is obtained by incorrectly using $F_{\text {net, } x} \cos \theta$ in place of $F_{\text {net, },} / \cos \theta$. Answer choice $\mathbf{B}$ is obtained by incorrectly using $F_{\text {net }, x} \sin \theta$ in place of $F_{\text {net, } x} / \cos \theta$. Answer choice $\mathbf{C}$ is obtained by incorrectly using $F_{\text {net }, x} / \sin \theta$ in place of $F_{\text {net }, x} / \cos \theta$.
28. Use the diagram below to answer the question that follows.


The diagram above represents a Ferris wheel rotating at a constant speed. Which of the following vectors represents the acceleration of a person on the wheel at point $Y$ ?
A.

B.

C.

D.


Correct Response: A. The direction of the acceleration vector for a mass in uniform circular motion is toward the center of its circular path. Therefore, the vector that represents the acceleration of the person riding the Ferris wheel must point straight up while the person is passing through point $Y$. The vector pointing to the right (B) represents the direction of the velocity vector for the person passing through point $Y$. The vector pointing straight down (C) represents the direction opposite to the acceleration vector. The vector pointing upward and toward the right (D) represents a direction between the directions of the velocity and acceleration vectors.
29. A satellite in a circular orbit travels at a speed $v$ at a distance $r$ above the center of the earth. If the satellite is boosted to a new orbital distance of $2 r$, what will be its speed?
A. $0.5 v$
B. $0.7 v$
C. $1.4 v$
D. $2 v$

Correct Response: B. For an object in uniform circular motion, the centripetal acceleration is $\mathrm{a}_{\mathrm{c}}=$ $v^{2} / r$. In the case of a satellite, $a_{c}$ is the gravitational acceleration due to Earth's gravity. When $r$ is doubled, $a_{c}$ is reduced to $a_{d} / 4$, so at the altitude $2 r, a_{d} / 4=v / 2 / 2 r$, where $v \|$ is the speed of the satellite at the altitude $2 r$. Substituting $a_{c}$ with $v^{2} / r$ in the equation for $v J: v^{2} / 4 r=v \|^{2} / 2 r$, so $v \|^{2}=\left(v^{2} / 4 r\right) 2 r=v^{2} / 2$, and $v \|=v / \sqrt{2}=0.7 v$. Answer choice A would result if a test taker used 2 in place of $\sqrt{2}$. Answer choice $\mathbf{C}$ would result if a test taker multiplied $v$ by $\sqrt{2}$ instead of dividing. Answer choice $\mathbf{D}$ would result if a test taker multiplied $v$ by 2 instead of dividing by $\sqrt{2}$.
30. Use the diagram below to answer the question that follows.


A light rod has masses attached to each end, as shown in the diagram above. At what distance from mass $m_{1}$ will the rod be balanced in equilibrium?
A. $\frac{L}{2}$
B. $\frac{m_{1} L}{m_{1}+m_{2}}$
C. $\frac{m_{2} L}{m_{1}+m_{2}}$
D. $\frac{L\left(m_{1}+m_{2}\right)}{2\left(m_{1}+m_{2}\right)}$

Correct Response: C. The rod-mass system is in equilibrium when supported at its center of mass. Let $x$ be the distance from $m_{1}$ to the system's center of mass. The sum of the torques about $x$ equals zero, so $m_{1} x=m_{2}(L-x),\left(m_{1}+m_{2}\right) x=m_{2} L$, and $x=m_{2} L /\left(m_{1}+m_{2}\right)$. Answer choice $\mathbf{A}$ is obtained by selecting the midpoint of the rod, which is at the distance $(1 / 2) L$ from $m_{1}$. Answer choice $\mathbf{B}$ is the correct distance from $m_{2}$, not from $m_{1}$. Answer choice $\mathbf{D}$ is actually equal to answer choice $\mathbf{A}$, but is expressed in a more complicated form.
31. Use the diagram below to answer the question that follows.


A right circular cylinder has a mass $m$, radius $r$, and a height $h$. The cylinder is completely submerged in a fluid of density $\rho$, as shown in the diagram above. What is the magnitude of the net force on the cylinder?
A. $r \rho g h+m g$
B. $r \rho g h-m g$
C. $\pi r^{2} \rho g h+m g$
D. $\pi r^{2} \rho g h-m g$

Correct Response: D. The net force on the cylinder is equal to the upward buoyant force minus the downward force of Earth's gravity on the cylinder. The buoyant force is equal to the weight of the water displaced, which equals the volume of the cylinder times the density of the liquid times acceleration due to gravity. Hence $F_{\text {net }}=\left(\pi r^{2} h\right) \rho g-m g=\pi r^{2} \rho g h-m g$. Answer choice $\mathbf{A}$ is obtained by omitting $\pi$, failing to square the radius, and adding the weight instead of subtracting it. Answer choice $\mathbf{B}$ is obtained by omitting $\pi$ and failing to square the radius. Answer choice $\mathbf{C}$ is obtained by adding the weight instead of subtracting it.
32. A horizontal pipe has a diameter of 10.0 cm . Fluid flows in the pipe at $0.500 \mathrm{~m} / \mathrm{s}$. The pipe is attached to a smaller pipe that has a diameter of 4.00 cm . What is the speed of the fluid in the smaller pipe?
A. $\quad 0.200 \mathrm{~m} / \mathrm{s}$
B. $\quad 1.25 \mathrm{~m} / \mathrm{s}$
C. $\quad 3.13 \mathrm{~m} / \mathrm{s}$
D. $\quad 12.5 \mathrm{~m} / \mathrm{s}$

Correct Response: C. This situation is an example of the conservation of mass and can be represented by the equation $A_{1} v_{1}=A_{2} v_{2}$, where $A_{1}$ is the area of the first pipe, $v_{1}$ is the speed of the fluid in the first pipe, $A_{2}$ is the area of the second pipe, and $v_{2}$ is the speed of the fluid in the second pipe.
Solving for $v_{2}$, the equation becomes $v_{2}=\left(A_{1} / A_{2}\right) v_{1}=\left(\pi r_{1}{ }^{2} / \pi r_{2}{ }^{2}\right) v_{1}=\left(r_{1}{ }^{2} / r_{2}{ }^{2}\right) v_{1}=\left[(10.0 \mathrm{~cm})^{2} /(4.00\right.$ $\left.\mathrm{cm})^{2}\right][0.500 \mathrm{~m} / \mathrm{s}]=3.13 \mathrm{~m} / \mathrm{s}$. Answer choice $\mathbf{A}$ is obtained by failing to square the radii and interchanging them in the equation, thus using $v_{2}=\left(r_{2} / r_{1}\right) v_{1}=(4.00 \mathrm{~cm} / 10.0 \mathrm{~cm})(0.500 \mathrm{~m} / \mathrm{s})=0.200$ $\mathrm{m} / \mathrm{s}$. Answer choice B is obtained by failing to square the radii and using $v_{2}=\left(r_{1} / r_{2}\right) v_{1}=(10.0 \mathrm{~cm} / 4.00$ $\mathrm{cm})(0.500 \mathrm{~m} / \mathrm{s})=1.25 \mathrm{~m} / \mathrm{s}$. Answer choice $\mathbf{D}$ is obtained by failing to square the second radius, thus using $v_{2}=\left(r_{1}{ }^{2} / r_{2}\right) v_{1}=\left[(10.0 \mathrm{~cm})^{2} /(4.00 \mathrm{~cm})\right][0.500 \mathrm{~m} / \mathrm{s}]=12.5 \mathrm{~m} / \mathrm{s}$.
33. An elevator with passengers has a total mass of 800 kg and moves a vertical distance of 20.0 m in 10.0 s . What is the average power expended in lifting this mass?
A. $\quad 1.57 \times 10^{2} \mathrm{~W}$
B. $\quad 1.57 \times 10^{4} \mathrm{~W}$
C. $\quad 1.57 \times 10^{5} \mathrm{~W}$
D. $\quad 1.57 \times 10^{6} \mathrm{~W}$

Correct Response: B. Power is the rate at which work is done. The power used to lift the mass is therefore given by $P=W / t=m g h / t=(800 \mathrm{~kg})\left(9.80 \mathrm{~m} / \mathrm{s}^{2}\right)(20.0 \mathrm{~m}) /(10.0 \mathrm{~s})=1.57 \times 10^{4} \mathrm{~W}$. A $(1.57 \times$ $\left.10^{2} \mathrm{~W}\right)$ is off by a factor of 0.01 . $\mathbf{C}\left(1.57 \times 10^{5} \mathrm{~W}\right)$ is off by a factor of 10 and would be obtained if mistakenly using the incorrect equation $P=m g h$. $\mathbf{D}\left(1.57 \times 10^{6} \mathrm{~W}\right)$ is off by a factor of 100 and would be obtained if mistakenly using the incorrect equation $P=m g h t$.
34. Use the graph below to answer the question that follows.


The graph above shows how the force on a mass depends on the position of the mass. What is the change in the kinetic energy of the mass as it moves from $x=0.0 \mathrm{~m}$ to $x=3.0 \mathrm{~m}$ ?
A. 0.0 J
B. 20 J
C. 50 J
D. 60 J

Correct Response: C. The work performed by the force on the mass is equal to the area under the curve, which equals 50 J . Using the work-kinetic energy theorem, $\Delta \mathrm{KE}=$ work $=50 \mathrm{~J}$. Answer choice A would apply only if no work were performed, so that the kinetic energy would remain constant. Answer choice $\mathbf{B}$ is the maximum magnitude of the force that performed the work. It does not represent the change in kinetic energy of the mass. Answer choice $\mathbf{D}$ is the maximum magnitude of the force that performed the work multiplied by the total displacement. It represents neither the area under the curve nor the change in kinetic energy of the mass.
35. A mass is pulled 5.00 m across a smooth, horizontal surface by a force of magnitude 12.0 N . The force acts at an angle of $60.0^{\circ}$ with the horizontal. What is the work done by the force?
A. 24 J
B. 30 J
C. 52 J
D. 60 J

Correct Response: B. The work done by a force can be calculated with this equation: $W=\mathbf{F} \cdot \mathbf{x}=$ $F x \cos \theta$, where $F$ is the magnitude of the force, $x$ is the distance through which the force acts, and $\theta$ is the angle between the direction of the force and the direction of motion. Therefore $W=$ (12.0 $\mathrm{N})(5.00 \mathrm{~m}) \cos 60.0^{\circ}=30.0 \mathrm{~J}$. Answer choice $\mathbf{A}$ is obtained by using the incorrect equation $W=F / \cos \theta$ $=(12.0 \mathrm{~N}) / \cos 60^{\circ}=(12.0 \mathrm{~N}) /(0.500)=24.0 \mathrm{~J}$. Answer choice $\mathbf{C}$ is obtained by using the incorrect equation $W=F x \sin \theta=(12.0 \mathrm{~N})(5.00 \mathrm{~m}) \sin 60.0^{\circ}=52.0 \mathrm{~J}$. Answer choice $\mathbf{D}$ is obtained by using the incorrect equation $W=F x=(12.0 \mathrm{~N})(5.00 \mathrm{~m})=60.0 \mathrm{~J}$.
36. Use the diagram below to answer the question that follows.


The length of each of the ropes on a playground swing is 2.00 m . What is the maximum speed attainable on the swing if the maximum value of $\theta$ is $45.0^{\circ}$ ?
A. $\quad 1.41 \mathrm{~m} / \mathrm{s}$
B. $\quad 2.00 \mathrm{~m} / \mathrm{s}$
C. $\quad 3.39 \mathrm{~m} / \mathrm{s}$
D. $\quad 8.85 \mathrm{~m} / \mathrm{s}$

Correct Response: C. The maximum speed attainable occurs when friction is negligible so mechanical energy is conserved. Let the potential energy be zero at the equilibrium point. Then $m g h(1 / 2) m v^{2}$, or $v=\sqrt{2 g h}$. Letting $h=2.00 \mathrm{~m}-(2.00 \mathrm{~m}) \cos 45.0^{\circ}=0.586 \mathrm{~m}$, so
$v=\sqrt{(2)\left(9.8 \frac{\mathrm{~m}}{\mathrm{~s}^{2}}\right)(0.585 \mathrm{~m})}=3.39 \mathrm{~m} / \mathrm{s}$. Answer choice $\mathbf{A}$ is numerically equal to (2.00) $\cos 45.0^{\circ}=1.41$.
Answer choice $\mathbf{B}$ is numerically equal to the length of each rope, 2.00. Answer choice $\mathbf{D}$ can be obtained by incorrectly using 4 m rather than 0.586 m as the maximum height, $h$.
37. A box of books that weighs 40 N is dragged at a speed of $1.5 \mathrm{~m} / \mathrm{s}$ across a rough floor. If the coefficient of friction between the floor and the box is 0.20 , what is the rate at which heat energy is dissipated?
A. $\quad 5.3 \mathrm{~W}$
B. 12 W
C. 60 W
D. 300 W

Correct Response: B. Assuming the speed is constant, the force applied ( $F_{\mathrm{a}}$ ) to drag the books equals the force of kinetic friction, so $F_{a}=\mu_{\mathrm{k}} W$, where $\mu_{\mathrm{k}}$ is the coefficient of kinetic friction between the box and the floor, and $w$ is the weight of the box of books, so $F_{a}=(0.20) 40 \mathrm{~N}=8 \mathrm{~N}$. The rate of energy dissipation is calculated with this equation: $P=F v$, where $P$ is power, $F$ is the applied force doing the work, and $v$ is the speed, so $P=(8 \mathrm{~N})(1.5 \mathrm{~m} / \mathrm{s})=12 \mathrm{~W}$. Answer choice $\mathbf{A}$ is obtained by using the incorrect equation $P=(8 \mathrm{~N}) /(1.5 \mathrm{~m} / \mathrm{s})=5.3 \mathrm{~W}$. Answer choice $\mathbf{C}$ is obtained by using the incorrect equation $P=(40 \mathrm{~N})(1.5 \mathrm{~m} / \mathrm{s})=60 \mathrm{~W}$. Answer choice $\mathbf{D}$ is obtained by using the incorrect equation $P=$ $(40 \mathrm{~N})(1.5 \mathrm{~m} / \mathrm{s}) / 0.2=300 \mathrm{~W}$.
38. Use the diagram below to answer the question that follows.


A person applies a force of 490 N over a distance $x$ to lift a 100 kg mass 6.0 m . If the pulley system is $100 \%$ efficient, what is $x$ ?
A. $\quad 3.0 \mathrm{~m}$
B. $\quad 6.0 \mathrm{~m}$
C. $\quad 8.0 \mathrm{~m}$
D. 12 m

Correct Response: D. Since the machine is $100 \%$ efficient, the work done by the machine,$W_{\text {out }}$, is equal to the work done by the person, $W_{\text {in }}$, where $W_{\text {out }}=F_{\text {out }} X_{\text {out }}$ and $W_{\text {in }}=F_{\text {in }} x$. Since $W_{\text {in }}=(490 \mathrm{~N}) x=$ $(100 \mathrm{~kg})\left(9.8 \mathrm{~m} / \mathrm{s}^{2}\right)(6.0 \mathrm{~m}), x=12 \mathrm{~m}$. Answer choice A is one-fourth the correct answer. Answer choice $\mathbf{B}$ is one-half the correct answer. Answer choice $\mathbf{C}$ is three-fourths the correct answer.
39. Use the graph below to answer the question that follows.


A 2.00 kg mass with an initial speed of $3.00 \mathrm{~m} / \mathrm{s}$ moving in a straight line in the positive direction is acted on by the force shown in the graph above. What is the speed of the mass at $t=5.00 \mathrm{~s}$ ?
A. $\quad 2.25 \mathrm{~m} / \mathrm{s}$
B. $\quad 4.50 \mathrm{~m} / \mathrm{s}$
C. $\quad 5.25 \mathrm{~m} / \mathrm{s}$
D. $\quad 10.5 \mathrm{~m} / \mathrm{s}$

Correct Response: C. The change in momentum of the mass can be calculated using the impulse momentum theorem: $F_{\text {avg }} \Delta t=\Delta p=m \Delta v$. Thus $\Delta v=F_{\text {avg }} \Delta t / m=$ (area under the force-versus-time curve $) / m=(4.5 \mathrm{~N} \cdot \mathrm{~s}) /(2.00 \mathrm{~kg})=(4.5 \mathrm{~kg} \cdot \mathrm{~m} / \mathrm{s}) /(2.00 \mathrm{~kg})=2.25 \mathrm{~m} / \mathrm{s}$; speed at $5.00 \mathrm{~s}=v_{\mathrm{i}}+\Delta v=3.00 \mathrm{~m} / \mathrm{s}$ $+2.25 \mathrm{~m} / \mathrm{s}=5.25 \mathrm{~m} / \mathrm{s} . \mathbf{A}(2.25 \mathrm{~m} / \mathrm{s})$ is the change in speed, not the final speed. $\mathbf{B}(4.50 \mathrm{~m} / \mathrm{s})$ is twice the change in speed. $\mathbf{D}(10.5 \mathrm{~m} / \mathrm{s})$ is twice the change in speed added to twice the initial speed.
40. A ball of mass 15 g initially moving at a speed of $20 \mathrm{~m} / \mathrm{s}$ is caught in a person's hand. If the average force exerted by the hand on the ball is 5.0 N , how long does it take for the ball to come to rest?
A. $\quad 0.06 \mathrm{~s}$
B. 0.15 s
C. $\quad 1.2 \mathrm{~s}$
D. $\quad 1.5 \mathrm{~s}$

Correct Response: A. The time it takes the ball to come to rest can be calculated using the impulse momentum theorem: $F \cdot \Delta t=\Delta p=m \Delta v$. Solving for $\Delta t, \Delta t=m \Delta v / F=m\left(v_{f}-v_{\mathrm{i}}\right) / F=(0.015 \mathrm{~kg})(0-20$ $\mathrm{m} / \mathrm{s}) /(-5 \mathrm{~N})=0.06 \mathrm{~s}$. Answer choice B is obtained by using the incorrect formula $\Delta t=\mathrm{m} /(\Delta v \cdot F)$ while failing to convert the 15 g mass to 0.015 kg . Answer choice $\mathbf{C}$ is obtained by using the incorrect formula $\Delta t=m(\Delta v)^{2} / F$ after correctly converting the 15 g mass to 0.015 kg . Answer choice D is obtained by using the incorrect formula $\Delta t=m /(\Delta v \cdot F)$ after incorrectly converting the 15 g mass to 150 kg .
41. Use the diagram below to answer the question that follows.


A 6.0 kg mass is moving to the right at $10 \mathrm{~m} / \mathrm{s}$. A 0.25 kg mass is fired toward the left at the larger mass. What speed $(v)$ must the smaller mass have to completely stop both masses?
A. $\quad 4.2 \mathrm{~m} / \mathrm{s}$
B. $\quad 15 \mathrm{~m} / \mathrm{s}$
C. $\quad 150 \mathrm{~m} / \mathrm{s}$
D. $240 \mathrm{~m} / \mathrm{s}$

Correct Response: D. Momentum is conserved, so the total momentum before the collision equals the total momentum after the collision. Furthermore, the total momentum must be set to zero to model the case described in the problem, where the two masses come to rest after colliding. Expressed mathematically, $m v_{1}+m v_{2}=m v_{1}^{\prime}+m v_{2}^{\prime}=0$. Therefore, $(6.0 \mathrm{~kg})(10 \mathrm{~m} / \mathrm{s})+(0.25 \mathrm{~kg}) v_{2}=0$, and $v_{2}=-$ $(6.0 \mathrm{~kg})(10 \mathrm{~m} / \mathrm{s}) /(0.25 \mathrm{~kg})=-240 \mathrm{~m} / \mathrm{s}$, so the speed of the 0.25 kg mass must be $240 \mathrm{~m} / \mathrm{s}$. Answer choice $\mathbf{A}$ is obtained by using the incorrect equation $v_{2}=[-(0.25 \mathrm{~kg}) /(6.0 \mathrm{~kg})](10 \mathrm{~m} / \mathrm{s})^{2}=-4.2 \mathrm{~m} / \mathrm{s}$. Answer choice $\mathbf{B}$ is obtained by using the incorrect equation $v_{2}=-(6.0 \mathrm{~kg})(10 \mathrm{~m} / \mathrm{s})(0.25 \mathrm{~kg})=-15 \mathrm{~m} / \mathrm{s}$. Answer choice $\mathbf{C}$ is obtained by using the incorrect equation $v_{2}=-\left[(6.0 \mathrm{~kg})(10 \mathrm{~m} / \mathrm{s})^{2}\right](0.25 \mathrm{~kg})=-150$ $\mathrm{m} / \mathrm{s}$.
42. Use the diagram below to answer the question that follows.


An object at rest in deep space explodes into three pieces. The momentum of two of the pieces is shown in the diagram above. Which of the following vectors best represents the momentum of the third piece?
A.

B.

C.

D.


Correct Response: C. Since momentum is conserved, the total momentum after the explosion must be zero. Therefore, the vector sum $\boldsymbol{p}_{1}+\boldsymbol{p}_{2}+\boldsymbol{p}_{3}=\mathbf{0}$ and the vector shown in $\mathbf{C}$ best represents $\boldsymbol{p}_{3}$, which is $-\left(\boldsymbol{p}_{1}+\boldsymbol{p}_{2}\right)$. Answer choice $\mathbf{A}$ has a vertical component that points in the right direction, but it has no horizontal component to cancel the horizontal component of $\boldsymbol{p}_{1}+\boldsymbol{p}_{2}$, which points toward the right. Answer choice $\mathbf{B}$ has a vertical component that points in the wrong direction, and it has no horizontal component to cancel the horizontal component of $\boldsymbol{p}_{1}+\boldsymbol{p}_{2}$, which points toward the right. Answer choice $\mathbf{D}$ best represents the vector sum $\boldsymbol{p}_{1}+\boldsymbol{p}_{2}$, rather than its negative.
43. The angular speed of a star spinning about its axis increases as the star begins to contract to a smaller radius. Which of the following quantities associated with the star must decrease as this occurs?
A. moment of inertia
B. angular momentum
C. rotational kinetic energy
D. net external torque

Correct Response: A. In this situation, there are no external torques on the star so the magnitude of the angular momentum, $L=l \omega$ will remain constant. Since the angular speed $(\omega)$ increases, the moment of inertia (I) must decrease. Angular momentum (B) does not decrease; it remains constant because no external torques are applied. Rotational kinetic energy (C) does not decrease; it increases due to the work done by the gravitational force that pulls matter toward the center of the star. The net external torque ( $\mathbf{D}$ ) is zero and would remain zero as the moment of inertia decreases and the angular speed increases.
44. A person holds a spinning bicycle wheel while sitting stationary on a chair that is free to rotate about a vertical axis. As the person changes the axis of the spinning bicycle wheel, the chair begins to rotate about its axis. The chair's rotation is a result of:
A. conservation of angular momentum.
B. a torque due to the force of gravity.
C. conservation of rotational kinetic energy.
D. the mechanical advantage of double-axis rotational system.

Correct Response: A. Angular momentum is a vector quantity. The conservation of angular momentum accounts for the rotation of the chair that takes place with a vector angular momentum, which when added to the final vector angular momentum of the wheel equals the initial vector angular momentum of the wheel. Answer choice B could be used to explain the precession of the bicycle wheel if it were held by only one end of its rotational axis, but it does not help explain the rotation of the chair in this case. Answer choice C does not apply, since rotational kinetic energy is not conserved. Answer choice D does not explain the rotation of the chair, although the chair-wheel system does involve two axes of rotation.
45. Which of the following graphs shows how the average kinetic energy of the molecules depends on the absolute temperature of an ideal gas?
A.

B.

C.

D.


Correct Response: A. For an ideal gas, the average kinetic energy of its molecules is proportional to its absolute temperature. This is graphically represented by a line with a positive slope. B represents an inverse relationship and is nonlinear. $\mathbf{C}$ is a graph that is increasing with an increasing slope and is nonlinear. D is a graph that is increasing with a decreasing slope and is nonlinear.
46. Which of the following describes the process by which energy is transmitted from one region of space to another through molecular collisions?
A. radiation
B. latent heat
C. convection
D. conduction

Correct Response: D. Conduction is the thermal-energy-transfer process that involves the transfer of kinetic energy between molecules as they collide. Radiation (A) is the thermal-energy-transfer process that involves the transfer of energy through electromagnetic waves. Latent heat (B) is not an energytransfer process. It is the energy per unit mass absorbed or released by a substance during a change in phase. Convection (C) is the thermal-energy-transfer process that involves the transfer of energy through currents in fluids caused by variations in density due to uneven heating or cooling.
47. Use the graph below to answer the question that follows.


Heat Added
The graph above shows a heating curve for a substance. Which segment represents the transition from solid to liquid phase?
A. $A B$
B. $B C$
C. $C D$
D. $D E$

Correct Response: B. Because line segment $B C$ has a slope of zero, it represents a change in phase, since the temperature remains constant as heat is added. A slope of zero means a segment represents either a transition from solid to liquid or from liquid to gas. Segment $D E$ is horizontal and has a slope of zero, indicating that it also represents a change in phase, but since segment $B C$ occurs at a lower temperature than segment $D E$, segment $B C$ must represent the transition from solid to liquid phase. Line segment $A B(\mathbf{A})$ represents a change in temperature while in the solid phase; it has a slope greater than zero and precedes segment $B C$, which represents a change in phase from a solid to a liquid. Line segment $C D(\mathbf{C})$ represents a change in temperature while in the liquid phase; it has a slope greater than zero and precedes segment $D E$, which represents a change in phase from a liquid to a gas. Line segment $D E(\mathrm{D})$ represents a transition from liquid to gas.

## 48. Use the diagram below to answer the question that follows.



The diagram above represents the pressure $(P)$ and volume $(V)$ of an ideal gas. If $A B$ is an isothermal process, which of the following must be true?
A. No work is done in going from state $A$ to state $B$.
B. Curve $A D$ represents an isobaric process.
C. The product of the pressure and the volume is constant along $A B$.
D. Curve $C D$ represents an adiabatic process.

Correct Response: C. Since $A B$ is isothermal, the temperature of the gas, $T$, is constant during $A B$ by definition. The ideal gas law can be applied using the equation $P V=n R T$, where $P$ is the pressure, $V$ is the volume, and $T$ is the absolute temperature of an ideal gas. Also, $n$ is a constant equal to the number of moles, and $R$ is the ideal gas constant. Since $n, R$, and $T$ are each constant during $A B$, their product $n R T$ must also be constant. Furthermore, the product, $P V$, must also be constant since $P V=n R T$. Answer choice $\mathbf{A}$ is incorrect because the gas is doing the amount of work equal to the area under the curve as it expands. Answer choice $\mathbf{B}$ is incorrect because the pressure increases during process $D A$ while the volume remains constant. Curve $A D$ actually represents an isochoric process. Answer choice $\mathbf{D}$ is actually an isothermal process. It is not an adiabatic process, because heat is lost by the gas at the same rate as work is being performed on the gas.
49. Which of the following best describes the microscopic interpretation of the concept of entropy?
A. the distribution of energy per degree of freedom of a molecule
B. the amount of randomness or disorder in a system
C. the average time required for a system to reach equilibrium
D. the lowest temperature a quantum mechanical system can reach

Correct Response: B. The amount of randomness or disorder in a system is a good definition of entropy. Answer choices A, C, and D do not define entropy.
50. On a dry winter day, a person walks across a carpet, reaches to touch a doorknob, and observes a spark about 3 mm long. Given that the dielectric breakdown of air is approximately $3 \mathrm{MV} / \mathrm{m}$, which of the following is best estimate for the potential difference between the person's hand and the doorknob?
A. $\quad 90 \mathrm{~V}$
B. $\quad 900 \mathrm{~V}$
C. $\quad 9,000 \mathrm{~V}$
D. $9,000,000 \mathrm{~V}$

Correct Response: C. A strong electric field can ionize air molecules, allowing them to conduct electricity. This process produces a spark. Since $V=E \cdot d$, the potential difference can be estimated by $\left[(3 \mathrm{MV} / \mathrm{m})\left(1 \times 10^{6} \mathrm{~V} / \mathrm{MV}\right)\right]\left[(3 \mathrm{~mm})\left(1 \times 10^{-3} \mathrm{~m} / \mathrm{mm}\right)\right]=\left(3 \times 10^{6} \mathrm{~V} / \mathrm{m}\right)\left(3 \times 10^{-3} \mathrm{~m}\right)=9 \times 10^{3} \mathrm{~V}=9,000 \mathrm{~V} . \mathrm{A}$ $(90 \mathrm{~V})$ is 0.01 times the correct answer. $\mathbf{B}(900 \mathrm{~V})$ is 0.1 times the correct answer. $\mathbf{D}(9,000,000 \mathrm{~V})$ is 1,000 times the correct answer.
51. Use the diagram below to answer the question that follows.


Given the electric field lines shown above, what are the charge pairs?
A. $\quad Q_{1}$ positive, $Q_{2}$ positive
B. $Q_{1}$ positive, $Q_{2}$ negative
C. $Q_{1}$ negative, $Q_{2}$ positive
D. $Q_{1}$ negative, $Q_{2}$ negative

Correct Response: B. By convention, electric field lines are shown leaving positive charges and entering negative charges. Based on this convention, $Q_{1}$ must be positive, and $Q_{2}$ must be negative. A incorrectly indicates that $Q_{2}$ is positive. C incorrectly indicates that $Q_{1}$ is negative and $Q_{2}$ is positive. $\mathbf{D}$ incorrectly indicates that $Q_{1}$ is negative.
52. Use the diagram below to answer the question the follows.


The diagram above shows an electric field of $10 \mathrm{~N} / \mathrm{C}$ that is constant in magnitude and direction. What is the electrostatic potential between points $A$ and $B$ ?
A. 3 V
B. 4 V
C. 5 V
D. 7 V

Correct Response: A. The electrostatic potential between points $A$ and $B$ is equal to the product of the electric field and the component of displacement that is parallel to the field, $V=E x=(10$ $\mathrm{N} / \mathrm{C})(0.3 \mathrm{~m})=3 \mathrm{~V}$. Answer choice $\mathbf{B}$ is obtained by using the component of the displacement that is perpendicular to the field, $V=(10 \mathrm{~N} / \mathrm{C})(0.4 \mathrm{~m})=4 \mathrm{~V}$. Answer choice $\mathbf{C}$ is obtained by using the magnitude of the displacement in place of its component that is parallel to the field, $V=(10 \mathrm{~N} / \mathrm{C})(0.5 \mathrm{~m})$ $=5 \mathrm{~V}$. Answer choice $\mathbf{D}$ is obtained by using the scalar sum of the components of the displacement in place of its component that is parallel to the field, $V=(10 \mathrm{~N} / \mathrm{C})(0.3 \mathrm{~m}+0.4 \mathrm{~m})=7 \mathrm{~V}$.
53. Use the diagram below to answer the question that follows.


A 36 V battery is in series with a parallel plate capacitor, as shown in the diagram above. The plate separation is 0.20 m . The plates are large, so that the electric field is approximately constant between them. What is the magnitude and direction of the field?
A. $\quad 7.2 \mathrm{~N} / \mathrm{C}$ to the left
B. $\quad 7.2 \mathrm{~N} / \mathrm{C}$ to the right
C. $180 \mathrm{~N} / \mathrm{C}$ to the left
D. $180 \mathrm{~N} / \mathrm{C}$ to the right

Correct Response: D. The magnitude of the electric field can be determined with the equation $E=$ $V / d$, where $E$ is the magnitude of the electric field, $V$ is the voltage across the plates of the capacitor, and $d$ is the distance between the plates. In this case, $E=(36 \mathrm{~V}) /(0.20 \mathrm{~m})=180 \mathrm{~V} / \mathrm{m}=180 \mathrm{~J} / \mathrm{C} / \mathrm{m}=$ 180 N/C. The direction of the field is from the positively charged plate to the negatively charged plate, which is to the right. Therefore, the electric field vector $E=180 \mathrm{~N} / \mathrm{C}$ to the right. Answer choice $A$ is obtained by using the incorrect equation $E=(36)(0.20)=7.2$ and selecting the opposite of the correct direction. Answer choice $\mathbf{B}$ is obtained by using the incorrect equation $E=36 \times 0.20=7.2$ and selecting the correct direction. Answer choice C is the correct magnitude, but the direction is opposite of the correct direction.
54. Use the diagram below to answer the question that follows.


A piece of bare conducting wire of cross-sectional area $A$ has a resistance $R$. If three identical pieces of the wire are twisted together as shown in the diagram above, the resistance will be closest to which of the following?
A. $\quad \frac{1}{3} R$
B. $R$
C. $3 R$
D. $9 R$

Correct Response: A. The equivalent resistance of $n$ parallel conductors, each with the same resistance $R$, can be calculated using the equation, $R_{\text {eq }}=R / n$; where $R_{\text {eq }}$ is the equivalent resistance, $R$ is the resistance of each of the conductors connected in parallel, and $n$ is the number of conductors. In this case, $R_{\text {eq }}=R / 3 . \mathbf{B}(R)$ is the resistance of each conductor. $\mathbf{C}(3 R)$ is the equivalent resistance of the 3 wires when connected in series, but these wires are connected in parallel. $\mathbf{D}(9 R)$ is the equivalent resistance of 9 of these wires connected in series, but 3 of these wires are connected in parallel.
55. Use the diagram below to answer the question that follows.


What is the current through the battery?
A. $\quad 0.3 \mathrm{~A}$
B. $\quad 1.2 \mathrm{~A}$
C. $\quad 1.5 \mathrm{~A}$
D. $\quad 2.4 \mathrm{~A}$

Correct Response: C. The current through the battery equals the sum of the currents through the resistors, which equals $1.2 \mathrm{~A}+$ the current through the $40 \Omega$ resistor. The current through the $40 \Omega$ resistor can be found using Ohm's law: $I=V / R$, where $I$ is the current through the resistor, $V$ is the voltage across the resistor, and $R$ is the resistance. In this case, $I=(12 \mathrm{~V}) /(40 \Omega)=0.3 \mathrm{~A}$. The total current through the battery is therefore $1.2 \mathrm{~A}+0.3 \mathrm{~A}=1.5 \mathrm{~A} . \mathrm{A}(0.3 \mathrm{~A})$ is the current only through the $40 \Omega$ resistor. B (1.2 A) is the current only through the unknown resistor. D (2.4 A) is twice the current through the unknown resistor.
56. The wall adapter for recharging a cell phone battery draws 20 mA at 115 V . If left plugged in for 24 hours, how much energy will the device dissipate?
A. $\quad 1.5 \times 10^{-5} \mathrm{~kW} \cdot \mathrm{~h}$
B. $\quad 9.0 \times 10^{-4} \mathrm{~kW} \cdot \mathrm{~h}$
C. $5.5 \times 10^{-2} \mathrm{~kW} \cdot \mathrm{~h}$
D. $5.5 \times 10^{-1} \mathrm{~kW} \cdot \mathrm{~h}$

Correct Response: C. Since power is the rate at which work is done, the energy can be found using the equation $E=P t=V I t$, where $P$ is power, $t$ is time, $V$ is voltage, and $I$ is current. Substituting each variable with its given value in units that are consistent with the answer choices, the equation becomes $P=(115 \mathrm{~V})(20 \mathrm{~mA})(0.001 \mathrm{~A} / \mathrm{mA})(24 \mathrm{~h})(0.001 \mathrm{~kW} / \mathrm{W})=5.5 \times 10^{-2} \mathrm{~kW} \cdot \mathrm{~h}$. Answer choice $\mathbf{A}$ can be obtained by incorrectly manipulating the variables, expressing the time in seconds, and using an incorrect conversion factor when converting watts to kilowatts: $P=I t / V=[(0.02 \mathrm{~A})(86,400 \mathrm{~s}) /(115 \mathrm{~V})] \times$ $10^{-6} \mathrm{~kW} / \mathrm{W}=1.5 \times 10^{-5} \mathrm{~kW} \cdot \mathrm{~h}$. Answer choice B is incorrect and not directly related to the information provided. Answer choice $\mathbf{D}$ is an order of magnitude greater than the correct answer. It can be obtained by misplacement of the decimal point in one or more of the variables in a manner that results in an answer that is ten times greater than the correct answer.
57. A 9.0 V battery has an internal resistance of about $2.0 \Omega$. If the terminals of the battery are short-circuited, the battery gets hot. At approximately what rate is heat generated by the battery?
A. $\quad 4.5 \mathrm{~W}$
B. 11 W
C. 18 W
D. 41 W

Correct Response: D. The power can be determined with the equation $P=V^{2} / R$, where $P$ is the power produced by the battery, which equals the rate of heat dissipation, $V$ is the battery voltage, and $R$ is the circuit resistance, which in this case is the battery's internal resistance. Applying the equation yields $P=V^{2} / R=(9.0 \mathrm{~V})^{2} /(2.0 \Omega)=41 \mathrm{~W}$. Answer choice $\mathbf{A}$ is numerically equal to $V / R=9 / 2=4.5$. Answer choice $\mathbf{B}$ is obtained by adding the voltage to the resistance, $9.0+2.0=11$. Answer choice $\mathbf{C}$ is obtained by multiplying the voltage by the resistance, $9.0 \times 2.0=18$.
58. Use the diagram below to answer the question that follows.


The capacitor is originally uncharged. When the switch is closed, which of the following represents the voltage across the capacitor?
A.

Time
B.

C.

D.

Time

Correct Response: B. The voltage across a charging capacitor starts at zero, initially increasing rapidly. As the capacitor charges, the rate at which it charges slows and continuously decreases toward zero as the voltage of the capacitor approaches the voltage of the battery. Answer choice A represents a discharging capacitor. The voltage starts at the voltage of the battery and decays exponentially toward zero. Answer choice $\mathbf{C}$ is a linear function that starts at zero and increases at a constant rate. Answer choice D starts at zero, initially increasing slowly with a slope that is continuously increasing so that the rate of increase of the voltage continuously increases as the voltage increases.
59. Use the diagram below to answer the question that follows.


The diagram above shows the magnetic field between two magnetic poles. Which of the following correctly identifies the poles?
A. $I=S, I I=S$
B. $\mathrm{I}=\mathrm{N}, \mathrm{II}=\mathrm{N}$
C. $I=N, I I=S$
D. $I=S, I I=N$

Correct Response: D. By convention, magnetic lines of flux are shown leaving through the north pole and entering through the south pole. Based on this convention, the right side of Magnet I is a south pole, and the left side of Magnet II is a north pole. A incorrectly indicates that the left side of Magnet II is a south pole. $\mathbf{B}$ incorrectly indicates that the right side of Magnet I is a north pole. $\mathbf{C}$ incorrectly indicates that the right side of Magnet I is a north pole and the left side of Magnet II is a south pole.
60. A circular loop of wire is connected in series with a voltage source $V$ and a resistor $R$. The strength of the magnetic field in the middle of the loop is directly proportional to:
A. $\quad V R$.
B. $\frac{V}{R}$.
C. $\quad V^{2} R$.
D. $\frac{V^{2}}{R}$.

Correct Response: B. The magnetic field strength is directly proportional to the current through the loop. Given Ohm's law, $I=V / R, V / R$ is also directly proportional to the magnetic field strength. $\mathbf{A}(V R)$ is the product of the voltage and resistance, which is not proportional to the magnetic field strength. C $\left(V^{2} R\right)$ also is not proportional to the magnetic field strength. $\mathbf{D}\left(V^{2} / R\right)$ is the power dissipated by the resistor, which is not proportional to the magnetic field strength.
61. The force on a charged particle moving in a direction perpendicular to a magnetic field is 0.50 N . What is the force on the particle in the same field if the angle between the particle's velocity vector and the field is $50^{\circ}$ ?
A. $\quad 0.25 \mathrm{~N}$
B. $\quad 0.32 \mathrm{~N}$
C. $\quad 0.38 \mathrm{~N}$
D. $\quad 0.60 \mathrm{~N}$

Correct Response: C. The force on a charge moving through a magnetic field is proportional to the component of the velocity vector that is perpendicular to the field. In this case, the velocity was originally perpendicular to the field, so the force on the particle could be represented by the equation $F$ $=q v B=0.50 \mathrm{~N}$. After the direction of the velocity changed to $50^{\circ}$ relative to the field, the component that is perpendicular to the field is equal to vsin $50^{\circ}$, and the force is now $F=q v B \sin 50^{\circ}=0.50 \mathrm{~N} \sin$ $50^{\circ}=0.38 \mathrm{~N}$. Answer choice $\mathbf{A}$ is half of the original force. Answer choice B would be obtained if $\cos 50^{\circ}$ were incorrectly used in place of $\sin 50^{\circ}$. Answer choice $\mathbf{D}$ would be obtained by multiplying the original force by $\tan 50^{\circ}$.
62. A wire coil of radius 2.0 cm with 10 turns is in a magnetic field of 2.0 T . The field is perpendicular to the plane of each turn of the coil. The coil is wired in series with a resistor of $5.0 \Omega$. The field drops at a constant rate to 0.0 T in 10 ms . What is the current through the resistor?
A. $\quad 0.50 \mathrm{~A}$
B. $\quad 2.5 \mathrm{~A}$
C. $\quad 8.0 \mathrm{~A}$
D. 13 A

Correct Response: A. The voltage induced in a coil can be determined with Faraday's law, $V=-N$ $\Delta(B A \cos \theta) / \Delta t$, where $V$ is the voltage induced, $N$ is the number of turns in the coil, $B$ is the magnetic field, $A$ is the area of the cross-section of the coil, $\theta$ is the angle between the magnetic field and a line perpendicular to the area, and $\Delta t$ is the time it takes for the magnetic flux to change. In this case $\Delta B / \Delta t$ $=(2.0 \mathrm{~T}) /(0.010 \mathrm{~s})=200 \mathrm{~T} / \mathrm{s}$, so $V=(-10)(200 \mathrm{~T} / \mathrm{s})(\pi)(0.02 \mathrm{~m})^{2} \cos 0^{\circ}=2.5 \mathrm{~V}$. The current through the resistor is therefore $I=V / R=2.5 \mathrm{~V} / 5.0 \Omega=0.50 \mathrm{~A}$. Answer choice $\mathbf{B}$ is numerically equal to the induced voltage. Answer choice $\mathbf{C}$ is numerically equal to $r B_{i} N / R$. Answer choice $\mathbf{D}$ is numerically equal to $V R=(2.5)(5.0)=13$.
63. Use the diagram below to answer the question that follows.


The diagram above shows an iron bar with two insulated coils of wire around the bar. The exterior coil is in series with a battery and a switch. The interior coil is in series with a resistor. The switch is originally open. Which of the following describes what happens to the current through the resistor when the switch is closed?
A. It will spike to some value and quickly drop to zero.
B. It will slowly build up to a constant value.
C. It will instantaneously jump to a constant value.
D. It will oscillate just above and below a nonzero value.

Correct Response: A. As soon as the switch is closed, a small current will start to flow in the outer coil. This current will produce a magnetic field inside the coil, since moving charges create magnetic fields. The current starts small due to the inductive properties of that coil. This current will rise quickly toward a steady state that equals the voltage of the battery divided by the resistance in the outer coil. During the short period that the current is increasing, it will be producing a magnetic field that is also increasing. This increasing magnetic field will induce a voltage in the inner coil, which in turn will produce a current through the resistor. As soon as the battery current in the outer coil reaches a steady state, its associated magnetic field will be constant, so it will no longer be inducing the voltage in the inner coil. At this point, the current through the resistor will be zero. In summary, when the switch is closed, the current through the resistor will spike to some value but will then quickly drop to zero as the magnetic field reaches a steady state. Answer choice B is incorrect because no voltage will be induced in the inner coil once the current in the outer coil stops changing. Answer choice $\mathbf{C}$ is incorrect because the inductive properties of the outer coil prevent the battery current from increasing instantaneously from zero to its steady state value. Answer choice $\mathbf{D}$ is incorrect because it describes the superposition of an alternating current (AC) and a direct current (DC). Without the use of an AC power supply, the AC could be produced only by alternately and repeatedly opening and closing the switch.
64. According to Maxwell's equations, a time-dependent magnetic field will be produced under which of the following circumstances?
A. The total magnetic flux through a surface is equal to zero.
B. A field exists that is the gradient of a scalar function.
C. An electric field varies with time.
D. The electric flux through surface is zero.

Correct Response: C. According to Maxwell's third equation (Faraday's law), an electric field that varies with time will always give rise to a magnetic field that also varies with time. Response A comes from Maxwell's second equation (Gauss's law for magnetism), which states that the total magnetic flux through a surface is equal to zero (A) for closed surfaces. This has nothing to do with producing a time dependent magnetic field. A time-dependent magnetic field is not produced from the gradient of a scalar function (B); it is produced by a time-dependent electric field. According to Maxwell's first law (Gauss's law for electric fields), the electric flux through a surface is zero (D) for any closed surface that contains no charges. This does not give rise to a time-dependent magnetic field.
65. Which of the following can be concluded about a region of space where the rate of change of the magnetic field is nonzero?
A. An electric field will be produced.
B. A harmonic electromagnetic wave will be produced.
C. Electromagnetic waves in the visible spectrum will be produced.
D. A magnetic material is present in the vicinity of the region.

Correct Response: A. A changing magnetic field produces a changing electric field. This will occur regardless of the rate of change as long as it is nonzero. Answer choice B could only be correct if the changing magnetic field were cyclical. An electromagnetic wave would then be produced that matches the fundamental frequency of the changing magnetic field. The fundamental frequency is the first harmonic. However, it was not specified that the change of the magnetic field is cyclical, so this answer is incorrect. Answer choice $\mathbf{C}$ is possible, but only if the changing magnetic field has a frequency that falls within the range of the visible spectrum. Answer choice $\mathbf{D}$ is possible, but not necessarily true since an accelerating charge will also produce a changing magnetic field.
66. Use the information below to answer the question that follows.

A pendulum swings back and forth. Due to frictional forces, the amplitude of motion decreases each cycle until the pendulum eventually comes to a stop.

Which of the following circuits behaves in a manner analogous to the system described above?
A.

B.

C.

D.


Correct Response: C. In a pendulum, energy is converted between kinetic energy and potential energy. When friction is present, the motion is damped and energy is converted to heat. The circuit in C is a damped electrical sinusoidal oscillator. Energy is converted between electric energy (in the capacitor) and magnetic energy (in the inductor), and also dissipated as heat through the resistor. The current in the circuit oscillates and decays as the resistor converts electrical energy into thermal energy. This is analogous to the pendulum, which is a damped mechanical simple-harmonic oscillator. Answer choice A is not an oscillator. Although it does include a capacitor, it does not include an inductor, and it must have both. Answer choice B is not an oscillator, because it includes a diode that limits the direction of the current. Although the circuit does include both a capacitor and an inductor, the diode prevents the circuit from oscillating. Answer choice $\mathbf{D}$ is an undamped oscillator. It will oscillate forever because it includes capacitors and an inductor. However, it is not analogous to the pendulum with friction, because it has no resistor.
67. Use the diagram below to answer the question that follows.


The input signal for the ideal circuit above is a sine wave. Which of the following graphs shows the voltage $\left(V_{R}\right)$ across the resistor with respect to time $(t)$ ?
A.

B.

C.

D.


Correct Response: B. A diode allows current in one direction only. The diode in the circuit will function as a half-wave rectifier, restricting the flow of current to one direction. This results in a wave form that includes only positive half cycles, as shown. Answer choice A is incorrect. It shows the graph of a full-wave rectifier. In this case, the negative half-cycles are inverted rather than eliminated. This cannot be accomplished with the circuit shown. Answer choice $\mathbf{C}$ is incorrect. It shows the inverted wave form of a full-wave rectifier. This cannot be accomplished with the circuit shown. Answer choice D is incorrect. It shows the wave form of an alternating current (AC). The diode in the circuit would allow the current to flow in only one direction.
68. A transducer is used to convert mechanical vibrations into electrical waves. The power output of the transducer is of the order of several microwatts. A scientist would like to increase this value so the signal can be recorded to magnetic tape. A circuit based primarily on which of the following components would be most appropriate for this purpose?
A. capacitors
B. diodes
C. transformers
D. transistors

Correct Response: D. The circuit would be based primarily on transistors because transistors can be used to amplify weak signals. Although answer choices A, B, and C might all be used in the circuits of the amplifier, it is the transistor that performs the amplification of the weak signal from the transducer.
69. Use the graph below to answer the question that follows.


The position versus time graph above represents a mass undergoing simple harmonic motion. At which of the following positions is the net force on the mass in the positive direction and maximum in magnitude?
A. I
B. II
C. III
D. IV

Correct Response: C. For a particle undergoing simple harmonic motion, the displacement is always the negative of the acceleration. At point III, the displacement is negative and at the maximum absolute value. This means the acceleration of the mass is positive and at its maximum value, as is the force since it is directly proportional to the acceleration. At point I (A), the displacement is positive and at the maximum value. This means the force on the mass is negative and at its maximum absolute value. At point II (B), the displacement is zero as the mass passes through equilibrium while moving in the negative direction, so that the force on the mass is also zero. At point IV (D), the displacement is zero as the mass passes through equilibrium while moving in the positive direction, so the force on the mass is also zero.
70. Use the graph below to answer the question that follows.


The graph above gives the displacement of a pendulum bob with respect to time. What is the length of the pendulum?
A. $\quad 0.74 \mathrm{~m}$
B. $\quad 1.5 \mathrm{~m}$
C. $\quad 2.2 \mathrm{~m}$
D. $\quad 3.0 \mathrm{~m}$

Correct Response: C. The relationship between the period of a pendulum and its length is represented by the equation $T=2 \pi \sqrt{\frac{L}{g}}$. Solving the equation for $L$ produces $L=g T^{2} /\left(4 \pi^{2}\right)$. According to the graph, one cycle is completed in 3 s , so the period of the pendulum is 3 s . Setting $T=3 \mathrm{~s}$ in the equation produces the answer $L=2.2 \mathrm{~m}$. Answer choice $\mathbf{A}$ is not related to the length of the pendulum. Answer choice $\mathbf{B}$ is numerically equal to one half the period of the pendulum, not the length of the pendulum. Answer choice $\mathbf{D}$ is numerically equal to the period of the pendulum, not the length of the pendulum.
71. The speed of sound in air is $340 \mathrm{~m} / \mathrm{s}$. At what pitch must a $170-\mathrm{cm}$-tall person sing to produce a sound wave with a wavelength equal to the person's height?
A. $\quad 24.5 \mathrm{~Hz}$
B. 200 Hz
C. 255 Hz
D. 578 Hz

Correct Response: B. The frequency of a wave can be calculated with the equation $f=v \lambda$, where $v$ and $\lambda$ are given to be $340 \mathrm{~m} / \mathrm{s}$ and 170 cm , respectively. Therefore, $f=(340 \mathrm{~m} / \mathrm{s}) /[(170 \mathrm{~cm})(1 \mathrm{~m} / 100$ $\mathrm{cm})]=200 \mathrm{~Hz}$. Answer choice A corresponds to a wavelength of 14 m . Answer choice $\mathbf{C}$ is one-half the sum of the speed in meters per second and the wavelength in centimeters. Answer choice $\mathbf{D}$ is the product of the speed in meters per second and the wavelength in meters.

## 72. Use the diagram below to answer the question that follows.



The two loudspeakers shown in the diagram above are in phase and produce a sound of frequency 680 Hz . The speed of sound is $340 \mathrm{~m} / \mathrm{s}$. At point $P$, no sound is heard. Given that $d_{1}$ and $d_{2}$ are the distances from $P$ to speaker 1 and speaker 2, respectively, which of the following equations could be true?
A. $\quad d_{2}-d_{1}=\frac{1}{4} m$
B. $\quad d_{2}-d_{1}=\frac{1}{2} m$
C. $d_{2}-d_{1}=2 m$
D. $d_{2}-d_{1}=3 \mathrm{~m}$

Correct Response: A. The wavelength of the sound produced by each speaker can be determined with the equation $\lambda=v / f=(340 \mathrm{~m} / \mathrm{s}) /(680 \mathrm{~Hz})=0.5 \mathrm{~m}$. At point $P$, the sound waves from the two speakers are destructively interfering so that at point $P$ the waves from the speakers are $180^{\circ}$ out of phase. Therefore the difference in the distances traveled by the waves must be an odd multiple of $(1 / 2) \lambda=0.25 \mathrm{~m}$. Stated mathematically, destructive interference will occur whenever this equation is satisfied: $d_{2}-d_{1}=n(0.25 \mathrm{~m})$, where $n$ is any odd whole number. Answer choice $\mathbf{B}$ describes a point where constructive interference takes place, because $d_{2}-d_{1}=\lambda$. The sound at this point would be at a maximum rather than silent. Answer choice $\mathbf{C}$ describes a point where constructive interference takes place, since 2 m is an even multiple of (1/2) $\lambda$, which means it is also a multiple of $\lambda$. Answer choice $\mathbf{D}$ describes a point where constructive interference takes place, since 3 m is an even multiple of (1/2) $\lambda$, which means it is also a multiple of $\lambda$.
73. A harmonic sound wave at a point $x$ and time $t$ is represented as a pressure wave by the following equation:
$P(x, t)=P \cos (k x-\omega t+\phi)$
Which of the following quantities associated with the sound wave is most closely related to the human perception of pitch?
A. $P$
B. $k$
C. $\omega$
D. $\phi$

Correct Response: C. The human perception of the pitch of a sound is determined primarily by the frequency of its sound wave, which in this case is equal to $\omega / 2 \pi . P(A)$ is the amplitude of the wave, which determines its loudness but has no effect on pitch, and $k(B)$ is the wave number equal to $2 \pi / \lambda$, which also has no effect on pitch. The phase of the wave is $\phi(\mathbf{D})$, which has no effect on pitch.
74. A piece of string, fixed at both ends, is struck to produce a wave in the string. Given that $\mu$ is the string's linear mass density and $T$ is its tension, which of the following combinations of values will produce the greatest wave speed?
A. $\quad \mu=0.1 \mathrm{~kg} / \mathrm{m}, T=0.1 \mathrm{~N}$
B. $\quad \mu=0.1 \mathrm{~kg} / \mathrm{m}, T=1.0 \mathrm{~N}$
C. $\quad \mu=1.0 \mathrm{~kg} / \mathrm{m}, T=0.1 \mathrm{~N}$
D. $\quad \mu=1.0 \mathrm{~kg} / \mathrm{m}, T=1.0 \mathrm{~N}$

Correct Response: B. The speed of a wave on a string can be calculated with the equation $v=\sqrt{\frac{T}{\mu}}$.
Based on this equation, the speed of the wave is highest when $\mu$ is minimized and $T$ is maximized. Answer choice $\mathbf{A}$ includes the minimum values of both $\mu$ and $T$, rather than the minimum value of $\mu$ and the maximum value of $T$. Answer choice $\mathbf{C}$ includes the maximum value of $\mu$ and the minimum value of $T$, rather than the minimum value of $\mu$ and the maximum value of $T$. Answer choice $\mathbf{D}$ includes the maximum value of both $\mu$ and $T$, rather than the minimum value of $\mu$ and the maximum value of $T$.
75. An organ pipe is closed at one end. As the temperature of the gas inside the pipe increases, which of the following will also increase?
A. the wavelength of the fundamental frequency
B. the ratio of the harmonics produced in the pipe
C. the speed of the waves produced in the pipe
D. the number of overtones produced in the pipe

Correct Response: C. The speed of sound increases as air temperature increases. Therefore, if the temperature of the air in the pipe increases, the speed of sound in the pipe will also increase. The wavelength of the fundamental frequency (A) for a pipe that is closed at one end is equal to four times the length of the pipe, so the wavelength will change only if the length of the pipe changes. Although the fundamental frequency and the harmonics will all shift upward, they will do so by the same factor as the velocity. The ratio of the harmonics produced in the pipe ( $B$ ) will therefore remain the same, since harmonics by definition are whole number multiples of their fundamental frequency. The number of overtones produced in the pipe (D) will not change, although their frequencies will shift upward by a common factor.
76. Use the diagram below to answer the question that follows.


A source produces a sound wave of frequency $f$ with a wavelength of 1.0 m . The sound travels to a detector through two different paths of lengths $L_{1}$ and $L_{2}$. The sound intensity at the detector will be at its maximum when which of the following is true?
A. $L_{2}-L_{1}=0.25 \mathrm{~m}$
B. $L_{2}-L_{1}=0.50 \mathrm{~m}$
C. $L_{2}-L_{1}=1.5 \mathrm{~m}$
D. $L_{2}-L_{1}=2.0 \mathrm{~m}$

Correct Response: D. $L_{2}-L_{1}=2.0 \mathrm{~m}$ describes a point where the waves are in phase and maximum constructive interference takes place, since 2 m is a multiple of $\lambda=1.0 \mathrm{~m}$. Answer choice $\mathbf{A}$ describes a point where the waves are $90^{\circ}$ out of phase, since 0.25 m is (1/4) $\lambda$. Maximum constructive interference does not take place, because the waves are not in phase. Answer choice $\mathbf{B}$ describes a point where the waves are $180^{\circ}$ out of phase, since 0.50 m is (1/2) $\lambda$. Maximum destructive interference takes place at this point. Answer choice C describes a point where the waves are $270^{\circ}$ out of phase, since 1.5 m is (3/4) $\lambda$. Maximum constructive interference does not take place, because the waves are not in phase.

## 77. Use the diagram below to answer the question that follows.



The diagram above shows a string of length 0.30 m oscillating in its first harmonic. What is the wavelength when the string is oscillating in its third harmonic?
A. $\quad 0.10 \mathrm{~m}$
B. $\quad 0.20 \mathrm{~m}$
C. $\quad 0.45 \mathrm{~m}$
D. 0.90 m

Correct Response: B. The wavelength of the third harmonic is one-third the wavelength of the fundamental. For the string oscillating in its first harmonic, one-half the wavelength of the fundamental is equal to the length of the string, so the wavelength of the fundamental is $\lambda_{1}=(2)(0.30 \mathrm{~m})=0.60 \mathrm{~m}$. The wavelength of the third harmonic is therefore $\lambda_{3}=0.60 \mathrm{~m} / 3=0.20 \mathrm{~m}$. Answer choice $\mathbf{A}$ is $(1 / 2)\left(\lambda_{1} / 3\right)=0.10 \mathrm{~m}$. Answer choice $\mathbf{C}$ is $(1 / 4)\left(\lambda_{1}\right)(3)=0.45 \mathrm{~m}$. Answer choice $\mathbf{D}$ is $(1 / 2) \lambda_{1}(3)=0.90 \mathrm{~m}$.
78. Which of the following electric circuits could be used to generate electromagnetic waves of a given frequency $f$ ?
A.

B.

C.

D.


Correct Response: A. An inductor-capacitor ( $L C$ ) circuit will oscillate at the frequency $f=1 /\left[2 \pi(L C)^{1 / 2}\right]$. Since accelerating charges produce electromagnetic waves, the circuit will oscillate waves of the same frequency. B is a resistor-inductor ( $R L$ ) circuit and exhibits exponential decay, to resonance. C is a resistor connected to a diode. It does not have a resonant frequency, nor does $\mathbf{D}$, a capacitor connected to a diode.
79. Use the diagram below to answer the question that follows.


The diagram above shows the geometry for a double-slit interference pattern produced by light from a laser that is incident on two slits separated by a distance $d$. For small values of $\theta$, which of the following best describes the significance of the length of segment $A B$ in the diagram?
A. It is equal to an integral multiple of the wavelength of the incident laser light.
B. It is directly proportional to the intensity of a bright region in the pattern.
C. It is equal to the distance between any two adjacent bright fringes on the screen.
D. It is related to the difference in phase between the two light waves arriving at a point on the screen.

Correct Response: D. Compared with light from the upper slit, light from the lower slit travels a greater distance before reaching the screen at the point shown in the diagram. The difference in the distances traveled by the light from the slits equals the length of segment $A B$. Therefore, the light from the slits arrives at the point on the screen with a phase difference that depends directly on the length of $A B$. Answer choice A would be correct only in the case where $\theta$ is selected, such that the length of $A B$ is an integral multiple of the wavelength. Answer choice $\mathbf{B}$ is incorrect. The intensity of the bright fringes does depend on the length of $A B$, but it is not proportional to this length. Answer choice $\mathbf{C}$ is incorrect. The length of $A B$ is not equal to the distance between any two adjacent bright fringes on the screen.
80. A solar panel is $12 \%$ efficient at converting sunlight into electrical energy. On average, the sunlight that strikes the earth's surface has an intensity of $250 \mathrm{~W} / \mathrm{m}^{2}$. Which of the following is the best estimate for the size of a solar panel needed to provide 1.2 kW of energy to a home?
A. $\quad 5 \mathrm{~m} \times 8 \mathrm{~m}$
B. $6 \mathrm{~m} \times 10 \mathrm{~m}$
C. $\quad 13 \mathrm{~m} \times 13 \mathrm{~m}$
D. $20 \mathrm{~m} \times 20 \mathrm{~m}$

Correct Response: A. The average amount of electrical power per square meter available from the solar panel is $(12 \%)\left(250 \mathrm{~W} / \mathrm{m}^{2}\right)=30 \mathrm{~W} / \mathrm{m}^{2}$. The area of the solar panel required for providing 1.2 kW of power can be determined with the equation $A=P /\left(30 \mathrm{~W} / \mathrm{m}^{2}\right)=(1.2 \mathrm{~kW})(1000 \mathrm{~W} / \mathrm{kW}) /\left(30 \mathrm{~W} / \mathrm{m}^{2}\right)=40$ $\mathrm{m}^{2}$. The $5 \mathrm{~m} \times 8 \mathrm{~m}$ panel will meet the requirement because it has an area of $40 \mathrm{~m}^{2}$. The area in answer choice B would provide $(1.2 \mathrm{~kW})\left(60 \mathrm{~m}^{2}\right) /\left(40 \mathrm{~m}^{2}\right)=1.8 \mathrm{~kW}$. The area in answer choice C would provide $(1.2 \mathrm{~kW})\left(169 \mathrm{~m}^{2}\right) /\left(40 \mathrm{~m}^{2}\right)=5.1 \mathrm{~kW}$. The area in answer choice $\mathbf{D}$ would provide ( 1.2 kW )(400 $\left.\mathrm{m}^{2}\right) /\left(40 \mathrm{~m}^{2}\right)=12 \mathrm{~kW}$.
81. Use the table below to answer the question that follows.

| Frequency of Electromagnetic <br> Waves (Hz) |  |
| :---: | :---: |
| infrared | $10^{12}$ |
| ultraviolet | $10^{15}$ |
| X-ray | $10^{18}$ |
| gamma | $10^{23}$ |

The table above gives the approximate frequency of some electromagnetic waves. Which of following wavelengths should be used for penetrating radiation designed to produce medical images?
A. $\quad 10^{-3} \mathrm{~m}$
B. $\quad 10^{-6} \mathrm{~m}$
C. $\quad 10^{-9} \mathrm{~m}$
D. $\quad 10^{-12} \mathrm{~m}$

Correct Response: C. X-rays are commonly used to produce medical images. The approximate wavelength of the $x$-rays is $\lambda=c / f$, where $\lambda$ is the wavelength of $x$-rays, $c$ is the speed of light in a vacuum, and $f$ is the frequency of the $x$-rays. In this case, $\lambda=\left(3.0 \times 10^{8} \mathrm{~m} / \mathrm{s}\right) / 10^{18} \mathrm{~Hz}=3.0 \times 10^{-10} \mathrm{~m}$, which is closest to $10^{-9} \mathrm{~m}$. Answer choice A corresponds to a frequency of ( $3 \times 10^{8} \mathrm{~m} / \mathrm{s}$ ) $/ 10^{-3} \mathrm{~m}=3$ $\times 10^{11} \mathrm{~Hz}$. This is closest to infrared. Answer choice B corresponds to a frequency of $\left(3 \times 10^{8} \mathrm{~m} / \mathrm{s}\right) / 10^{-6}$ $\mathrm{m}=3 \times 10^{14} \mathrm{~Hz}$. This is closest to ultraviolet. Answer choice D corresponds to a frequency of ( $3 \times 10^{8}$ $\mathrm{m} / \mathrm{s}) / 10^{-12} \mathrm{~m}=3 \times 10^{20} \mathrm{~Hz}$. This is between x-rays and gamma rays.
82. Use the diagram below to answer the question that follows.


Light is incident on the first polarizing filter. As the second filter is rotated, at what angles will the intensity of the transmitted light be a minimum?
A. $45^{\circ}, 90^{\circ}$
B. $45^{\circ}, 225^{\circ}$
C. $90^{\circ}, 180^{\circ}$
D. $90^{\circ}, 270^{\circ}$

Correct Response: D. As the second filter is rotated, the angle at which the intensity of the transmitted light will be a minimum is $90^{\circ}$ either clockwise or counterclockwise. This corresponds to the angles $\pm 90^{\circ}$, which are the same as $90^{\circ}, 270^{\circ}$. Answer choices $\mathbf{A}$ and $\mathbf{C}$ each include one of the two correct angles, and answer choice $\mathbf{B}$ includes neither of the correct angles.
83. Use the diagram below to answer the question that follows.


The diagram above shows two mirrors attached at a right angle. A ray of light is incident on one mirror with an angle of incidence of $\theta$. What is the angle of reflection from the second mirror?
A. $\frac{1}{2} \theta$
B. $\theta$
C. $90-\theta$
D. $180-2 \theta$

Correct Response: C. According to the law of reflection, the angle of reflection from mirror 1 equals the angle of incidence, $\theta$. The angle formed by mirror 1 and its reflected ray is $90^{\circ}-\theta$, so the angle formed by this same ray and Mirror 2 must be $\theta$. Therefore, the angle of incidence for Mirror 2 is $90^{\circ}-\theta$, and by the law of reflection, the angle of reflection must also be $90^{\circ}-\theta$. A is equal to half of the incident angle for Mirror 1. $\mathbf{B}(\theta)$ is the incident angle for mirror 1. D $(180-2 \theta)$ is twice the reflected angle for Mirror 2.
84. A ray of light passes from air $(n=1.0)$ into a material. The angle of incidence is $40^{\circ}$ and the angle of refraction is $25^{\circ}$. What is the index of refraction of the material?
A. 0.66
B. 0.85
C. 1.2
D. 1.5

Correct Response: D. According to Snell's law, $n_{1} \sin \theta_{1}=n_{2} \sin \theta_{2}$, so $n_{2}=n_{1} \sin \theta_{1} / \sin \theta_{2}=1.0$ $\sin 40^{\circ} / \sin 25^{\circ}=1.5$. Answer choice A would be obtained if the two angles were interchanged$\sin 25^{\circ} / \sin 40^{\circ}=0.66$. Answer choice B would be obtained if the cosines of the two angles were mistakenly used in place of their sines- $\cos 40^{\circ} / \cos 25^{\circ}=0.85$. Answer choice $\mathbf{C}$ would be obtained if the cosines of the two angles were mistakenly used in place of their sines after interchanging the angles- $\cos 25^{\circ} / \cos 40^{\circ}=1.2$.
85. Use the diagram below to answer the question that follows.


The diagram above shows a concave mirror with focal point $F$ and center of curvature $C$. An object placed at which of the following positions in front of the concave mirror will produce a magnified, virtual image?
A. I
B. II
C. III
D. IV

Correct Response: A. Placing the object between the focal point and the mirror will produce an image that is virtual, upright, and magnified. Placing the object at the focal length (B) will produce an image at infinity. Placing the object at the center (C) will produce an image at the center that is real, inverted, and the same size as the object. Placing the object farther away than the center (D) will produce an image that is real and inverted, that is smaller than the object, and that is located between the focal point and the center.
86. A converging lens produces a real image at a distance of 20 cm for an object located 40 cm in front of the lens. What is the focal length of the lens?
A. $\quad 0.50 \mathrm{~cm}$
B. 2.5 cm
C. 13 cm
D. 20 cm

Correct Response: C. The focal length can be found with the equation $1 / f=1 / d_{i}+1 / d_{0}=1 / 20 \mathrm{~cm}+$ $1 / 40 \mathrm{~cm}=3 / 40 \mathrm{~cm}$, so $f=40 \mathrm{~cm} / 3=13 \mathrm{~cm}$. Answer choice $\mathbf{A}$ is obtained using the incorrect equation $f=d_{\mathrm{i}} / d_{\mathrm{o}}=20 \mathrm{~cm} / 40 \mathrm{~cm}=0.50$. Answer choice $\mathbf{B}$ is obtained using the incorrect equation $f=d_{\mathrm{i}} / d_{\mathrm{o}}+$ $d_{\mathrm{o}} / d_{\mathrm{i}}=(20 \mathrm{~cm} / 40 \mathrm{~cm})+(40 \mathrm{~cm} / 20 \mathrm{~cm})=2.5$. Answer choice $\mathbf{D}$ is $d_{\mathrm{i}}=20 \mathrm{~cm}$.
87. An ideal gas is in a container. In a time interval $\Delta t, n$ particles with momentum $p$ in the $x$ direction undergo elastic collisions with the wall of the container. The area of the wall is $A$. Which of the following expressions is equal to the average pressure on the wall?
A. $\frac{n p}{A \Delta t}$
B. $\frac{2 n p}{A \Delta t}$
C. $\frac{2 n p \Delta t}{A}$
D. $\frac{n p \Delta t}{A}$

Correct Response: B. The pressure of a gas is the result of molecular collisions with the walls of the container. It is also equal to the average force divided by area. According to the impulse-momentum theorem, $F_{\mathrm{avg}} \Delta t=\Delta p$, so $F_{\mathrm{avg}}=\Delta p / \Delta t=-2 p / \Delta t$ for each particle, since each particle collides elastically in one dimension. There are $n$ particles, so the magnitude of the average force for all the particles is $n 2 p / \Delta t=2 n p / \Delta t$. Since pressure is force per unit area, the average pressure is $2 n p /(A \Delta t)$. A does not properly account for the magnitude of the change in momentum for each particle. The change in momentum is $-2 p$ not $-p: \Delta p=p_{\mathrm{f}}-p_{\mathrm{i}}=-p_{\mathrm{i}}-p_{\mathrm{i}}=-2 p_{\mathrm{i}}=-2 p$, which has a magnitude of $2 p . \mathrm{C}$ is incorrect because it has time in the numerator rather than in the denominator. $\mathbf{D}$ is incorrect because it has time in the numerator and because it is missing the factor of 2 in the numerator.
88. Which of the following describes the primary significance of Rutherford's alpha-scattering experiments?
A. They developed the concept of the half-life of a radioactive element.
B. They created new radioactive isotopes by nuclear bombardment.
C. They changed one atomic element into another through nuclear reactions.
D. They demonstrated the existence of a small, dense, positively charged atomic nucleus.

Correct Response: D. The scattering of the alpha particles that were used to bombard a thin sheet of gold foil demonstrated the existence of a small, dense, positively charged atomic nucleus. Although Rutherford did develop the concept of half-life of a radioactive element (A), the alpha-scattering experiments did not contribute to the development of that concept. Creation of new radioactive isotopes by nuclear bombardment (B) is incorrect because Rutherford's alpha-scattering experiments had nothing to do with creating new isotopes. Changing one atomic element into another through nuclear reactions (C) is incorrect because Rutherford's alpha-scattering experiments had nothing to do with changing one atomic element into another.
89. The energy levels of the hydrogen atom are given by the equation below.
$E_{n}=\frac{-13.6}{n^{2}} \mathrm{eV}$
What is the energy of a photon released when an electron transitions from the $n=3$ level to the $n=1$ level?
A. $\quad 4.53 \mathrm{eV}$
B. $\quad 1.51 \mathrm{eV}$
C. $\quad 12.1 \mathrm{eV}$
D. $\quad 15.1 \mathrm{eV}$

Correct Response: C. The energy of the photon is $E_{3}-E_{1}=-1.51 \mathrm{eV}-(-13.6 \mathrm{eV})=12.1 \mathrm{eV}$. Answer choice $\mathbf{A}$ is obtained using the incorrect equation $13.6 \mathrm{eV} / 3=4.53 \mathrm{eV}$. Answer choice $\mathbf{B}$ is obtained using the incorrect equation $13.6 \mathrm{eV} / 3^{2}=1.51 \mathrm{eV}$. Answer choice $\mathbf{D}$ is obtained using the incorrect equation $-E_{3}-E_{1}=1.51 \mathrm{eV}-(-13.6 \mathrm{eV})=15.1 \mathrm{eV}$.
90. Which of the following is one of Einstein's postulates of special relativity?
A. Events that are simultaneous for one observer are not simultaneous for another observer in motion relative to the first.
B. The energy of a photon is directly proportional to the frequency of the light.
C. The momentum of an object approaches infinity as its speed approaches that of light.
D. The speed of light in a vacuum has the same value in all inertial reference frames.

Correct Response: D. One of the two postulates of special relativity is that the speed of light in a vacuum has the same value in all inertial reference frames. Answer choices A and C are both included in special relativity as conclusions. Answer choice $\mathbf{B}$ is associated with the photoelectric effect. It was first proposed by Max Planck, and then used by Albert Einstein in developing his theory that explained the photoelectric effect.
91. An elementary particle moving at 0.99 c with respect to the laboratory frame has a half-life of $16 \mu \mathrm{~s}$ in the laboratory frame. What is the half-life of the particle in its own frame of reference?
A. $\quad 0.50 \mu \mathrm{~s}$
B. $\quad 2.3 \mu \mathrm{~s}$
C. $\quad 4.0 \mu \mathrm{~s}$
D. $15 \mu \mathrm{~s}$

Correct Response: B. The elementary particle moving at $0.99 c$ with respect to the laboratory frame will appear to have a longer half-life to an observer in the laboratory's frame of reference compared with the half-life observed by an observer in the particle's frame of reference. The half-life observed in the particle's frame of reference can be found using the equation $\Delta t_{0}=\Delta t\left(1-v^{2} / c^{2}\right)^{1 / 2}=(16 \mu \mathrm{~s})$ $\left(1-0.99^{2}\right)^{1 / 2}=2.3 \mu \mathrm{~s}$. Answer choice A would be the half-life observed in the particle's frame of reference if the $16 \mu$ s half-life had been observed when the relative speed of the particle was $0.9995 c$. Answer choice C would be the half-life observed in the particle's frame of reference if the $16 \mu$ s half-life had been observed when the relative speed of the particle was 0.97 c. Answer choice $\mathbf{D}$ would be the half-life observed in the particle's frame of reference if the $16 \mu$ s half-life had been observed when the relative speed of the particle was 0.35 c.
92. The work function for potassium metal is 2.2 eV . If $h$ is Planck's constant, what is the minimum frequency of light required to remove an electron from potassium metal?
A. $\frac{2.2}{h}$
B. $\frac{h}{2.2}$
C. $2.2 h$
D. $h^{2.2}$

Correct Response: B. The minimum frequency of light required to remove an electron from potassium metal is the frequency of a photon with energy equal to the work function $E=h f=2.2 \mathrm{eV}$, so $\mathrm{f}=2.2 \mathrm{eV} / \mathrm{h}$. Answer choices $\mathbf{A}, \mathbf{C}$, and $\mathbf{D}$ are variations based on the quantities used in the correct formula.
93. Which of the following expressions gives the de Broglie wavelength of an electron of mass $m$ and kinetic energy $E$ ?
A. $\frac{h}{\sqrt{2 m E}}$
B. $h \sqrt{2 m E}$
C. $\frac{\sqrt{2 E}}{m h}$
D. $m h \sqrt{2 E}$

Correct Response: A. The de Broglie wavelength of the electron can be determined with the equation $\lambda=h / p$, where $h=$ Planck's constant and $p$ is the momentum of the electron, which is equal to the mass of the electron times its velocity $(p=m v)$. The kinetic energy of the electron traveling at speeds much less than the speed of light can be determined with the equation $E=(1 / 2) m v^{2}$, where $m$ is the mass of the electron and $v$ is its speed. Substituting $m v$ with $p$ in the kinetic energy equation produces the equation $E=(1 / 2) p v=(1 / 2) p m v / m=p^{2} /(2 m)$. Solving this equation for momentum yields $p=(2 m E)^{1 / 2}$. Substituting momentum with $(2 m E)^{1 / 2}$ in the equation for the de Broglie wavelength produces $\lambda=h /(2 m E)^{1 / 2}$. Answer choice $\mathbf{B}$ shows the denominator of the correct answer being multiplied by its numerator. Answer choice $\mathbf{C}$ is the reciprocal of the correct answer, except that $m$ appears in the denominator rather than under the radical sign in the numerator. Answer choice $\mathbf{D}$ shows the denominator of the correct answer being multiplied by its numerator but with $m$ appearing as a factor rather than under the radical sign.
94. If $\psi(x)$ is a solution to the one-dimensional, time-independent Schrödinger equation, which of the following is proportional to the probability of finding an electron in a region $\Delta x$ ?
A. $\sqrt{\psi(x)}$
B. $\int|\psi(x)|^{2} \mathrm{~d} x$
C. $\int \psi(x) \mathrm{d} x$
D. $i h \frac{d \psi(x)}{d x}$

Correct Response: B. The wave function $\Psi(x)$ describes the state of a particle, in this case the electron. To find the relative probability that an electron is located in a region $\Delta x$, the square of the absolute value of the wave function is integrated over $\Delta x$, so the relative probability equals the integral $\int_{x_{1}}^{x_{2}}|\Psi(x)|^{2} d x$, where $x_{1}$ and $x_{2}$ represent the endpoints of $\Delta x$. The absolute probability can then be determined by normalizing the relative probability density function $|\Psi(x)|^{2}$ so that the total probability over all possible values of $x$ is set to equal one. Answer choice $\mathbf{A}$ is the square root of the wave function. Answer choice $\mathbf{C}$ is the integral of the wave function with respect to $x$. Answer choice $\mathbf{D}$ is the momentum operator.
95. The hydrogen atom in the ground state has a radius of approximately $0.53 \times 10^{-10} \mathrm{~m}$ and an ionization energy of 13.6 eV . To "see" a hydrogen atom, light with a wavelength of the same order of magnitude of the size of the atom must be used. Which of the following statements describes how a photon corresponding to this wavelength will interact with the hydrogen atom?
A. The photon will have little effect on the ground-state energy of the electron.
B. The photon will have enough energy to transition the electron to a slightly higher energy level.
C. The photon will have just enough energy to completely ionize the hydrogen atom.
D. The photon will have an energy of several orders of magnitude greater than the ionization energy.

Correct Response: D. The energy of a photon can be calculated with the equation $E=h f=h c / \lambda$, where $h$ is Planck's constant (which equals $6.63 \times 10^{-34} \mathrm{~J} \cdot \mathrm{~s}$ ), $f$ is the frequency of the photon, $c$ is the speed of light in a vacuum (which equals $3.00 \times 10^{8} \mathrm{~m} / \mathrm{s}$ ), and $\lambda$ is the wavelength of the photon. The energy of a photon with $\lambda=0.53 \times 10^{-10} \mathrm{~m}$ is therefore given by the equation $E=\left(6.63 \times 10^{-34} \mathrm{~J} \cdot \mathrm{~s}\right)$ $\left(3.00 \times 10^{8} \mathrm{~m} / \mathrm{s}\right) /\left(0.53 \times 10^{-10} \mathrm{~m}\right)=3.75 \times 10^{-15} \mathrm{~J} /\left(1.6 \times 10^{-19} \mathrm{~J} / \mathrm{eV}\right)=2.3 \times 10^{4} \mathrm{eV}$. This is greater than the ionization energy by approximately three orders of magnitude, which means that a photon at that energy will remove the electron from the atom. Answer choices A, B, and C each greatly understate the energy of the photon.
96. A system consists of 3 electrons. The electrons have spin of either $\frac{1}{2}$ or $-\frac{1}{2}$ and energy quantum numbers of either $n=1$ or $n=2$. Which of the following explains why one electron must have an energy corresponding to $n=2$ ?
A. Compton effect
B. Meissner effect
C. Pauli exclusion principle
D. Heisenberg uncertainty principle

Correct Response: C. The Pauli exclusion principle states that no two electrons of an atom can occupy the same quantum states, which means they cannot have the same set of quantum numbers. If the three electrons were to simultaneously occupy the energy level $n=1$, two would have the same spin, which is not permitted within energy level $n=1$. Answer choice $\mathbf{A}$ pertains to the scattering of $x$ rays or gamma rays as they interact with electrons, resulting in ionization and scattered photons of reduced energy. Answer choice B pertains to superconductors that expel magnetic flux when cooled to the point of superconductivity. Answer choice $\mathbf{D}$ asserts that there is a fundamental limit to the precision with which certain pairs of measurements can be made, such as position and velocity. The more precisely one is measured, the less precisely the other can be known.
97. The chemical symbol for sodium is ${ }_{11}^{23} \mathrm{Na}$. How many electrons does the ion $\mathrm{Na}^{+2}$ have?
A. 9
B. 13
C. 21
D. 25

Correct Response: A. A sodium atom has 11 protons, so a neutral sodium atom must have 11 electrons. An $\mathrm{Na}^{+2}$ ion must therefore have 11-2 = 9 electrons. Answer choice B results from adding 2 electrons to the number of electrons in a neutral atom, rather than subtracting 2 electrons. Answer choice $\mathbf{C}$ results from subtracting 2 from the mass number, 23 , rather than the atomic number, 11. Answer choice $\mathbf{D}$ results from adding 2 to the mass number, 23.
98. The half-life of ${ }^{90} \mathrm{Sr}$ is 27.7 years. Approximately how long will it take for a sample consisting of $10^{6}$ strontium- 90 atoms to decay to $10^{3}$ strontium- 90 atoms?
A. 30 years
B. 110 years
C. 280 years
D. 730 years

Correct Response: C. The number of radioactive atoms remaining after a given period of time, $t$, can be modeled with the equation $N(t)=N_{0} \mathrm{e}^{-\lambda t}$, where $N(t)$ is the number of radioactive atoms remaining after time $t, N_{0}$ is the initial number of atoms, and $\lambda$ is equal to ( $\ln 2$ ) divided by the half-life ( $\mathrm{T}_{1 / 2}$ ) of the isotope. Solving the equation for $\left.t, t=\square \ln \left[N(t) / N_{0}\right] / \lambda=\square \ln \left[10^{3} / 10^{6}\right] /[(\ln 2) / 27.7 \mathrm{y})\right]=276 \mathrm{y}$, which equals 280 y when rounded to two significant figures. Answer choice $\mathbf{A}$ is about 1 half-life. After 30 years, there would be $4.72 \times 10^{5}$ strontium- 90 atoms. Answer choice $\mathbf{B}$ is about 4 half-lives. After 110 years, there would be $6.39 \times 10^{4}$ strontium- 90 atoms. Answer choice $\mathbf{D}$ is about 26 half-lives. After 730 years, there would most likely be 0 strontium- 90 atoms since $N(730)=0.0119$.
99. Which of the following best describes why temperatures of the order of $10^{8} \mathrm{~K}$ are necessary for a fusion reaction to occur?
A. The reactants must be stripped of all electrons to form a plasma before they can fuse together.
B. The reactants must be separated into nucleons before the reaction can take place.
C. The reactants must be confined in a strong magnetic field produced by thermally active nucleons.
D. The reactants must have sufficient kinetic energy to overcome the Coulomb barrier.

Correct Response: D. The reactants must have sufficient kinetic energy to overcome the Coulomb barrier. Temperatures on the order of $10^{8} \mathrm{~K}$ provide the atoms of the reactants with sufficient kinetic energy to overcome the mutual, repulsive electrostatic forces between their positively charged nuclei. Answer choice A is incorrect because plasma forms at temperatures well below $10^{8} \mathrm{~K}$. Answer choice $\mathbf{B}$ is incorrect because the reactants are not separated into nucleons before the reaction can take place. Answer choice $\mathbf{C}$ is incorrect because the need to confine the reactants is not the reason that temperatures on the order of $10^{8} \mathrm{~K}$ are necessary for a fusion reaction to occur. It is also incorrect in stating that the magnetic confinement field is produced by thermally active nucleons.
100. Which of the following is a significant advantage of using radioactive tracers in nuclear medicine?
A. The radiation passes through the less dense matter such as skin and muscle and is absorbed by denser material such as bone.
B. The physiological function of organs can be studied by following the movement of a radioisotope through the organ.
C. The radioactive tracers emit high-energy particles that can be used to destroy malignant tumors.
D. No ionization energy is released during the use of tracers since the imaging equipment measures the perturbed magnetic field of the water molecules in the body.

Correct Response: B. Radioactive tracers are used for the medical diagnoses of organs. The tracer can be tracked as it passes through the organ by detecting the gamma radiation emitted by the radioisotope. Radioisotopes with short half-lives are used so that they do not remain in the body for long periods of time. Answer choice A is a true statement that describes the basis for medical radiography commonly known as x-rays and is most commonly performed with x-rays, not gamma rays. Answer choice $\mathbf{C}$ is incorrect, although radioactive isotopes are commonly used as sources of gamma rays for the destruction of malignant tumors. Radioactive tracers use smaller quantities of radioisotopes that emit relatively low-energy gamma rays. Their purpose is not for destroying tissue but for the diagnoses of organs. Answer choice $\mathbf{D}$ is incorrect because radioactive tracers emit gamma radiation, which is ionizing radiation. The statement would be true if it were applied to magnetic resonance imaging (MRI) rather than radioactive tracers.


[^0]:    www.mtel.nesinc.com
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