2015 PhysicsBowl Solutions

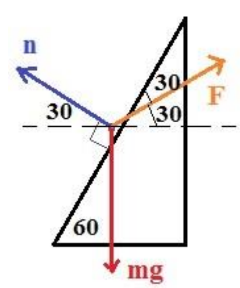
#	Ans		#	Ans		#	Ans		#	Ans		#	Ans
1	B		11	B		21	B		31	D		41	A
2	C		12	D		22	A		32	D		42	C
3	A		13	C		23	A		33	C		43	B
4	B		14	D		24	C		34	A		44	E
5	E		15	E		25	E		35	E		45	B
6	D		16	A		26	A		36	B		46	E
7	A		17	D		27	D		37	A		47	C
8	E		18	C		28	B		38	D		48	B
9	C		19	B		29	E		39	E		49	A
10	E		20	C		30	B		40	C		50	D

1. **B…** milli represents 10^{-3}
2. **C… METHOD #1:** Using constant acceleration kinematics, we have the average velocity computed as $\langle v\rangle = \frac{\Delta x}{\Delta t} = \frac{7.5}{12} = 0.625\frac{m}{s}$ which leads to $\langle v\rangle = \frac{1}{2}\left(v_0 + v_f\right) \rightarrow 0.625 = \frac{1}{2}(v_0 + 0) \rightarrow v_0 = 1.25\frac{m}{s}$. **METHOD #2:** One can graph velocity vs time for the box. Knowing that the area under the curve is the change in position, we have $A = \frac{1}{2}bh \Rightarrow 7.5 = \frac{1}{2}(12.0)v_0 \Rightarrow v_0 = 1.25\frac{m}{s}$
3. **A…** Vector quantities point… and speed is a scalar.
4. **B…** Locations of complete constructive interference are known as antinodes on the standing wave.
5. **E…** The gravitational force is always directed downward!!
6. **D…** Converting units… $20\frac{miles}{hr} \times \frac{1\ hr}{60\text{ min}} \times \frac{1\text{min}}{60\ s} \times \frac{1600\ m}{1\ mi} = 8.9\frac{m}{s}$
7. **A…** Objects that move in uniform circular have a velocity direction change toward the center of the circle being traced out.
8. **E…** After the balloon obtains charge from being rubbed, it causes polarization in the wall allowing like charges to be closer to each other when they come in contact, providing an attractive force to prevent the balloon from falling to the ground.
9. **C…** Since $v_{car_1} > v_{car_2}$ at the start of the interval, the distance between the cars increases. However, noting at that the end of the second that the speed of the cars are $v_{car_1} = v_0 + at = 13 + (1.5)(1) = 14.5\frac{m}{s}$ and $v_{car_2} = 9.3 + (5.5)(1) = 14.8\frac{m}{s}$, by the interval's end, car 2 is moving faster than car 1 and catching up to it. Hence, the distance between cars is now decreasing. Since the speed of car 2 is only slightly greater than car 1 at the end and started off much slower, then car 1 will actually increase its distance from car 2. To check, one can compute the position changes as $\Delta x_1 = v_1 t + \frac{1}{2}a_1 t_1^2 = (13)(1) + \frac{1}{2}(1.5)(1)^2 = 13.75\ m$ with $\Delta x_2 = v_2 t + \frac{1}{2}a_2 t_2^2 = (9.3)(1) + \frac{1}{2}(5.5)(1)^2 = 12.05\ m$.
10. **E…** When the switch is closed, a wire of zero resistance is added to the circuit. We note, though, that the wire is connected to the left side of the battery. In other words, we have effectively added a shorting wire in parallel to the other resistance-less wires on the left side of the circuit. There is no effect on any of the bulbs as a result because the circuit is effectively unchanged.
11. **B…** When adding/subtracting, the key is to line up the values and look at the last column of digits for which each quantity has a significant digit. That is, $L_1 + L_2 = 118.10\ cm$ and $L_3 + L_4 = 3.000\ cm$. Upon subtracting, we have then $118.10 - 3.000 = 115.10\ cm$ since we cannot keep the thousandths place in the result since 118.10 only has values to the hundredths place!
12. **D… METHOD #1:** Knowing that the linear momentum is computed as $p = mv$, we need to find the speed. This is obtained from the kinetic energy as $KE = \frac{1}{2}mv^2 \rightarrow 12 = \frac{1}{2}(12)v^2 \rightarrow v = \sqrt{2}\frac{m}{s}$. So, $p = mv = (12)\left(\sqrt{2}\right) = 17.0\ kg\frac{m}{s}$.

METHOD #2: By rewriting the kinetic energy slightly, one has the form $KE = \frac{p^2}{2m}$ and so $p = \sqrt{2m\,KE} = \sqrt{2(12)(12)} = 17.0\ kg\frac{m}{s}$

13. **C…** If we rotate our coordinates slightly to take advantage of the incline, we find in the direction perpendicular to the incline that the total normal force acts off the incline and only a portion of the gravitational force acts that way. That is, $n < w$. Also, along the incline's surface, there are two downward forces (applied and a piece of the gravitational) and one upward force. Since there is no acceleration, these forces sum to zero N. Hence, $F + w_{along\ incline} = f$ meaning that $F < f$.
14. **D…** When the position takes the form given, we have constant acceleration with $x = x_0 + v_0 t + \frac{1}{2}at^2$. By identifying terms, we see that $\frac{1}{2}a = 10$ or that $a = 20\frac{m}{s^2}$.
15. **E…** The molecules in the air exert a force upward on the skydiver….
    The skydiver exerts a force downward on the molecules in the air.
16. **A…** This is the de Broglie hypothesis.
17. **D…** With the positive velocity, the object is moving "to the right" arbitrarily. The total change in position is from the area under the curve. Hence, as long as the velocity is positive, the object is moving away from the origin. The negative slope from 5 to 7 seconds simply indicates that the object moves forward but is slowing down (like a vehicle approaching a stop sign).
18. **C...** For an open tube, we can use that $f_n = \frac{nv}{2L} \to L = \frac{nv}{2f_n} \to L = \frac{(3)(340)}{2(680)} = 0.75\ m$
19. **B…** From $PV = nRT$, rearrange to compute the volume of the gas as $V = \frac{nRT}{P} = 0.328\ m^3$. The total mass is $m = nM = (10)\left(0.004\frac{kg}{mol}\right) = 0.040\ kg$. Finally, $\rho = \frac{m}{V} = \frac{0.040}{0.328} = 0.12\frac{kg}{m^3}$.
20. **C…** The Nobel Prize was awarded to Shuji Nakamura, Hiroshi Amano, and Isamu Akasaki for the invention of the blue LED.
21. **B… METHOD #1:** By breaking the initial velocity into components, we have $v_x = 20\cos 60^\circ = 10\frac{m}{s}$ and $v_y = 20\sin 60^\circ = 17.3\frac{m}{s}$. And so, since the acceleration is only in the y-direction, $\langle v_x\rangle = 10\frac{m}{s}$ and $\langle v_y\rangle = \frac{1}{2}(v_{0y} + v_y) = \frac{1}{2}(17.3 + 0) = 8.66\frac{m}{s}$. So, the total average velocity is computed using the Pythagorean Theorem giving $|\langle v\rangle| = \sqrt{\langle v_x\rangle^2 + \langle v_y\rangle^2} = \sqrt{10^2 + 8.66^2} = 13.2\frac{m}{s}$.

    METHOD #2: Again, we start by breaking the velocity into components, but go about finding the location of the highest point in the trajectory. From the vertical component of motion, we have $v_y = v_{0y} + at \to 0 = 17.3 + (-10)t \to t = 1.73\ s$. Now, $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 \to y = 0 + (17.3)(1.73) + \frac{1}{2}(-10)(1.73)^2 = 15.0\ m$ and $x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2 \to x = 0 + (10)(1.73) + 0 = 17.3\ m$. Hence, the magnitude of the displacement of the object is $\sqrt{17.3^2 + 15.0^2} = 22.9\ m$. And finally from the definition of average velocity, we compute $|\langle\vec{v}\rangle| = \left|\frac{\Delta\vec{r}}{\Delta t}\right| = \frac{22.9\ m}{1.73\ s} = 13.2\frac{m}{s}$
22. **A…** Making the free body for each satellite and writing Newton's Second Law gives $F_{net} = ma \to \frac{GmM}{r^2} = ma \to a = \frac{GM}{r^2}$. Since the radius of satellite 2 is twice as great, the acceleration is ¼ as large compared to satellite 1. As for the speed, we write $a = \frac{v^2}{r}$ and discover that $\frac{v^2}{r} = \frac{GM}{r^2} \to v = \sqrt{\frac{GM}{r}}$. Hence, satellite 2 will be slower by a factor of $\sqrt{2}$.



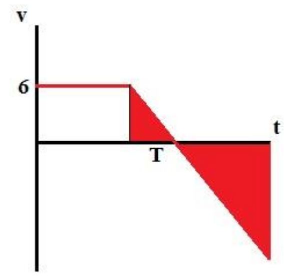
23. **A…** From the definition of average acceleration, we compute $\langle\vec{a}\rangle = \frac{\Delta\vec{v}}{\Delta t}$. Looking only at directions of vectors, we have $\langle\vec{a}\rangle = \frac{1}{\Delta t}(\vec{v}_f - \vec{v}_0) = \frac{1}{\Delta t}(\downarrow - (\rightarrow)) = \frac{1}{\Delta t}(\downarrow + \leftarrow) = \swarrow$.
24. **C…** In order for the sum of 3 equal-sized vectors to be zero, the angle between each vector with any other needs to 120°. Since the gravitational force is straight downward, the normal force is directed 30° above the horizontal. A picture is useful! From the

construction, we see that the angle $\theta = 60^{\circ}$ making the applied force half-way between the horizontal and the level of the incline. So the applied force would have to be 30° below the incline's surface. This matches answer C.

25. **E…** Since the pressure and volume decreased, from $PV = nRT$, the temperature must decrease. This means that the internal energy change is negative since the internal energy depends on the temperature for an ideal gas. Since the volume decreases, the work done on the gas by the surroundings is positive (force is directed inward on gas and movable piston of container moves inward). Finally, from the First Law of Thermodynamics, $\Delta U = Q + W \Rightarrow (-) = Q + (+)$. This means that the quantity of heat in this process will have to be negative $Q = (-) + (-) = (-)$.
26. **A…** The maximum speed during oscillation is $v_{max} = \omega A = \frac{2\pi A}{T}$ which could be found in multiple ways, including equating the maximum KE during oscillation to the maximum potential energy $\left(\frac{1}{2}kA^2 = \frac{1}{2}mv_m^2 \rightarrow v_m = \sqrt{\frac{k}{m}}\sqrt{A^2} = \omega A\right)$. Now, for one full oscillation, the mass moves from full extension to equilibrium (A), then to full compression (A) and back again (2A) for a total distance traveled of 4A. Consequently, $v_{avg} = \frac{d}{t} = \frac{4A}{T} = 4\left(\frac{A\omega}{2\pi}\right) = 4\left(\frac{v_{max}}{2\pi}\right) = \frac{2}{\pi}v_{max}$
27. **D…** The area under the force-time curve gives the impulse on mass 2. By Newton's Third Law, the force on mass 1 has the same magnitude but is in the opposite direction. The area is computed as $\frac{1}{2}(10kN)(3ms) = 15\ Ns$. So, the impulse for mass 1 is $-15\ Ns$. Using the impulse-momentum theorem, $\Delta p_1 = -15 = m_1(v_{1f} - v_{1i}) \Rightarrow -\frac{15}{3.50} = v_f - 7.0 \Rightarrow v_f = 2.71\frac{m}{s}$. So, using the impulse on mass 2, we find $\Delta p_2 = 15 = m_2(v_{2f} - v_{2i}) \Rightarrow m_2 = \frac{15}{2.71-0} = 5.54\ kg$.
28. **B…** The initial kinetic energy of the system is $\frac{1}{2}m_1v_1^2 = \frac{1}{2}(3.50)(7.0)^2 = 85.75\ J$. After the collision, the kinetic energy is computed as $\frac{1}{2}(m_1 + m_2)v_f^2 = \frac{1}{2}(3.50 + 5.53)(2.71)^2 = 33.16\ J$. The difference in these quantities is $\Delta KE = KE_f - KE_i = 33.16 - 85.75 = -52.6\ J$.
29. **E…** By using the right hand rule with the thumb directed along the current, we find that the wire on the right produces a field directed out of the plane of the page at the electron's location. Performing the same procedure for the left wire, that field also is directed out of the plane of the page. So, the total field is out of the plane of the page and from $\vec{F} = q\vec{v} \times \vec{B}$, the magnetic force is directed to the right (the cross term is to the left, but the electron makes the force to the right). Hence, we now need an electric force directed to the left to balance the magnetic force. From $\vec{F} = q\vec{E} \rightarrow \vec{E} = \frac{\vec{F}}{q}$, we see that if the force is to the left, then the field must be to the right since an electron is a negative charge.
30. **B…** The free body diagram of the solid mass in the water has three forces acting … gravitational, a spring force from the scale, and a buoyant force from the water. Writing Newton's Second Law, we have $F_{net} = ma \rightarrow B + T - mg = 0$. We have from the measurement in the air (since the buoyant force on the small mass from the air will be effectively negligible), that $mg = 2.50\ N$. Also, we have that $T = 1.58\ N$. Solving for the buoyant force yields $B = 2.50 - 1.58 = 0.92\ N$. The buoyant force is computed as $\rho_{water}g\,V = 0.92 \Rightarrow V = \frac{0.92}{(1000)(10)} = 9.2 \times 10^{-5}m^3$. The mass of the object is found as $m = \frac{2.50}{10} = 0.250\ kg$ leading to a density of the mass as $\rho = \frac{m}{V} = \frac{0.250}{9.2\times10^{-5}} = 2.7 \times 10^3\frac{kg}{m^3}$
31. **D…** Approximately 70% of the Earth's surface is water. Approximating the volume of water with the surface area of the earth multiplied by a depth of about 3 mile (5000 meters approximately), we have $V_{water} = \frac{7}{10}4\pi r^2(3\ mi) = \frac{28}{10}\pi(6.4 \times 10^6)^2(5000) = 1.8 \times 10^{18}m^3$. The density of water is $1000\frac{kg}{m^3}$ and so the total mass of water in the oceans is $1.8 \times 10^{18} * 1000 = 1.8 \times 10^{21}kg$. The molar mass of water is $18\frac{g}{mol}$ $(H = 1, O = 16)$ yielding $n = \frac{1.8\times10^{21}}{0.018} = 1.0 \times 10^{23}\ mol$. There are 2

hydrogen atoms per water molecule, and so we need the number of molecules from Avogadro… $N = nN_A = (1.0 \times 10^{23})(6.02 \times 10^{23}) = 6.0 \times 10^{46}$ giving $2(6.0 \times 10^{46}) = 1.2 \times 10^{47}$ H atoms.
*** http://water.usgs.gov/edu/earthwherewater.html is where this question was vetted.

32. D… For the average speed to be $10\frac{m}{s}$, a total distance of $200\ m$ must be traveled. In the first 12 seconds, a total of $\Delta x = \langle v \rangle \Delta t = \left(6.0\frac{m}{s}\right)(12s) = 72\ m$ has been traveled. This means that in the last 8 seconds, a distance of 128 m needs to be traversed. Let's draw a graph of velocity vs time. The shaded regions have to add to a total distance of 128 m. In the first T seconds, the object slows to rest. Mathematically, $|a| = \frac{6}{T}$ with area $\frac{1}{2}(6)(T) = 3T$. For the remaining time, the area is $\frac{1}{2}(8-T)\big(a(8-T)\big) = \frac{1}{2}a(8-T)^2$. Hence, $3T + \frac{1}{2}a(8-T)^2 = 128$. Substituting the expression for the acceleration and multiplying by T yields $3T^2 + 3(8-T)^2 = 128\,T \Rightarrow 3T^2 - 88T + 96 = 0$. Solving this expression yields times of $T = 1.13\ s, 28.2\ s$. Using $T = 1.13\ s$ gives $a = \frac{6}{1.13} = 5.3\frac{m}{s^2}$.



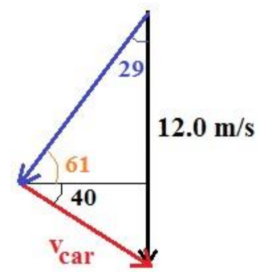
33. C… The wavelength of the sounds is $v = f\lambda \Rightarrow \lambda = \frac{v}{f} = \frac{342}{57} = 6.0\ m$. This means that the speakers are separated by exactly 5 wavelengths. For constructive interference, the path difference between the waves from the speakers must differ than an integer number of wavelengths. Hence, there are 11 locations at or between the speakers where this happens $-5\lambda, -4\lambda, -3\lambda, \ldots 3\lambda, 4\lambda, 5\lambda$. A place of destructive interference occurs directly between the constructive interference locations… hence, there are 10 of them.

34. A… The image from the first lens is found from $\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \rightarrow \frac{1}{10} = \frac{1}{15} + \frac{1}{q} \rightarrow q = 30\ cm$.

- **Far from 1st lens** (more than 40 cm from the first lens) - we have that the image from the first lens is the object for the second lens and that the object is greater than a focal length from the 2nd lens. This means that we will end up with a real image from the 2nd lens and the image will be flipped from the "object". Since the 1st lens formed a real image, that image was flipped from the original object. In other words, for large distance between the lenses, the image is *real and pointing upward*.
- **Medium range from 1st lens (**between 30 and 40 cm from the 1st lens) - the image from the first lens is now inside the focal length of the 2nd lens. Hence, between 30 and 40 cm, the image formed is *virtual and pointing downward* (there is still the inversion from the 1st lens).
- **Close range –** (less than 30 cm from the first lens) - we have a virtual object! For simplicity, let the 2nd lens be placed 20 cm from the first lens making $p = -10\ cm$ for the second lens. This gives $\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \rightarrow \frac{1}{10} = \frac{1}{-10} + \frac{1}{q} \rightarrow q = 5\ cm$. Because we have a positive image position, the image is real. Further, the magnification of the image from the 2nd lens is $M = -\frac{q}{p} = -\left(\frac{5}{-10}\right) = \frac{1}{2}$. Because it is positive, the image has the same orientation as the object. The object for this lens was the upside-down image from the first lens. Hence, the image is *real and pointing downward*.

35. E … From the angular impulse-momentum theorem, the change in angular momentum is the torque multiplied by the time. As the forces are equal but at different distances from the center of each object, $\tau_X < \tau_Y$ meaning that $L_X < L_Y$ since the forces are applied for the same time. As for the kinetic energy, we note that $KE = \frac{1}{2}I\omega^2 = \frac{L^2}{2I} = \frac{\tau^2 t^2}{2\left(\frac{1}{2}Mr^2\right)} = \frac{r^2F^2t^2}{Mr^2} = \frac{F^2t^2}{M}$. All of these quantities (force, time, mass) were equal for the two disks thereby making the kinetic energy the same for the disks!

36. B… METHOD #1: algebra - One way to handle this problem is to make little pictures and use subscripts. We write $\vec{v}_{rain\ wrt\ Earth} = (0)\hat{x} + (-12)\hat{y}$, $\vec{v}_{car\ wrt\ Earth} = (v_{car}\cos 40)\hat{x} + (-v_{car}\sin 40)\hat{y} = (0.776\ v_{car})\hat{x} + (-0.643\ v_{car})\hat{y}$. Now, to find the velocity of the rain with respect to the car, we compute $\vec{v}_{rain\ wrt\ car} + \vec{v}_{car\ wrt\ Earth} = \vec{v}_{rain\ wrt\ Earth}$. Hence, we rearrange this expression to find $\vec{v}_{rain\ wrt\ car} = \vec{v}_{rain\ wrt\ Earth} - \vec{v}_{car\ wrt\ Earth} = (0 - 0.776\ v_{car})\hat{x} + (-12 + 0.643\ v_{car})\hat{y}$. Since these components of the velocity are known to make a 29 degree angle with the vertical, we can write $\tan 29^0 = \frac{(-0.776\, v_{car})}{-12+0.643 v_{car}}$. Using a little algebra, we can solve this equation for the unknown v_{car}. Doing this leads to $v_{car} = 5.93\,\frac{m}{s}$.

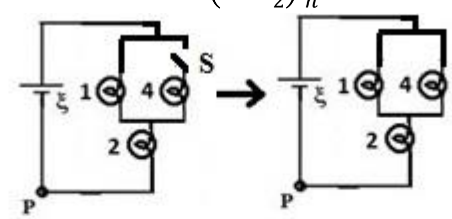


METHOD #2: pictorial – Using $\vec{v}_{rain\ wrt\ car} + \vec{v}_{car\ wrt\ Earth} = \vec{v}_{rain\ wrt\ Earth}$, we construct the picture shown to the right for the velocities. Hence, from the Law of Sines, $\frac{12}{\sin 101} = \frac{v_{car}}{\sin 29} \Rightarrow v_{car} = \frac{12 \sin 29^\circ}{\sin 101^\circ} = 5.93\,\frac{m}{s}$

37. A… The energy stored by an inductor takes the form $U = \frac{1}{2}LI^2$ and be rearranging, the units of inductance are found from

$$\frac{U}{I^2} \to \frac{J}{A^2} = \frac{Nm}{A^2} = \frac{\left(kg\frac{m}{s^2}\right)m}{A^2} = \frac{kg\, m^2}{A^2 s^2}$$

38. D… To create constructive interference with the $540\ nm$ light, we need to be sure that the interfering rays from the reflection off the alcohol and the ray that passes into the alcohol and is reflected back at the glass surface are in phase. Since the light is traveling from air to alcohol to glass, the index of refraction increases at each interface, meaning that the reflected light is phase-shifted by $\frac{\lambda}{2}$. This means that for light traveling down through the alcohol a distance t to the glass surface and then traveling an additional distance t back to the air, we need this extra path length to be an integer number of wavelengths to put the our two waves in phase. That is, $2t = m\frac{\lambda}{n}$. Solving for $t = \frac{m\lambda}{2n} = m\left(\frac{540}{(2)(1.35)}\right) = 200\ m$. Since m is an integer, the only possible choice would be $t = 400\ nm$. Likewise, destructive interference is needed for the $432\ nm$ light and that condition is$2t = \left(p + \frac{1}{2}\right)\frac{\lambda}{n}$. Solving this expression with $p = 2$ also yields that $t = 400\ nm$.



39. E… By use a Kirchhoff loop with the battery and bulb 3, we see that there is no difference in the voltage or current through it whether the switch is open or closed. By looking at what is left, from Kirchhoff's Loop Rule, the potential difference across bulb 1 is $\xi/_2$ with the switch open. After closing the switch, the effective resistance of the bulb 1-4 branch decreases resulting in more current through bulb 2 (and P). This increases the potential difference across bulb 2 thereby decreasing the potential difference across bulb 1 and the branch from W to X!

40. C… From the free body diagram of the mass, there are two forces: gravitational and tension. Writing Newton's Second Law for each component of motion, we have $F_{net_y} = ma_y \to T\cos\theta - mg = 0 \Rightarrow T\cos\theta = mg$ and $F_{net_x} = ma_x \to T\sin\theta = m\left(\frac{v^2}{r}\right) = m\left(\frac{v^2}{L\sin\theta}\right) \Rightarrow T\sin^2\theta = \frac{mv^2}{L}$. To find the tension directly, we'll take the y-component expression and square it. After this, we multiply the x-component by T leading to $T^2\sin^2\theta = \frac{mv^2}{L}T$ and $T^2\cos^2\theta = (mg)^2$. Adding these relations (note that $\sin^2\theta + \cos^2\theta = 1$) gives $T^2 - \left(\frac{mv^2}{L}\right)T - (mg)^2 = 0 \ \Rightarrow T^2 - 12.8\,T - 400 = 0$. Using the Pythagorean Theorem yields $T = 27.4\ N;\ -14.6\ N$. The physical answer therefore is $T = 27.4\ N$.

41. A… The average speed is distance divided by time. The truck moves at constant rate from the start to end position while the car initially moves "backward" and then forward to the same ending location of the truck. Consequently, the car travels a greater distance than the truck and has a higher average speed.

42. C… The slope of the position vs, time graph. The car moves faster than the truck initially and eventually come to rest, which means that at some point, the speed of the car and truck are the same. From rest, the car accelerates and catches up to the truck by eventually moving faster. This means that the car and truck have the same speed again before time T. Finally, for times $T < t < 2T$, the car slows down close to rest and the truck catches up. Hence, the car's speed is again equal to that of the truck at some time. This makes C the correct answer.

43. B… Since $K = \frac{p^2}{2m}$, we can write that $K = \frac{p_x^2}{2m} + \frac{p_y^2}{2m} \Rightarrow 100 = \frac{(24)^2}{2(4)} + \frac{p_y^2}{2(4)} \Rightarrow 800 = 576 + p_y^2 \;\Rightarrow p_y^2 = 224$. Hence, $p_y = \sqrt{224} = 14.97\ kg\frac{m}{s} = 15.0\ kg\frac{m}{s}$

44. E… Jacques Charles is the scientist associated with the observation that volume is proportional to temperature at constant pressure.

45. B… The work done by the person inserting the dielectric would be equal to the change in the potential energy for the capacitor. Since the battery was disconnected, the charge on the plates remains constant and $W_{person} = \Delta U = \frac{1}{2}Q\Delta V$. The charge on the plates would be $Q = CV = (6.00\ \mu F)(12.0\ v) = 72.0\ \mu C$. The final capacitance can be found by moving the dielectric to any location in the space between plates and treating the system as 2 capacitors in series. The potential difference through the air-filled portion would be 6 volts since the field strength is unchanged and we are crossing half the original capacitor (which had 12 volts). For the dielectric portion, the dielectric decreases the field strength by a factor of 2… which means that the potential difference across the dielectric would be 3 volts for a grand total of 9 volts across the entire capacitor. Hence, $W_{person} = \frac{1}{2}Q\Delta V = \frac{1}{2}(72\mu C)(-3v) = \ -108\ \mu J$.

46. E… We write $\tau_{net} = I\alpha$ and note that the moment of inertia of the rod is $I = \frac{1}{12}ML^2$ about an axis through the center of mass. To find the moment of inertia about the pivot, we need the parallel axis theorem to obtain $I = \frac{1}{12}ML^2 + md^2$ where $d = \frac{L}{6}$ (the distance between the center of the mass and the pivot) leading to $I = \frac{1}{12}ML^2 + m\left(\frac{L}{6}\right)^2 = \frac{1}{9}\ ML^2$. Calculating the torque from the gravitational force at the center of the stick gives $\tau = Fd\sin\theta = Mg\left(\frac{L}{6}\right)\sin -90^\circ = -\frac{MgL}{6}$. (The minus sign for clockwise). So, $\tau_{net} = I\alpha \;\Rightarrow\; -\frac{MgL}{6} = \frac{1}{9}ML^2\alpha \;\Rightarrow\; \alpha = -\frac{3}{2}\frac{g}{L}$. Using $a_t = r\alpha$ leads to $a_t = \left(\frac{L}{6}\right)\left(-\frac{3}{2}\frac{g}{L}\right) \;\Rightarrow\; |a_t| = \frac{g}{4}$.

47. C… From the First Law of Thermodynamics, $\Delta U = Q + W$, and since it is an adiabatic process $Q = 0$. We can therefore find the work done by looking at the internal energy change with $\Delta U = n\left(\frac{5}{2}R\right)\Delta T$ for a diatomic gas. Using $PV = nRT \;\Rightarrow T = \frac{PV}{nR} = \frac{(2.0\ atm)(30\ L)}{(1\ mol)\left(0.0821\ L\cdot\frac{atm}{mol}\cdot K\right)} = 730.8\ K$. For an adiabat, $PV^\gamma = constant$ and $P = \frac{nRT}{V}$ which upon substitution gives $TV^{\gamma-1} = Const$. Hence, $(730.8)(30)^{\frac{2}{5}} = T_f(15)^{\frac{2}{5}} \;\Rightarrow T_f = 964.3\ K$. Finally, $W = \Delta U = n\left(\frac{5}{2}R\right)(964.3 - 730.8) = 4850\ J$

48. B… Outside the shell of radius $3a$, the total field will be that of a point charge and so will the potential giving $V_{3a} = \frac{kQ}{3a}$. Between 2a and 3a, there is no field interior to the conductor (since the shells are in free space and there is no mention of any other charges nearby… the system quickly attains static equilibrium) and so the potential at $2a$ is given as $V_{2a} = \frac{kQ}{3a}$. Noting that there is a field between a and 2a, we have a potential difference computed as $\Delta V = V_f - V_i$ where $V_f = V_a$ and $V_i = V_{2a}$ and on the left side we write $\Delta V = V(r) - V(2a) = \frac{kQ_{in}}{a} - \frac{kQ_{in}}{2a}$. And so, we have $\frac{kQ_{in}}{a} - \frac{kQ_{in}}{2a} = 0 - \frac{kQ}{3a}$. This leads to $\frac{kQ_{in}}{2a} = -\frac{kQ}{3a} \;\Rightarrow Q_{in} = -\frac{2}{3}Q$

49. A… From relativity, we know $KE = (\gamma - 1)m_0c^2$ and so, $2m_0c^2 = (\gamma - 1)m_0c^2 \;\Rightarrow \gamma = 3$. From this, $\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = 3 \;\Rightarrow \frac{1}{9} = 1 - \frac{v^2}{c^2} \Rightarrow v^2 = \frac{8}{9}c^2 \Rightarrow v = \sqrt{\frac{8}{9}}c = 2.83 \times 10^8\,\frac{m}{s}$

50. D… By traversing a loop around the outside, we enclose an entire emf ξ which would be equally distributed across each identical resistor since the outer loop is the only one with current. Hence, the voltage is $\frac{\xi}{3}$ for any resistor. By traversing the top triangular loop, we enclose $\frac{\xi}{2}$ and have 2 resistors dropping potential $\frac{\xi}{3}$, we have $\frac{\xi}{2} = 2\left(\frac{\xi}{3}\right) + V_{voltmeter} \Rightarrow V_{voltmeter} = -\frac{\xi}{6}$. As a check, the lower triangular loop gives $\frac{\xi}{2} = \left(\frac{\xi}{3}\right) - V_{voltmeter} \Rightarrow V_{voltmeter} = -\frac{\xi}{6}$. The magnitude of the voltage is therefore $\frac{\xi}{6}$.