*Multiple-Choice Questions*

1. **(E) is correct.** The rate of change of velocity is defined as the acceleration.
2. **(B) is correct.** The projectile fired straight up in the air will land after $t$ seconds, where $y = y_0 + v_{y0}t + 1/2(a_yt^2)$, so $0\text{ m} = 0\text{ m} + (66\text{ m/s})t - 4.9t^2$, and $t = 13.5$ s. The projectile fired at a 60° angle has a $y$ component that is $66 \sin 60° = 33\sqrt{3} = 57$ m/s, and it will land after $t$ seconds, where $y = y_0 + v_{y0}t + 1/2a_yt^2, 0 = 0 + 57t - 4.9t^2$ so $t = 11.6$ s, $\Delta t = 13.5\text{ s} - 11.6\text{ s} = 1.9$ s.
3. **(A) is correct.** The vector components of velocity $V$ at a 30° angle will be $V_x = V\cos 30° = V\sqrt{3}/2$ and $V_y = V\sin 30° = V/2$. The time the projectile will remain aloft will be $t$, where $y = y_o + v_yt - gt^2/2$, so $0\text{ m} = 0\text{ m} + V/2t - gt^2/2$ and $t = V/g$. The horizontal distance will be $x = v_xt = ([V\sqrt{3}]/2)(V/g) = (V^2\sqrt{3})/2g$.
4. **(C) is correct.** Using the relation between initial and final velocities for a constant accelerating body traversing a distance $x$, $v^2 = v_o^2 + 2a(x - x_o)$, $(0\text{ m/s})^2 = (20\text{ m/s})^2 + 2a(35\text{ m})$, so $a = -400\text{ m}^2/\text{s}^2/70\text{ m} = -5.7\text{ m/s}^2$.
5. **(B) is correct.** The angle would be given by $\theta$, where $\tan\theta$ = opposite/adjacent. Here, the opposite, perpendicular to the motion of the rear engine alone, is $v_1 = 173$ m/s, while the adjacent, collinear to the motion of the rear engine alone, is $v_2 = 300$ m/s. So $\theta = \tan^{-1}(173/300)$. Examination questions for

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Section I tend to use the most common trigonometric values as given on the "Table of Information." As listed there, $\tan 30° = \sqrt{3}/3 = 1.73/3 = 173/300$.

**6. (D) is correct.** The proper SI units for force are newtons, where $1\ N = 1\ kg{\cdot}m/s^2$, as evidenced by the equation $F = ma$. Joules are units of work, where $1\ J = 1\ kg{\cdot}m^2/s^2 = 1\ N{\cdot}m$, as can be seen in the equation $W = Fd$. So $J/m = N{\cdot}m/m = N$.

**7. (D) is correct.** Weight is defined as the force by gravity, $F = ma$, where on the Earth $m = F/g = 343\ N/9.80\ m/s^2 = 35\ kg$. On this planet, $g' = 7.00\ m/s^2$, so $F = (35.0\ kg)(7.00\ m/s^2) = 245\ N$.

**8. (E) is correct.** The normal force can be ascertained from the sum of forces in the $y$ direction, where $\Sigma F_y = F_N + F_1 \sin\theta + F_2 \sin\theta - mg = 0$, so
$F_N = mg - F_1 \sin\theta - F_2 \sin\theta$
$= (100\ kg)(9.8\ m/s^2) - (400\ N)(\sin 30°) - (320\ N)(\sin 30°)$
$= 980\ N - 200\ N - 160\ N = 620\ N$.

**9. (A) is correct.** Resolving the forces into the components relative to the surface of the incline, $\Sigma F_y = F_N - mg\cos 60° = ma = m(0\ m/s^2)$ so
$F_N = mg\cos 60° = Mg(1/2)$, which can be applied to
$\Sigma F_x = mg\sin 60° - \mu F_N = Mg(\sqrt{3}/2) - (0.20)Mg(1/2)$
$= Mg(1/2)(\sqrt{3} - 0.2) = ma = Ma$, so $a = g(\sqrt{3} - 0.2)/2$.

**10. (C) is correct.** Defining axes so that $x$ is parallel to the surface of the incline, $\Sigma F = mg\sin 30° = ma$. So $a = g\sin 30° = 4.9\ m/s^2$. Using the relation $x = x_0 + v_x t + 1/2at^2 = 0\ m + (0\ m/s)(6\ s) + 1/2(4.9\ m/s^2)(6.0\ s)^2 = 88.2\ m$.

**11. (A) is correct.** Again, defining axes so that $x$ is parallel to the surface of the incline, $\Sigma F = mg\sin 30° = ma$, and $a = g\sin 30° = 4.9\ m/s^2$. Based on the equation $v = v_0 + a_y t = 0\ m/s + (4.9\ m/s^2)(6\ s) = 29.4\ m/s$.

**12. (A) is correct.** A conservative force is one in which the work done is independent of the path taken. Frictional forces, however, depend on the precise path taken and are not simply a function of the initial and final positions.

**13. (B) is correct.** Using a form of the conservation of energy,
$1/2(mv_1^2) + 1/2(kx_1^2) = 1/2(mv_1^2) + 1/2(kx_1^2)$.
Here, $1/2(4\ kg)(8\ m/s)^2 + 1/2(6.4\ N/m)(0\ m)^2$
$= 1/2(4\ kg)(0\ m/s)^2 + 1/2(6.4\ N/m)(x\ m)^2$
but on either side of the equation, this is precisely the quantity of energy that will be returned to the ball in kinetic energy as the ball reaches the equilibrium point again, and the value for compression does not need to be calculated. While the velocity will be $-8\ m/s$, speed is only the magnitude of the vector.

**14. (B) is correct.** To determine the horizontal component of force, the normal force must first be determined from the vertical components, so
$\Sigma F_y = F_N + F_R \sin 30° - Mg = 0\ N$, and $F_N = Mg - F_R/2$.
In the horizontal direction, $\Sigma F_x = F_R \cos 30° - \mu F_N$
$= F_R\sqrt{3}/2 - \mu(Mg - F_R/2) = Ma$.
So $a = [F_R\sqrt{3}/2 - \mu(Mg - F_R/2)]/M$.

**15. (D) is correct.** From the conservation of energy, $E = mgh + 1/2(mv^2) =$ constant. At its maximum height, all energy is potential and
$E = (50\ kg)(9.8\ m/s^2)(100\ m) = 49000\ J$. When it lands, all energy is kinetic, so $KE_f = 49000$. When it is 10 meters from the ground,

$KE = E - PE = 49000\text{ J} - (50\text{ kg})(9.8\text{ m/s}^2)(10\text{ m}) = 49000\text{ J} - 4900\text{ J}$
$= 44100$ J, so the ratio $44100/49000 = 0.9$ or 90%.

**16. (A) is correct.** Since masses are identical, and since the initial velocity of the first is equal to the final velocity of the second, while the initial velocity of the second is equal to the final velocity of the first, kinetic energy is conserved: $1/2mv_A^2 + 1/2mv_B^2 = 1/2mv_A'^2 + 1/2mv_B'^2$. This defines an elastic collision.

**17. (B) is correct.** The fourth piece clearly has a mass of $M/4$, and its velocity $v'$ is sought. From the conservation of momentum, the expectation will be that velocity vector will be in the up and left direction, and the signs of the resulting vector will indicate whether or not this is true. Breaking these pieces into components and applying the conservation of linear momentum,
$P_x = M/4V + M/4V\cos 45° - M/4v_x' = 0$ and
$P_y = M/4v_y' - M/4V - M/4V\cos 45° = 0$.
The $P_x$ equation can be rearranged as
$V + V\cos 45° = (1 + \sqrt{2}/2)V = (2 + \sqrt{2})V/2 = v_x'$
and the $P_y$ equation can be rearranged so that
$v_y' = V + V\cos 45° = (1 + \sqrt{2}/2)V = (2 + \sqrt{2})V/2$.
Each component has a magnitude of $(2 + \sqrt{2})V/2$.

**18. (C) is correct.** This applies the conservation of linear momentum,
$m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2'$, so here $MV + (M/2)(V/4) = (M + M/2)v$
so $v = [MV + (M/2)(V/4)]/(M + M/2)$
$= [MV + (MV/8)]/(3M/2) = [9MV/8]/[3M/2] = 3V/4$.

**19. (E) is correct.** Using the formula for moment of inertia, $I = \Sigma mr^2$. Initially, $I_i = mr^2 + mr^2 = (50\text{ kg})(0.8\text{ m})^2 + (50\text{ kg})(0.8\text{ m})^2 = 64\text{ kg}\cdot\text{m}^2$. Finally, $I_f = mr^2 + mr^2 = (50\text{ kg})(0.7\text{ m})^2 + (50\text{ kg})(0.9\text{ m})^2 = 65\text{ kg}\cdot\text{m}^2$. Their difference is $1\text{ kg}\cdot\text{m}^2$.

**20. (A) is correct.** First converting to the correct SI units for frequency, $f =$ (20 rev/min)(1 min/60 s) $= 1/3$ rev/s. Next, angular velocity is given by $\omega = 2\pi f = 2\pi/3$ rad/s.

**21. (C) is correct.** As a unit of frequency, hertz is measured in inverse seconds, $s^{-1}$, whereas watts measures power and has the units of joules/s. Their product is $J/s^2$.

**22. (B) is correct.** Using the conservation of energy,
$1/2mv_1^2 + 1/2kx_1^2 = 1/2mv_2^2 + 1/2kx_2^2$,
$1/2(k)(A)^2 = 1/2(k)(x)^2 + 1/2(M)(v^2)$,
so $(k)(A)^2 - (k)(x)^2 = (M)(v^2)$, and $v = \sqrt{[k(A^2 - x^2)/M]}$.

**23. (D) is correct.** The Doppler effect is the perceived change in the frequency of waves, including light, whose source of emission (and/or of the observer) is in motion. For light reaching the Earth from a source that is moving away, the perceived frequencies are shifted lower, toward the "red" end of the visible spectrum.

**24. (D) is correct.** The third harmonic has three antinodes, which together represent 1.5 wavelengths. As such, $L = 1.5\lambda = 1.5(0.96) = 1.44$ m. The

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general relation between wavelength, string length and harmonic number is $\lambda = 2L/n$.

**25. (D) is correct.** The inverse of the relation between length and period $T = 2\pi\sqrt{(L/g)}$ provides the applicable equation $f = \sqrt{(g/L)}/2\pi = \sqrt{(9.8\ \text{m/s}^2/0.098\ \text{m})}/2\pi = 5/\pi\ \text{s}^{-1}$.

**26. (D) is correct.** The weight of the object is $mg = (600\ \text{kg})(9.8\ \text{m/s}^2) = 5880\ \text{N}$. The buoyant force is equal to the weight of water displaced by the object, such that $F_B = mg = \rho Vg = (1.25 \times 10^3\ \text{kg/m}^3)(0.375\ \text{m}^3)(9.8\ \text{m/s}^2) = 4594\ \text{N}$ in the opposite direction, and the apparent weight is $5880\ \text{N} - 4594\ \text{N} = 1286\ \text{N}$, or 1300 N to significant figures. Again, if utilizing the correct principle, estimates can quickly point to the correct answer.

**27. (A) is correct.** Using the equation of continuity, $A_1v_1 = A_2v_2$, $\pi(7R)^2v_i = \pi R^2V$. Solving for $v_i = \pi R^2V/\pi(7R)^2 = V/49 = 0.02V$.

**28. (B) is correct.** The given terms can be applied to Bernoulli's equation, $P_1 + 1/2(\rho v_1^2) + \rho gy_1 = P_2 + 1/2(\rho v_2^2) + \rho gy_2$. In terms of final pressure, $P + 1/2\rho(V^2 - 4V^2) - \rho gx = P - 1/2\rho(3V^2 + 2gx) = P_2$.
Note some algebraic manipulation, such as factoring out the negative, is required to put it into the form presented.

**29. (E) is correct.** Specific gravity is the ratio of a substance's density to that of water at 4 °C, and the quotient of two values for density yields no units.

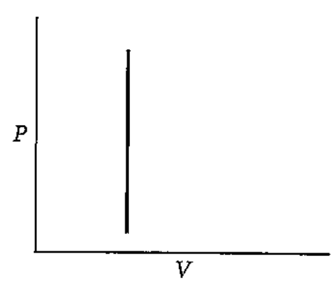
**30. (C) is correct.** If the volume of a cube is $2.7 \times 10^{10}\ \text{m}^3$, the length of each side is $3.0 \times 10^3$ m. When heated by 750 °C, the change in length is given by $\Delta L = \alpha L_o \Delta T = (30 \times 10^{-6}\ {}^\circ\text{C}^{-1})(3.0 \times 10^3\ \text{m})(750\ {}^\circ\text{C}) = 68\ \text{m}$.

**31. (D) is correct.** Using the constituent proportions of the ideal gas law as a ratio, $P_1V_1/T_1 = P_2V_2/T_2$. Based on the information provided, $(2P)(V/4)/xT = PV/T$, so $x = 1/2$ for the ratio to remain constant. Temperature, therefore, is halved.

**32. (A) is correct.** According to this graph, it takes the addition of 10 kcal/kg to fully convert all liquid to steam and complete a phase change, after the temperature has been first raised to 45 °C.

**33. (A) is correct.** Based on the axes of the graph, the specific heat for a state is represented by the inverse of the slope of the line in that state. The slope for the liquid state is $15\ {}^\circ\text{C}/10\ \text{kcal/kg} = 3/2\ \text{kg}\cdot{}^\circ\text{C/kcal}$. The inverse is $0.67\ \text{kcal/kg}\cdot{}^\circ\text{C}$. By anticipating the correct units, several answer choices can be immediately eliminated.

**34. (E) is correct.** In an isochoric process, the volume is constant and therefore is represented by a vertical line, which has an infinitely steep slope.




**35. (C) is correct.** Ideal efficiency is given by $e_c = 1 - T_L/T_H = 1 - 300\ \text{K}/900\ \text{K} = 2/3$, while real efficiency, $e$, is given by

$e = 1 - Q_L/Q_H = 1 - x/5100$ J/s, where $x$ is the heat output per second, so $1 - x/5100$ J/s $= 2/3$, and $x = 1700$ J/s. Note the temperatures are converted to kelvins for all of the calculations.

**36. (C) is correct.** The force between two charges is quantified in Coulomb's law, $F = kQ_1Q_2/r^2$
$= (9 \times 10^9\ \mathrm{N{\cdot}m^2/C^2})(4.0 \times 10^{-6}\ \mathrm{C})(4.9 \times 10^{-6}\ \mathrm{C})/(0.010\ \mathrm{m})^2 = 1800$ N. Note that using estimates, that is $4.9 \approx 5.0$ can allow for quick calculation.

**37. (E) is correct.** The direction of the electric field is tangent to field lines at each point along it.

**38. (A) is correct.** The equation for a single point charge is a function of charge and distance, where $E = kQ/r^2$, so $Er^2 = kQ$
$= (6 \times 10^3\ \mathrm{N/C})(0.15\ \mathrm{m})^2 = kQ$, which can be used for $E = kQ/(0.20\ \mathrm{m})^2$
$= (6 \times 10^3\ \mathrm{N/C})(0.15\ \mathrm{m}/0.20\ \mathrm{m})^2 = (6 \times 10^3\ \mathrm{N/C})(3/4)^2 = 3.8 \times 10^3$ N/C.

**39. (A) is correct.** From trigonometry, the distance between point $X$ and both charges is 5 cm. Leaving the values in terms of $k$ until the end can make algebraic manipulation easier. So for the left charge and $X$,
$E_1 = k(.25\ \mathrm{C})/(.05\ \mathrm{m})^2 = 100k$ while for the right charge and $X$,
$E_2 = k(0.50\ \mathrm{C})/(0.05\ \mathrm{m})^2 = 200k$. While the angle $\theta$ from horizontal to $X$ is unknown, clearly $\sin\theta = 3/5$ and $\cos\theta = 4/5$. So $E_x = +E_1\cos\theta - E_2\cos\theta$
$= +100k(4/5) - 200k(4/5) = -80k$ and $E_y = -E_1\sin\theta - E_2\sin\theta$
$= -100k(3/5) - 200k(3/5) = -180k$. So the magnitude is given by
$\sqrt{(-180k)^2 + (-80k)^2} = k\sqrt{(-180)^2 + (-80)^2} = 197k$
$\cong (9 \times 10^9\ \mathrm{N{\cdot}m^2/C^2})(200)$
$= 18 \times 10^{11}$ N/C.

**40. (C) is correct.** The units of capacitance are farads, equivalent to coulombs per volt (which is the inverse of II). An electromagnetism term, henries are units for mutual inductance, equivalent to V·s/A or Ω·s.

**41. (C) is correct.** The equation for capacitance is given by $C = \varepsilon_0 A/d$ and can be rearranged so that $A = Cd/\epsilon_0$
$= (8.85 \times 10^{-14}\ \mathrm{F})(0.002\ \mathrm{m})/(8.85 \times 10^{-12}\ \mathrm{C^2/N{\cdot}m^2})$
$= 0.00002\ \mathrm{m^2}$ or $20\ \mathrm{mm^2}$.

**42. (B) is correct.** By conservation of energy, the change in potential energy must equal the change in kinetic energy. A charge moved across an electric potential has a change in potential energy of $qV = (-4.0 \times 10^{-14}\ \mathrm{C})(100\ \mathrm{V})$
$= -4.0 \times 10^{-12}$ J, which is in turn equal to the change in kinetic energy, so $1/2mv^2 = -(\Delta PE)$ so $1/2(5.0 \times 10^{-19}\ \mathrm{kg})v^2 = 4.0 \times 10^{-12}$ J
so $v = \sqrt{(4.0 \times 10^{-12}\ \mathrm{J}/25 \times 10^{-20}\ \mathrm{kg})} = 4 \times 10^3$ m/s.

**43. (B) is correct.** The voltages of batteries in series are summed, so 48 V is the potential difference for the circuit. Next, applying Ohm's law, $V = IR$, so $R = V/I = 48\ \mathrm{V}/3\ \mathrm{A} = 16\ \Omega$.

**44. (C) is correct.** The current for each type of bulb can be determined from the relationship $P = IV$, so $60\ \mathrm{W} = (I_1)(120\ \mathrm{V})$ and $45\ \mathrm{W} = (I_2)(120\ \mathrm{V})$, so $I_1 = 0.5$ A and $I_2 = 0.375$ A. Now the total current of the circuit, accounting

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for the number of bulbs, is $n_1I_1 + n_2I_2 = (10)(0.5\text{ A}) + (20)(0.375\text{ A}) = 12.5\text{ A}$. So a fuse would have to have a rating higher than that, and of the choices, 13 A is the minimum rating that could handle the current.

**45. (E) is correct.** Combining the relations $V = IR$ and $P = IV$, $P = V^2/R$ or $R = V^2/P = (120\text{ V})^2/(60\text{ W}) = 240\ \Omega$.

**46. (E) is correct.** The equivalent capacitance of each can be obtained by inspection, in which the series and parallel rules are the opposites of those for resistors. For answer *A*, using the capacitance series rules, $C_{eq} = C/3$. For answer *B*, similarly $C_{eq} = C/2$. For (*C*), using the parallel rule, $C_{eq} = 2C$. For answer *D*, both rules are combined, with the parallel rule applied to two branches each with an equivalent capacitance of $C/2$, so $C_{eq} = C/2 + C/2 = C$. For answer *E*, the parallel rule is applied to three branches each with an equivalent capacitance of $C/2$, so $C_{eq} = C/2 + C/2 + C/2 = 3C/2$.

**47. (A) is correct.** The equivalent resistance must satisfy $V = IR$, so $R_{eq} = V/I = 18\text{ V}/6\text{ A} = 3\ \Omega$. Next, if each resistor is rated $R$, we can determine the equivalent resistance in terms of $R$ and then use $R_{eq} = 3\ \Omega$ to solve for $R$. In the parallel branch at the top of the circuit, using first the series rule for the upper portion and the parallel rule for both, $R_{eq} = 2R/3$. This is itself in parallel with the middle branch, in which the two series resistors have an equivalent resistance of $2R$, so $3/(2R) + 1/(2R) = 4/(2R)$, so $R_{eq} = R/2$ for the entire circuit. Next $R/2 = 3\ \Omega$, so $R = 6\ \Omega$.

**48. (E) is correct.** The force on an electric current in a magnetic field is given by $F = IlB \sin\theta$. Here, however, $\theta = 0°$ so $F = 0$ N.

**49. (C) is correct.** The force on an electric charge is given by $F = qvB \sin\theta = (0.0050\text{ C})(3.0\text{ m/s})(4.5\text{ T}) \sin 60° = 0.034\sqrt{3}$ N.

**50. (B) is correct.** The force per unit length between two wires is given by $F/l = \mu_0 I_1 I_2/[2\pi L] = (2.0 \times 10^{-7}\text{ T·m/A})(6.0\text{A})(6.0\text{A})/[2\pi(0.02\text{ m})]$ or in the terms given, $36\ \mu_0/[2\pi(0.02)] = 900\ \mu_0/\pi$ N/m.

**51. (A) is correct.** Average induced emf is given by $\varepsilon = -N\,\Delta\Phi_B/\Delta t = -24\text{ turns}/6\text{ s}\,[(12\text{ T})(0.8\text{ m}^2)(\cos 60°) - (7\text{ T})(0.8\text{ m}^2)(\cos 60°)] = -8$ V.

**52. (D) is correct.** From the transformer equation, $V_s/V_p = N_s/N_p$ so $N_s = N_p\,V_s/V_p = (40\text{ loops})(1.5\text{ V})/(12\text{ V}) = 5$ loops. This can be applied to the relation $I_s/I_p = N_p/N_s$ where $I_s = I_pN_p/N_s = (3\text{ A})(40\text{ loops})/(5\text{ loops}) = 24$ A. An alternate solution can be based on input power = output power for an ideal transformer. $P_P = P_S$ gives $I_PV_P = I_SV_S$ or $(3\text{ A})(12\text{ V}) = (I_S)(1.5\text{ V})$. Therefore $I_S = 24$ A.

**53. (A) is correct.** The motional emf equation $\varepsilon = Blv$ derived for such situations can be rearranged and applied to this situation, where $v = \varepsilon/Bl = 2.7\text{ V}/(32\text{ T})(0.028\text{ m}) = 2.7\text{ V}/(0.896\text{ T·m})$ which is approximately 3 m/s.

**54. (E) is correct.** The frequency of the *n*th harmonic is a function of wave velocity and the wavelength, or equivalently, of $n$, the wave velocity and the length of the string. This is given by $f_n = v/\lambda_n = nv/2L = (5)(303\text{ m/s})/2(0.75\text{ m}) = (1515/1.5)\text{ s}^{-1} = 1010$ Hz.

**55. (B) is correct.** The frequency of beats is the difference of their frequencies, $f_n = f_2 - f_1 = 330\text{ Hz} - 247\text{ Hz} = 83$ Hz. The number of vibrations per minute is $(83\text{ s}^{-1})(60\text{ s/min}) = 4980$.

56. **(C) is correct.** Wave velocity along a string of mass $M$ and length $L$ under a tension of $F_T$ is given by $v^2 = F_T/(M/L)$, or $v = \sqrt{F_T L/M}$ $= \sqrt{(900\text{ N})(0.25\text{ m})/0.04\text{ kg}} = [(30)(0.5)/0.2]\text{ m/s} = 75\text{ m/s}$.

57. **(E) is correct.** The displacement of air in a bilaterally open-ended tube has $n + 1$ antinodes for the $n$th harmonic and $n$ nodes, whereas the pressure in the air has $n + 1$ nodes and $n$ antinodes for the $n$th harmonic. Thus, the ratio of nodes is $n/(n + 1)$.

58. **(E) is correct.** For a single slit, the maximum occurs at $m = 0$, but subsequent integers for $m$ in $D \sin\theta = m\lambda$ correspond to the minima, destructive interference, of the diffraction pattern.

59. **(E) is correct.** The placement of constructive interference satisfies the equation $d \sin\theta = m\lambda$ or $d \sin\theta = mc/f$ using the relation $\lambda = c/f$, so $d = mc/f \sin\theta = 16(3.0 \times 10^8\text{ m/s})/6.4 \times 10^{14}\text{ s}^{-1} = 7.5 \times 10^{-6}\text{ m}$.

60. **(D) is correct.** The relationship between frequency and wavelength for light is given by $f\lambda = c$, so $f = c/\lambda = 3.0 \times 10^8\text{ m/s}/2.7 \times 10^{-4}\text{ m} = 1.1 \times 10^{12}\text{ s}^{-1}$.

61. **(C) is correct.** Using the mirror equation, $1/d_o + 1/d_i = 1/f$, where the focal length, $f$, is half the radius of curvature of a spherical mirrored surface, $1/15\text{ cm} + 1/d_i = 1/5\text{ cm}$ and $d_i = 7.5\text{ cm}$.

62. **(A) is correct.** Using the lens equation, $1/d_o + 1/d_i = 1/f$ while respecting the sign conventions for lenses, $1/10\text{ cm} + 1/d_i = 1/4\text{ cm}$, and $d_i = 20/3\text{ cm}$. Using the lateral magnification, $h_i/h_o = -d_i/d_o$ so $h_i = (-d_i/d_o)h_o = (20/30)18\text{ cm} = -12\text{ cm}$. The negative means that the image height is inverted.

63. **(D) is correct.** Using Snell's law, $n_1 \sin\theta_1 = n_2 \sin\theta_2$ where a material's index of refraction, $n$, is the quotient of the speed of light in a vacuum with the speed of light in the material. Also note that $\theta$ is measured from the normal, so 60° from the surface means $\theta_1 = 30°$ from the normal. Thus $n_1 = 1$, and $n_2 = \sin\theta_1/\sin\theta_2 = (\sqrt{2}/2)/(1/2) = \sqrt{2}$. Further, because of the absolute nature of the speed of light, $n$ cannot be less than 1, which eliminates answers *A* and *B*.

64. **(E) is correct.** This situation illustrates the Compton effect where x-rays are scattered from various materials. Compton observed that the incoming photons always lost energy when they collided with electrons in the material, and the amount of energy lost depended on the angle of scattering. Since they lost energy but still traveled at "c," the photons would leave with a lower frequency and a longer wavelength. Because only answer *E* shows a longer wavelength, all of the other answers can be eliminated.

65. **(A) is correct.** The daughter nucleus following gamma decay is not that of a new element, so transmutation does not occur. Similarly, electron, positron, and neutrino emission are associated with beta decay. In gamma decay, gamma rays, or high energy photons, are emitted.

66. **(D) is correct.** Heisenberg's uncertainty principle can be stated in two equivalent forms: $\Delta E \Delta t \geq h/2\pi$ as well as $\Delta x \Delta p \geq h/2\pi$.

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67. **(B) is correct.** One of the first demonstrated shortcomings of the Rutherford model of the atom was the line spectra emission of the hydrogen atom, as seen in the Balmer series, which contradicted the continuous spectrum predicted in the Rutherford model.

68. **(C) is correct.** The de Broglie wavelength of a particle, a representation of wave-particle duality, is given by $\lambda = h/mv$, which here is

$$\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}\ \text{J·s}}{(0.003\ \text{kg})\left(\frac{36\ \text{m}}{1\ \text{h}}\right)\left(\frac{1\ \text{h}}{60\ \text{min}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right)}$$

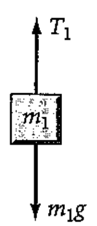
$$= \frac{6.6 \times 10^{-34}\ \text{J·s}}{3 \times 10^{-5}\ \text{kg·m/s}} = 2.2 \times 10^{-29}\ \text{m}.$$

69. **(D) is correct.** While a positron and an electron, such as those created in pair production caused by a photon interaction, can eventually annihilate each other, it is not a direct result of photon interaction.

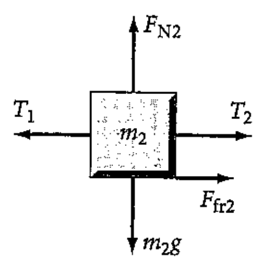
70. **(D) is correct.** In the common elemental notation ${}^{A}_{Z}X$, $A$ is the nucleon number (the total number of neutrons and protons) and $Z$ is the number of protons in the nucleus. Therefore, the number of neutrons is represented by $A - Z$.

### *Free-Response Questions*

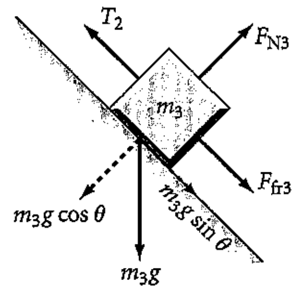
1. (a) Although the three blocks are of equal mass, you can use the name conventions as shown. The fact that $m_1 = m_2 = m_3$ will be used again in part (c), but it applies here also. The direction of force is clear, as the free-hanging block has a greater force of gravity than does the block on the incline, which also has the force of friction against it. For the block of mass $m_1$,




For the block of mass $m_2$,



For the block of mass $m_3$,




(b) For the block of mass $m_1$, $\Sigma F_y = T_1 - m_1g$.
For the block of mass $m_2$, $\Sigma F_x = T_1 - T_2 - \mu F_{N2}$ and $\Sigma F_y = F_{N2} - m_2g$.
For the block of mass $m_3$, if the $x$-axis is given by the surface its resting on, $\Sigma F_x = T_2 - \mu F_{N3} - m_3g\sin\theta$ and $\Sigma F_y = F_{N3} - m_3g\cos\theta$.

(c) When velocity is constant, the acceleration zero and $\Sigma F = ma = 0$. First, $\Sigma F_y = T_1 - m_1g = 0$, so $T_1 = m_1g = (12\text{ kg})(9.8\text{ m/s}^2) = 117.6\text{ N}$. For the same reason, $\Sigma F_x = T_1 - T_2 - \mu F_{N2} = 0$.
Because $\Sigma F_y = F_{N2} - m_2g = 0$, $F_{N2} = m_2g = (12\text{ kg})(9.8\text{ m/s}^2) = 117.6\text{ N}$.
Therefore $117.6\text{ N} - T_2 - \mu(117.6\text{ N}) = 0$.
Next $\Sigma F_x = T_2 - \mu F_{N3} - m_3g\sin\theta = 0$ for the same reason where $\Sigma F_x = F_{N3} - m_3g\cos\theta = 0$, so $F_{N3} = m_3g\cos 15°$,
and $\Sigma F_y = T_2 - \mu(m_3g\cos 15°) - m_3g\sin 15° = 0$.

Using the two relations, $117.6\text{ N} - T_2 - \mu(117.6\text{ N}) = 0$ and $T_2 - (12\text{ kg})(9.8\text{ m/s}^2)\cos 15° - (12\text{ kg})(9.8\text{ m/s}^2)\sin 15° = 0$.
By rearranging, so that $117.6\text{ N} - \mu(117.6\text{ N}) = T_2$ and $T_2 = \mu(12\text{ kg})(9.8\text{ m/s}^2)\cos 15° + (12\text{ kg})(9.8\text{ m/s}^2)\sin 15°$,
we can equate these, after simplifying the latter.
Thus, $117.6\text{ N} - \mu(117.6\text{ N}) = 113.6\text{ N}\mu + 30.4\text{ N}$,
and $87.2\text{ N} = 231.2\text{ N}\,\mu$, and $\mu = .38$.

(d) If the force of gravity on the block of mass $m_3$ is sufficient, the blocks will move to the right. Otherwise, the blocks will remain at rest. For the block of mass $m_2$, $\Sigma F_x = T_2 - \mu F_{N2} = m_2a$, where $F_y = F_{N2} - m_2g = 0$, so $F_{N2} = m_2g$ and $T_2 - \mu(117.6\text{ N}) = (12\text{ kg})a$. For the block of mass $m_3$, if the $x$-axis is given by the surface its resting on,
$\Sigma F_x = m_3g\sin\theta - T_2 - \mu F_{N3} = m_3a$, where $F_y = F_{N3} - m_3g\cos\theta = 0$,
so $F_{N3} = m_3g\cos\theta = (12\text{ kg})(9.8\text{ m/s}^2)\cos 15° = 113.6\text{ N}$,
and $30.4\text{ N} - T_2 - \mu\,113.6\text{ N} = (12\text{ kg})a$.
Substituting the value $\mu = 0.38$, $T_2 - (0.38)(117.6\text{ N}) = (12\text{ kg})a$,
or $T_2 - (44.7\text{ N}) = (12\text{ kg})a$.
For block $m_3$, $30.4\text{ N} - T_2 - 43.2\text{ N} = (12\text{ kg})a$.

These equations assume that the system will accelerate to the right, which is chosen as the positive direction. However, solving these equations

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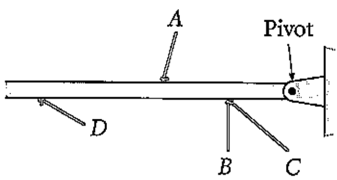
yields a negative value for acceleration. This would mean that frictional force accelerates the system to the left, which is physically impossible. Clearly friction must be sufficient to hold the system at rest. Although the coefficient of sliding friction (from part c) was used in these equations, the coefficient of static friction is generally $\geq$ this value. Therefore there will be sufficient static friction to hold the system in place.

Note that this same conclusion could be reached more quickly by simply comparing the downhill component of the weight ($m_{3g} \sin\theta = 30.4$ N) with the maximum available friction ($\mu m_3 g \cos\theta = 43.2$ N). As above, friction will hold the system at rest.

*This response correctly models the variety of forces experienced by the objects in the system: for the free-hanging block, gravity and the tension of the rope; for the top block, the opposing tensions of two ropes and friction in one dimension and gravity and the normal force in the perpendicular dimension; and for the third block, the tension of rope and friction in one dimension and the appropriate components of gravity and the normal force due to the incline in the perpendicular dimension. An understanding of static equilibrium is also demonstrated, such that $\Sigma F = 0$ where applicable. The response to part c correctly shows that the force of gravity is inadequate to set the system in motion from rest.*

2. (a) Based on the definition of torque, the net torque will be $\Sigma\tau = F_{B\perp} \cdot r + F_{\perp C} \cdot r - F_{\perp A} \cdot r$, if counterclockwise is defined as positive. So, $\Sigma\tau = F/3 \sin 90°\ x/2 + F/2 \sin 40°\ x/2 - F \sin 75°\ x$ $= (0.17)Fx + (0.16)Fx - 0.97Fx = -0.64Fx$.
So the torque is $0.64Fx$ clockwise.
(b) For equilibrium, the second condition is $\Sigma\tau = 0$. For that to happen, a $0.64Fx$ counterclockwise torque must be applied—that is, the rope must be tied on the same side as $B$ and $C$, where $\tau = F/2 \sin 30°\ r = 0.25Fr = 0.64Fx$, so $r = 2.56x$.




(c) The first condition for equilibrium is that the net forces in three perpendicular directions are zero, that is $\Sigma F_x = 0$, $\Sigma F_y = 0$, and $\Sigma F_z = 0$. The second condition for equilibrium is that the sum of torques is zero, $\Sigma\tau = 0$.
(d) If only the first condition is met, an object will experience only rotational motion. If only the second condition is met, an object will experience only translational motion.

*This response shows a thorough understanding of torque, as well as static equilibrium as related to torque. The angles of force are correctly utilized, and calculations with a mix of variable and numerical terms are accurately performed. Finally, a theoretical comprehension of more general statics is shown.*

3. (a) Root-mean-square velocity is related to mass and temperature by $v_{rms} = \sqrt{3kT/m}$. Temperature must be in kelvins, so $T = C + 273 = 300$ K. Mass is given by $(44 \text{ amu})(1.66 \times 10^{-27} \text{ kg}/u) = 7.3 \times 10^{-26}$ kg. Therefore, by $v_{rms} = \sqrt{3kT/m}$ = by $v_{rms} = \sqrt{3(1.38 \times 10^{-23} \text{ J/K})(300 \text{ K})/(7.3 \times 10^{-26} \text{ kg})} = 412$ m/s.
   (b) Relating average kinetic energy to temperature, $KE_{avg} = 3/2kT = 3/2(1.38 \times 10^{-23} \text{ J/K})(300 \text{ K}) = 6.2 \times 10^{-21}$ J. Alternately, $KE_{avg} = 1/2mv_{rms}^2 = 1/2(7.3 \times 10^{-26} \text{ kg})(412 \text{ m/s})^2 = 6.2 \times 10^{-21}$ J.
   (c) Avogadro's number, $6.022 \times 10^{23}$, is defined as the number of molecules in a mole.
   (d) Rearranging the ideal gas law, $PV = nRT$ as $n = PV/RT = (1.013 \times 10^5 \text{ N/m}^2)(1 \text{ m}^3)/(8.315 \text{ J/mol·K})(300 \text{ K}) = 40.6$ moles. The number of molecules can be obtained using Avogadro's number, and $(40.6 \text{ mol})(6.022 \times 10^{23} \text{ molecules}/1 \text{ mol}) = 2.44 \times 10^{25}$ molecules.

*This response uses the molecular mass and temperature in kelvins to find the root-mean-square velocity in part a. The response to part b shows two equivalent methods for finding average kinetic energy: first as a function of temperature, and then as a function of mass and root-mean-square velocity. The response to part d utilizes the ideal gas law and then uses the definition of moles previously explained to find the number of molecules.*

4. Defining the perpendicular reference axes where up and right are positive, and down and left are negative with $Q_1$ at the origin: by trigonometry, where $\tan\theta$ = (opposite)/(adjacent), the angle below horizontal of $Q_1$ to $Q_4$ is 37°.
   The forces are:
   $F_{12} = (9.0 \times 10^9 \text{ N·m}^2/\text{C}^2)(5.6 \times 10^{-6} \text{ C})(5.0 \times 10^{-6} \text{ C})/(0.20 \text{ m})^2 = 6.3$ N (attractive to the right)
   $F_{13} = (9.0 \times 10^9 \text{ N·m}^2/\text{C}^2)(5.6 \times 10^{-6} \text{ C})(3.2 \times 10^{-6} \text{ C})/(0.15 \text{ m})^2 = 7.2$ N (attractive down)
   $F_{14} = (9.0 \times 10^9 \text{ N·m}^2/\text{C}^2)(5.6 \times 10^{-6} \text{ C})(8.1 \times 10^{-6} \text{ C})/(0.25 \text{ m})^2 = 6.5$ N (repulsive, up and left)
   Signs can then be assigned for force where the appropriate vectors are broken into components. $\Sigma F_x = F_{12} - F_{14x} = 6.3 \text{ N} - 6.5 \text{ N} \cos 37° = 1.1$ N. $\Sigma F_y = -F_{13} + F_{14y} = -7.2 \text{ N} + 6.5 \text{ N} \sin 37° = -3.3$ N.
   The magnitude and direction of the net force is $F = \sqrt{(F_x^2 + F_y^2)} = \sqrt{[(1.1\text{N})^2 + (-3.3 \text{ N})^2]} = 3.5$ N and $\theta = \tan^{-1} F_y/F_x = \tan^{-1} - 3.3 \text{ N}/1.1 \text{ N} = -72°$ or 72° below the horizontal as defined.

*In this response, each of the individual forces is correctly calculated and classified as repulsive or attractive to determine the direction. Using the appropriate signs, these forces are summed in their respective dimensions, enabling the magnitude and direction of the net force to be calculated.*

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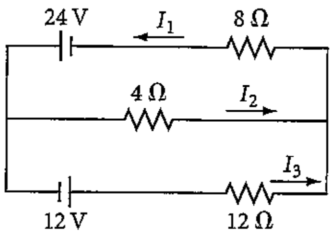
5. (a) First, current directions can be arbitrarily assigned, and the sign of the resulting value will indicate whether each assumption is correct or reversed.




Next, three equations with three variables can be obtained. First, by the junction rule, $I_1 = I_2 + I_3$. Next, around two closed loops: $24\text{ V} + 12\text{ V} - 12\ \Omega I_3 - 8\ \Omega I_1 = 0$ and $12 - 12\ \Omega I_3 + 4\ \Omega I_2 = 0$. These can be rearranged so that $4.5 - 1.5I_3 = I_1$ and $-3 + 3I_3 = I_2$ and substituted into $I_1 = I_2 + I_3$, so that $4.5 - 1.5I_3 = -3 + 3I_3 + I_3$. Collecting like terms, $7.5 = 5.5I_3$ and $I_3 \doteq 1.36$ A. This can be plugged back into the equations to find $I_2 = 1.08$ A and $I_1 = 2.44$ A.

(b) Kirchhoff's rules consist of the junction rule (which states that the sum of all currents entering a junction is equal to the sum of all currents leaving that junction) and the loop rule (which states that the sum of potential changes in every closed circuit pathway is equal to zero).

(c) In series, arranging two batteries of differing voltage in reverse can effectively charge the battery of lesser voltage. In parallel, two batteries will have less internal resistance than one battery, and they will last longer. Two batteries in series, with the potential difference in the same direction, will increase the total voltage available to the circuit.

*This response applies Kirchhoff's rules to quantify current in the loops of a circuit. As noted, current directions are initially assumed and later verified by the sign of the solution. The response to part b outlines both of Kirchhoff's rules. Finally, a practical application of such a situation is described in the response to part c.*

6. (a) The relation between wavelength and string length for the fundamental frequency is given by $\lambda = 2L = 2(0.4\text{ m}) = 0.8$ m, which can be used to determine velocity, $v = \lambda f$, so $296\text{ m/s} = (0.8\text{ m})f$. Therefore, 370 Hz is the fundamental frequency.

(b) The second overtone is the third harmonic, which has a frequency of $3f_1 = 3(370\text{ Hz}) = 1110$ Hz. The third overtone is the fourth harmonic, which has a frequency of $4f_1 = 4(370\text{ Hz}) = 1480$ Hz.

(c) The fundamental frequency has two nodes and one antinode. The second overtone has four nodes and three antinodes. The third overtone has five nodes and four antinodes.

(d) The tension of this string will be $F_T = mv^2/L$ $= (0.064\text{ kg})(296\text{ Hz})^2/0.40 = 1.4 \times 10^4$ N.

*This response uses the relation between wave velocity, wavelength, and frequency, and applies the fundamental frequency to find overtones. The nth overtone is correctly identified as the $n + 1^{st}$ harmonic, and the relation between wavelength and string length is correctly used. Finally, the relation between these values and tension is utilized.*

7. (a) Alpha decay describes the nuclear emission of a $^{4}_{2}He$ particle. For $^{A}_{z}N$, if such alpha decay occurs, a $^{4}_{2}He$ particle is released, and $^{A-4}_{z-2}N$ represents the resulting nucleus by the conservation of nucleon number.
   (b) In one type of beta decay, a nonorbital electron and a form of neutrino are emitted. From beta decay, an electron is released, and $_{z+1}^{A}N$ represents the resulting nucleus by the conservation of nucleon number.
   (c) Gamma decay describes the emission of a photon by an excited nucleus. The nucleus remains $^{A}_{z}N$. But it goes to a lower energy state.

*This response shows an understanding of the three types of radioactive decay, their products, and the resulting nuclei. The student describes each of these resulting nuclei using the correct nuclear notation, as well as noting that the conservation of nucleon number enables calculations for variable quantities such as those given.*