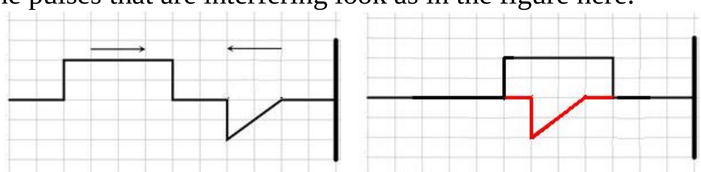
2011 PhysicsBowl Solutions

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

1. **D…** The average human male is closest to 100 kg (a bit more than 200 pounds)
2. **E…** The "E" stands for energy. Units for energy include joules.
3. **B…** The metric prefix for million (or 10^6) is mega.
4. **C…** Rules of addition look at the precision of a measurement. In other words, we look at the last column for which each value has a number… lining up these values gives a sum of $(4.57 + 0.213) \times 10^3\ m$. Since the first value only has two places past the decimal (and the other value has 3 places), the sum must end 2 places past the decimal. Hence, $(4.57 + 0.213) \times 10^3\ m = 4.78 \times 10^3 m$
5. **B…** Protons in the metal are not free to move as they are in the nuclei of the atoms. The mobile charges here are electrons. There are no positrons ("positive electrons") in the metal.
6. **C…** The net force by Newton's Second Law is $F_{net} = ma$. The object is in free fall, so the acceleration is $10\,{}^{m}/_{s^2}$ giving $F_{net} = (0.100\ kg)\left(10\ {}^{m}/_{s^2}\right) = 1.00\ N$.
7. **D…** Using constant acceleration kinematics, $v^2 = v_0^2 + 2a\Delta x \ \rightarrow 0 = v_0^2 + 2(-10)(12) \rightarrow v_0^2 = 240\frac{m^2}{s^2}$ which gives $v_0 = 15.5\frac{m}{s}$. Now, $v = v_0 + at\ \rightarrow 0 = 15.5 + (-10)t\ \ \rightarrow\ t = 1.55\ s$.
8. **E…** In order for the speed of the object to increase, the velocity and acceleration must have the same sign. This means that the acceleration is directed with the velocity, thereby increasing the size of the velocity vector (the speed).
9. **A…** Using unit conversions: $60.0\frac{miles}{hr} \times \frac{24\ hr}{day} \times \frac{1.609\ km}{1\ mile} = 2320\frac{km}{day}$. Using $5\ km \approx 3\ miles$ or $1\ mile\ \approx 1600\ m$ still leads to the conclusion that (A) is the most correct answer.
10. **E…** There are 2 forces on the free body diagram of the hanging mass (T, G). Writing Newton's Second Law for this problem, we have $F_{net} = Ma\ \rightarrow T - G = F$. Since the elevator is said to be moving downward with a constant speed of $3.0\ {}^{m}/_{s}$, we have $F = 0 = T - G$ and so, $T = G$. Hence, this gives as our result that $F < T = G$.
11. **E…** The LHC is the Large Hadron Collider
12. **D…** Writing Newton's Second Law for this problem, we have $F_{net} = (5.0\ kg)\left(4.0\,{}^{m}/_{s^2}\right) = 20\ N$
13. **A…** The force in question is : the contact force on the book by the table
    The Newton's Third Law pair force: the contact force on the table by the book.
14. **A…** by definition, the average speed is distance divided by time. So, in order to calculate the average speed for the trip, we need the time for each portion of the total trip. For part : $t_1 = \frac{\Delta x_1}{v_1} = \frac{800\ m}{4\,{}^{m}/_{s}} = 200\ s$. For part 2: $t_2 = \frac{\Delta x_2}{v_2} = \frac{1200\ m}{20\,{}^{m}/_{s}} = 60\ s$. Hence, for the entire trip, we have $\langle v \rangle = \frac{(800+1200\ )m}{(200+60)s} = 7.7\ \frac{m}{s}$.
15. **B…** From Newton's Second Law, we write $F_{net} = ma\ \rightarrow F - f = ma\ \rightarrow\ 15 - f = (4)(2.5)$. Solving for the friction therefore gives us $15 - f = (10)\ \ \rightarrow\ \ f = 5\ N$.
16. **E…** Energy is a scalar quantity and has no direction associated with it.

17. **B…** The frequency can be found using $v = f\lambda \rightarrow f = \frac{v}{\lambda} = \frac{3\times10^8}{3.40} = 8.82 \times 10^7 Hz$ as all EM waves travel at the speed of light $3 \times 10^8\, {}^{m}/_{s}$.
18. **D…** By definition, the average acceleration is found as the change in the velocity divided by the time. Hence, we compute from the points on the graph that $\langle a \rangle = \frac{\Delta v}{\Delta t} = \frac{-4\,{}^{m}/_{s} - (4\,{}^{m}/_{s})}{5.0\ s} = -1.6\ {}^{m}/_{s^2}$.
19. **E…** By drawing the line tangent to the point on the graph at time $t = 5.0\ s$, we have a straight line that passes very closely to the points (4,4) and (6,-4). Computing the slope from these points gives $\frac{\Delta v}{\Delta t} = \frac{-4\,{}^{m}/_{s} - 4\,{}^{m}/_{s}}{2.0\ s} = -4.0\ {}^{m}/_{s^2}$.
20. **C…** The transistor was introduced around 1947 with the Nobel Prize awarded for its invention in 1956.
21. **C…** Aside from knowing this bit of information, one can make a calculation. Using Newton's Second Law on the Moon with Newton's Universal Law of Gravitation, one has $\frac{GM_{Earth}M_{Moon}}{r^2} = M_{Moon}\frac{v^2}{r}$. Using $v = \frac{2\pi r}{T}$, we rewrite this to obtain $\frac{GM_{Earth}}{r^2} = \frac{4\pi^2 r^2}{rT^2} \rightarrow r^3 = \frac{GM_E}{4\pi^2}T^2$. This is Kepler's Third Law. The period of the Moon in orbit is about 1 month, so an estimate of the distance from Moon to Earth can now be made as $r^3 = \frac{(6.7\times10^{-11})(6.0\times10^{24})}{4\pi^2}(1\ mnth)^2 \rightarrow$ $r \approx 4.1 \times 10^8\ m$ after converting the time to seconds. Hence the light gets to the Earth in a time computed as $t = \frac{\Delta x}{v} = \frac{4.1\times10^8\ m}{3.0\times10^8\ m/s} \approx 1.4\ s$
22. **B…** Using the ideal gas equation, we write $PV = nRT \rightarrow T = \frac{PV}{nR} = \frac{(5.00\times10^5\ Pa)(0.025\ m^3)}{3(8.31)} = 501\ K$.
23. **A…** Wave speed for a string depends on the tension in the string and the mass per unit length. Since these have not changed, the wave speed is unchanged. Using $v = f\lambda$, an increase in the frequency means that the wavelength decreases. So, doubling the frequency results in halving the wavelength.
24. **A…** When the triangular pulse reaches the fixed end, it undergoes a phase shift and is inverted upon reflection. Hence, the pulses that are interfering look as in the figure here.



25. **E…** The product shown is of magnetic field by length by speed… in symbols, this is Blv which can represent an emf which has units of volts.
26. **C…** The Moon always receives sunlight on approximately 50% of its surface. What we see is a function of the location of the Moon in its orbit and whether the illuminated side of the Moon is facing the Earth.
27. **D…** Since the density of the material is less than the density of water, the object will float. The object must displace enough water to create a buoyant force to balance the gravitational force. So, from the free body diagram analysis, we have $F_{net} = ma \rightarrow B - mg = 0 \rightarrow \rho_{water}gV_{underwater} = \rho_{block}gV_{total}$. Solving for the fraction below the water, we compute $\frac{V_{underwater}}{V_{total}} = \frac{\rho_{block}}{\rho_{water}} = 75\%$.
28. **B…** From mechanical energy conservation of the object-Earth system, we write $\Delta KE + \Delta PE = 0 \rightarrow$ $-\Delta KE = mg\Delta y$. Since the speed doubles in the second throw, this means that the change in vertical position will be four times what it was in the first throw from $-\left(0 - \frac{1}{2}mv^2\right) = mg\Delta y \rightarrow \Delta y = \frac{v^2}{2g}$. Note that the answer is independent of the mass here.
29. **C…** The magnetic force does no work on the charged particle (it is a *deflecting* force resulting in a change in direction of travel). Consequently, the speed of the particle never changes while in the magnetic field, independent of its direction with respect to the field.

30. D… Using constant acceleration kinematics, we write for car A: $v^2 = v_0^2 + 2a\Delta x = 0 + 2ad$. So, $v = v_A = \sqrt{2ad}$. Writing the same equation for car B yields $v^2 = v_0^2 + 2a\Delta x = 0 + 2\frac{a}{2}d \rightarrow v_B = \sqrt{ad}$. This means that $v_B = \sqrt{ad} = \frac{1}{\sqrt{2}}\sqrt{2ad} = \frac{\sqrt{2}}{2}v_A = \frac{\sqrt{2}}{2}v$.

31. D… Adding energy to the ice results in the ice changing its temperature to zero degrees, melting into water, and then having its temperature rise to 10 degrees. The computation of this energy is done as

$Q = mc_{ice}\Delta T + mL_f + mc_{water}\Delta T$

$Q = (0.020\ kg)\left[\left(2100\frac{J}{kg\cdot K}\right)(10\ K) + \left(3.3\times 10^5\frac{J}{kg}\right) + \left(4200\frac{J}{kg\cdot K}\right)(10\ K)\right] = 7900\ J.$

32. E… Pigments work on the subtractive color system. This means that a blue pigment is blue because it reflects blue light and absorbs both red and green light. The green pigment absorbs the red and blue, reflecting only green. When mixed, all three primary colors will be absorbed, meaning that none of the colors are reflected and the pigment is very dark, making (E) (black) the correct response.

33. C… From the lens equation, $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$, for the first scenario we have $d_o = 12\ cm$ and $d_i = 18\ cm$. The lens equation will also work by reversing the image and object distances. Hence, the other location has $d_o = 18\ cm$ and $d_i = 12\ cm$. This means that the lens must be moved toward the screen by $6\ cm$.

34. B… By the right-hand rule, with the right thumb along the current, the right fingers wrap in the sense of the magnetic field from the wire. This means that the magnetic field from the wire is out of the plane of the page at the location of the electron. To find the force on the electron, now we point the right fingers in the direction of the velocity and curl them into the direction of the magnetic field. The thumb points in the direction of the force (toward the bottom of the page) EXCEPT that since the charge in question is negative, the hand has to be turned 180 degrees which results in the right thumb pointing toward the top of the page and in the direction of the force.

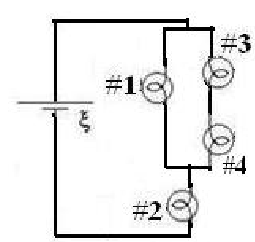
35. E… Looking at the front wheel as it travels to the South, the wheel spins forward. By the right-hand rule, this means that the direction of the angular velocity points to the left which would be Eastward. Now, since the angular speed is decreasing, this means that the angular acceleration is in the direction opposite to the angular velocity. This means that the angular acceleration is directed to the West.

36. A… METHOD #1: The actual mechanical advantage is computed as resistive force divided by applied force. This gives $AMA = \frac{F_{resistive}}{F_{Applied}} = \frac{100\ N}{150\ N} = \frac{2}{3}$.

METHOD #2: The efficiency of a machine is computed as "what you get" divided by "what you pay for". Here, we get the mass to the top of the ramp and what we pay for is applying the force along the incline. This means that $= \frac{get}{pay\ for} = \frac{(mg)(3)}{(150)(5)} = \frac{2}{3}\frac{3}{5} = \frac{2}{5}$. Now, efficiency for a machine is also $e = \frac{AMA}{IMA}$ where for the incline, the IMA (ideal mechanical advantage) is found as "input distance" divided by "resistive distance" which is $IMA = \frac{5}{3}$. Hence, $e = \frac{AMA}{IMA} \rightarrow \frac{2}{5} = \frac{AMA}{5/3} \rightarrow AMA = \frac{2}{3}$.

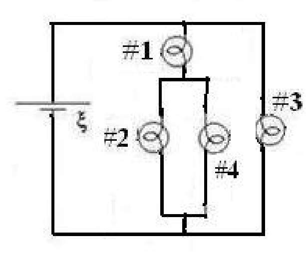
37. D… Linear momentum of the system is constant (and zero) during the oscillation of the masses. By calling the speed of the heavy mass v when the kinetic energy is maximized for the 2M mass, this means by linear momentum conservation that the lighter mass (M) will have speed $2v$. The kinetic energy of the 2M mass is $= \frac{1}{2}(2M)v^2 = Mv^2$ and for the light mass we have $K_B = \frac{1}{2}(M)(2v)^2 = 2Mv^2 = 2K$.

38. A… Before the switch is closed, the circuit looks like the diagram to the right. We assume all resistances of value R.



Writing the potential difference across each bulb in terms of the battery emf, we start by noting that the resistance of the bulb 1-3-4 combination is written as 2/3 R. Hence, the voltage is divided as $^{3}/_{5}\,\xi$ for bulb 2 and $^{2}/_{5}\,\xi$ for the 1-3-4 combination. Bulb 1 will get a full $^{2}/_{5}\,\xi$ while bulbs 3 and 4 split the voltage giving each $^{1}/_{5}\,\xi$.

After closing the switch, the circuit is redrawn as shown to the right. Here, bulb #3 gets a voltage equal to that of the battery. Bulbs 1-2-4 now split voltage. The

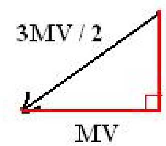


bulbs 2-4 combination have ½ the effective resistance of bulb 1, so they have ½ of the voltage of bulb 1. Hence, bulb 1 has a voltage of ${}^{2}/_{3}\,\xi$. while bulbs 2 and 4 each have voltage ${}^{1}/_{3}\,\xi$. The following table summarizes what happens to each bulb.

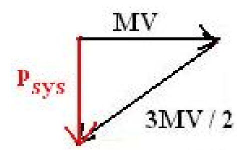
Bulb #	Original voltage	Final voltage	Change in brightness
1	${}^{2}/_{5}\,\xi = 0.40\,\xi$	${}^{2}/_{3}\,\xi = 0.67\,\xi$	Brightens
2	${}^{3}/_{5}\,\xi = 0.60\,\xi$	${}^{1}/_{3}\,\xi = 0.33\,\xi$	Dims
3	${}^{1}/_{5}\,\xi = 0.20\,\xi$	$\xi = 1.00\,\xi$	Brightens
4	${}^{1}/_{5}\,\xi = 0.20\,\xi$	${}^{1}/_{3}\,\xi = 0.33\,\xi$	Brightens

The brightness is determined from the power which is computed as $P = \frac{(\Delta V)^2}{R}$, so as the voltage increases, so does the brightness. Only bulb 2 dims.

39. C… By using linear momentum conservation, we have that the East-West component of momentum must be zero since there is no motion East-West after the collision. The object moving directly to the East has linear momentum $p = MV$ which means that the West component of the momentum of the other object must be the same.



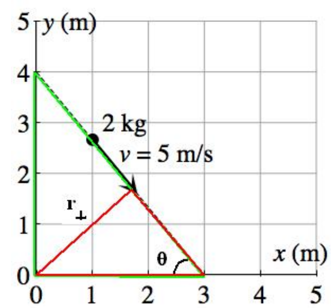
METHOD #1: making a right triangle of momentum for the second object as seen above. Using the Pythagorean Theorem, we compute the unknown downward component of linear momentum to be $p_y = \sqrt{\frac{9}{4}(MV)^2 - (MV)^2} = \frac{\sqrt{5}}{2}MV$. Since this is the total momentum of the system… we then have from linear momentum conservation that $\frac{\sqrt{5}}{2}MV = \left(\frac{3}{2}M\right)V_{final\ South} \rightarrow V_{final\ South} = \frac{\sqrt{5}}{3}V$



METHOD #2: A similar approach is to use vector addition of the linear momentum to produce the total of the two-mass system. This picture is shown to the right where we have momentum MV to the East and 3/2 MV directed so that the total linear momentum (p_{sys}) is directed Southward. Again, the Pythagorean Theorem is used to find the total linear momentum of the system to the South and we use the procedure outlined in Method #1.

METHOD #3: A more quantitative approach can be done by writing linear momentum conservation in both the East-West direction and North-South direction leading to the derivation of the west component of object 2's velocity… leading to (with the Pythagorean Theorem), the South component of velocity…

40. B… METHOD #1: Angular momentum can be computed for the particle as $L = rp\sin\theta$. We will compute this quantity we have when the particle reaches the x-axis. At this point, $r = 3.0\ m$, $p = mv = (2\ kg)(5\ {}^{m}/_{s}) = 10\ kg\,{}^{m}/_{s}$ while the angle θ is computed from the picture as $\sin\theta = \frac{4}{5}$. Putting all of this together gives us $L = rp\sin\theta = (3)(10)\left(\frac{4}{5}\right) = 24\,kg \cdot m^2/s$.



ALTERNATIVELY: Again using $L = rp\sin\theta$, but this time we will find the length of the perpendicular line from the origin to the line of motion. That is, $L = p(r\sin\theta) = pr_\perp$. From the green triangle, we have $\sin\theta = \frac{4}{5}$. Now, in the red triangle, the length of $r_\perp = (3m)\sin\theta = 2.4\ m$. So, the angular momentum is $L = pr_\perp = (10)(2.4) = 24\,kg \cdot m^2/s$.

41. A… The conventional current is directed counterclockwise in the circuit, meaning from a right-hand rule that the magnetic field interior to the loop is directed out of the plane of the page. As a result, the magnetic field at P (outside the loop) would be oppositely directed to the interior or into the page's plane. Since the resistance is decreasing, the current in the outer circuit increases, thereby increasing the field strength through the inner circuit. By Lenz's Law, there is an induction to fight the change in field and there is a current in the inner circuit producing a magnetic field into the page. This means that the current is directed clockwise and hence, from X to Y in the inner circuit's resistor.

42. **B…** By disconnecting the battery, the charge on the capacitor plates is fixed. By removing the dielectric, the capacitance is reduced by a factor of κ. So, by using $U = \frac{1}{2}\frac{Q^2}{C}$, with the reduction in the capacitance by κ with no charge change, the energy is increased by a factor of κ.

43. **D…** Since consecutive standing wave modes for tubes open at both ends have a difference in frequency equal to the fundamental frequency, we know that the fundamental frequency of the tube is $644 - 552 = 92\ Hz$. So, for the 1st harmonic, we can write $v = f\lambda \rightarrow \lambda = \frac{v}{f} = \frac{340}{92} = 3.70\ m$. For this standing wave mode, there is only ½ of a wavelength within the tube of length L. Hence, the tube length is $L = \frac{1}{2}\lambda = 1.85\ m$.

44. **C…** For the isobaric expansion, we have the work done by the gas computed as $W = P\Delta V$ which by the ideal gas equation is the same as $W = P\Delta V = nR\Delta T = (1\ mole)\left(8.31 \frac{J}{mole \cdot K}\right)(200\ K) = 1662\ J$.

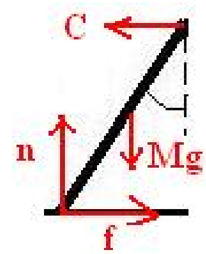
45. **E…** Even with half of the lens covered, there is still a full image formed, but only half as many rays from the object are focused onto the screen. This means that a full image will form but it will be less intense and hence, will appear dimmer.

46. **C…** The electric field interior to the shell is zero since it is in static equilibrium. This means that the electric potential in the interior of the shell is the same as it is on the surface of the shell. Outside the shell, it acts like a point charge of total charge Q. Consequently, the electric potential at the surface is equal to $kQ/(3a)$ which means that this is the electric potential at all points interior to the shell.

47. **A…** From mechanical energy conservation, we compute for the mass-Earth system when the mass reaches the point P that $\Delta KE + \Delta PE = 0 \rightarrow \left(\frac{1}{2}mv^2 - 0\right) + (-mgL) = 0 \rightarrow \frac{mv^2}{L} = 2mg$. Now, from the free body diagram of the mass at P, we have $F_{net} = ma \rightarrow T - G = F$. At the bottom of the swing, the mass is accelerating and so $F = ma = \frac{mv^2}{L} = 2mg$. Finally, this means that $T - G = F \;\rightarrow\; T - mg = 2mg \;\rightarrow\; T = 3mg$. Hence, $T = 3mg; F = 2mg; G = mg$ meaning that $G < F < T$.

48. **D…** The EM wave associated with this magnetic field travels along the +z direction from the argument in the cosine term. The magnetic field at the position and time given points along the +x direction since cos(0) = 1. The Poynting vector gives the direction of energy flow for the EM wave which is also the same as the direction of travel of the wave. Hence, writing that $\vec{S} \sim \vec{E} \times \vec{B}$, we need to figure out $\overrightarrow{??} \times \hat{x} = \hat{z}$. By Right-hand rules… $-\hat{y} \times \hat{x} = -\hat{z}$, and so the electric field is directed along -y here.

49. **B…** From the symmetry of the situation, the normal force from the ground on the left side and on the right side of the "V" are the same and equal to the gravitational forces from each leg. This can be shown by calculating torques from an axis perpendicular to the plane of the page below the center of the "V" at the ground. Let us consider the free body diagram of ONLY the left half of the V. "C" in the diagram is the contact force from the right-half of the V which must point to the left (n and Mg are already equal). Performing a torque analysis from the lower left corner, we have $\tau_{net} = 0 \rightarrow \tau_{Mg} + \tau_C = 0 \rightarrow -(Mg)\left(\frac{L}{2}\right)\sin(150^\circ) + CL\sin(120^\circ) = 0 \rightarrow C = \frac{Mg}{2}\frac{\sin 150^\circ}{\sin 120^\circ} = \frac{120}{2}\frac{1}{\sqrt{3}} = 34.6\ N$. Now, by Newton's Second Law, $F_{net\ x} = 0 \rightarrow f + (-C) = 0 \rightarrow f = C = 34.6\ N$.



50. **E…** We are effectively looking at a length contraction problem here. From the stick set-up frame, we have a length along the x-axis of $x_i = (1\ m)\cos 30^\circ = \frac{\sqrt{3}}{2}$ and a y-component of $(1\ m)\sin 30^\circ = \frac{1}{2}$. From the other frame, in order to have a 60° angle, we note that the length along the y-axis is unaltered and so, the triangle must have an x-component of length $\tan 60^\circ = \frac{1/2}{X} \rightarrow X = \frac{1/2}{\sqrt{3}} = \frac{1}{3}\frac{\sqrt{3}}{2} = \frac{1}{3}x_i$. In other words, the length is reduced by a factor of 3… so by the length contraction equation, $L' = L/\gamma$, this means that $\gamma = 3 = \frac{1}{\sqrt{1-\beta^2}} \rightarrow \frac{1}{9} = 1 - \beta^2 \;\rightarrow \beta^2 = \frac{8}{9} \;\rightarrow v = \sqrt{\frac{8}{9}}c = \frac{2\sqrt{2}}{3}c$.