2008 Physics Bowl Solutions

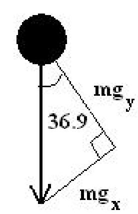
#	Ans	#	Ans	#	Ans	#	Ans	#	Ans
1	E	11	A	21	C	31	D	41	E
2	B	12	B	22	A	32	B	42	D
3	C	13	D	23	C	33	E	43	A
4	D	14	B	24	D	34	B	44	A
5	C	15	D	25	E	35	A	45	E
6	A	16	D	26	C	36	C	46	B
7	E	17	E	27	D	37	E	47	C
8	A	18	A	28	B	38	A	48	C
9	B	19	B	29	C	39	B	49	B
10	D	20	A	30	E	40	C	50	E

1. **E…** Linear Momentum has both magnitude and direction.
2. **B…** $10^3 = kilo\ (k)$; $10^6 = Mega\ (M)$; $10^9 = Giga\,(G)$; $10^{-3} = milli\,(m)$; $10^{-12} = pico\,(p)$
3. **C…** Using constant acceleration kinematics, one has

   $$\Delta x = v_o t + \frac{1}{2}at^2 \rightarrow 10 = 0 + \frac{1}{2}(2.5)t^2 \rightarrow 10 = 1.25t^2 \rightarrow t^2 = 8 \rightarrow t = \sqrt{8} = 2.8\,s$$
4. **D…** Applying the ideal gas equation, $PV = nRT$, we substitute to find

   $$P = \frac{nRT}{V} = \frac{(1\,mol)\left(8.31\,{}^{J}\!/_{mol\cdot K}\right)(373\,K)}{10\,m^3} = 310\,Pa$$
5. **C…** The total cost is computed as $\dfrac{\$0.10}{kW\cdot hr}\times\dfrac{100\,W}{1}\times\dfrac{1\,kW}{1000\,W}\times\dfrac{1\,yr}{1}\times\dfrac{365\,dy}{1\,yr}\times\dfrac{24\,hr}{1\,dy} = \$87.60$

   which is closest to \$100.
6. **A…** Coulomb's Law gives the force of one point charge on a second point charge. This relation is $F = \dfrac{kQ_1Q_2}{r^2}$. Since the force is inverse-square, by halving the distance, one quarters the denominator… meaning that the force is 4 times greater.
7. **E…** In terms of increasing energy (frequency)… one roughly has - standard broadcast, microwave, infrared, and then visible light. This makes violet light have the greatest energy per photon.
8. **A…** From the figure, we have $mg_x = (10)\sin(36.9^\circ) = +6.0\,N$ and $mg_y = -(10)\cos(36.9^\circ) = -8.0\,N$. The minus sign on the y-component arises since the force is directed into the incline (-y direction)

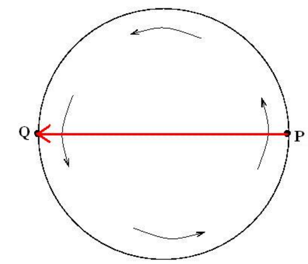


9. **B…** When a medium is dispersive, the different wavelengths of light experience different indices of refraction, resulting in different refraction angles, leading to the separation of the colors.
10. **D…** Pressure is Force / Area. Writing the units for these quantities, we have

    $$\frac{N}{m^2} = \frac{kg\,{}^{m}\!/_{s^2}}{m^2} = \frac{kg\cdot m}{m^2\cdot s^2} = \frac{kg}{m\cdot s^2}$$
11. **A…** Marie Curie won the Nobel Prize in physics in 1903 for work on radiation.

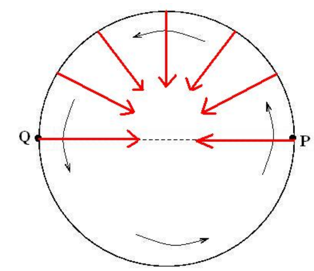
12. **B…** The average angular speed of the second hand is computed as $\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi\, rad}{60\, s} = 0.105\frac{rad}{s}$ where the second hand makes a full revolution in one minute.

13. **D…** The ideal mechanical advantage of a pulley system is computed in relation to the number of strings effectively acting to pull upward on a load. Here, the 4 inner strings provide a force acting upward on the bottom pulley system connected to the mass.



14. **B…** Average velocity is found as displacement divided by time. The object moves from P to Q in the diagram which is directly to the left. This is shown in the figure at the right.

15. **D…** Average acceleration is computed as the change in velocity divided by the time. There are two ways to approach this problem:
Method 1: By drawing in the instantaneous acceleration at various points along the trajectory, we can see by symmetry that the horizontal components of acceleration will cancel.



Method 2: The initial velocity (at P) is directed straight upward, whereas the final velocity over the interval is directed straight down (at Q). Using the mathematical relation indicating the directions of the velocity, we have $\langle\vec{a}\rangle = \frac{\vec{v}_f - \vec{v}_i}{\Delta t} = \frac{\downarrow - \uparrow}{\Delta t} = \frac{\downarrow + \downarrow}{\Delta t}$ and so the direction of the average acceleration is straight downward.

16. **D…** Using the free body diagram on the block, we have three forces… the gravitational force and the force from the string are downward while the buoyant force acts upward. Writing Newton's Second Law, we have $F_{net} = ma \rightarrow B - T - mg = 0 \Rightarrow B = T + mg = 3.0 + 5.0 = 8.0\,N$. Since the buoyant force is computed as $B = \rho V g$, we solve for the volume of the water displaced (equal to the volume of the block) as $V = \frac{B}{\rho g} = \frac{8.0N}{\left(1000\,{kg}/{m^3}\right)\left(10\,{m}/{s^2}\right)} = 8.0\times10^{-4}\,m^3$.

17. **E…** For the ideal situation… the red pigment reflects red and absorbs both green and blue light. The blue pigment reflects blue light and absorbs both the red and green light. As pigments work on the subtractive color system, by mixing them we create something that absorbs red, green, and blue light… leaving a very dark pigment (black).

18. **A…** Using the Doppler Shift equation, and that the speed of sound is given as $340\,{m}/{s}$ (see the constants sheet provided), we have $f_o = f_s\left(\frac{v_s - v_{obs}}{v_s + v_{src}}\right) = (5000)\left(\frac{340-20}{340+25}\right) = 4384\ Hz$. The minus sign in the numerator arises since the observer is moving away from the source and the positive sign in the denominator arises since the source is moving away from the observer.

19. **B…** Kepler's Second Law is most directly related to the law of conservation of angular momentum.

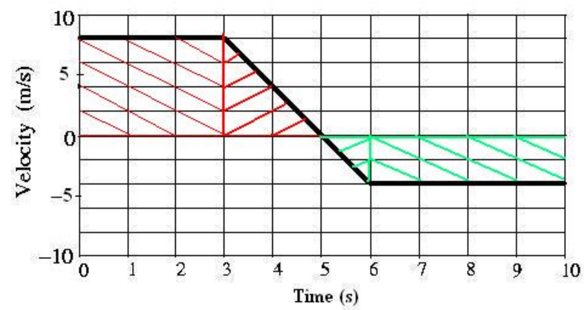
20. **A…** The block is pushed with constant speed in a constant direction, meaning that the velocity is constant… which means no acceleration. As a result, from Newton's Second Law, there is NO net force acting on the mass.

21. **C…** Lenses are made of material which will be subject to dispersion. This means that different colors of visible light focus to different places because they experience different indices of refraction within the lens material.

22. **A…** By the Zeroth Law of Thermodynamics, when materials are brought into contact at the same temperature, they are in thermal equilibrium. Hence, no net energy exchange occurs.

23. C… The car moves away from the origin initially and then slows to a stop at 5.0 seconds. One notes, though, that while the car is slowing down from t=3.0 to t=5.0 seconds… since the velocity is still positive, the car continues to move away from the origin. This is like coming to a stop light and applying the brakes… the car continues to move forward. After t=5.0 s, the car reverses direction as the velocity is negative and heads back toward the origin.

24. D… Average speed is distance divided by time. The total distance traveled by the car is found as the magnitude of the area under the velocity vs. time curve. Breaking this computation into pieces:



$$t = 0 \rightarrow 3s: \ A = LW = \left(8\,{}^{m}\!/_{s}\right)(3s) = 24m$$

$$t = 3 \rightarrow 5s: \ A = \frac{1}{2}LW = \frac{1}{2}\left(8\,{}^{m}\!/_{s}\right)(2s) = 8m$$

$$t = 5 \rightarrow 6s: \ A = \frac{1}{2}LW = \frac{1}{2}\left(-4\,{}^{m}\!/_{s}\right)(1s) = -2m$$

$$t = 6 \rightarrow 10s: \ A = LW = \left(-4\,{}^{m}\!/_{s}\right)(4s) = -16m$$

Adding the magnitudes of the position changes together gives a total distance traveled of $24 + 8 + 2 + 16 = 50\,m$.

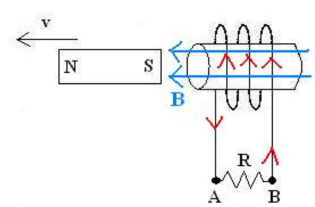
Hence, $\langle v \rangle = \dfrac{50m}{10s} = 5.0\,{}^{m}\!/_{s}$.

25. E… To balance the nuclear reaction, the sum of the values across the "top" and across the "bottom" must match… That is, we have $4 + 9 = 12 + A \rightarrow A = 1$ and $2 + 4 = 6 + Z \rightarrow Z = 0$. This gives us a particle with 1 nucleon, but 0 protons. This is a neutron. ${}^{A}_{Z}X = {}^{1}_{0}n$.

26. C… The principal quantum number allows one to find the azimuthal quantum number, l as $l = 0,1,2,3$. The magnetic quantum number is then found as $m_l = -l, -1+1, ..., 0, ...l-1, l$. Since $l = 3$, the values of m_l are $m_l = -3, -2, -1, 0, 1, 2, 3$ which is a total of 7 possible values.

27. D... For a tube open at both ends, there is ½ wavelength within the tube. For the tube closed at one end, there is only ¼ wavelength contained in the tube. Hence, the tube closed at one end is half as long as the tube open at both ends when the fundamental frequency is the same.
More mathematically, the speed of the wave, frequency, and hence wavelength are all the same for the resonance of the two tubes. One can derive that the frequencies of resonance for a tube open at both ends takes the form $f_n = n\dfrac{v}{2L}$ and for a tube closed at one end as $f_n = n\dfrac{v}{4L}$. Setting $n = 1$ for both cases, and solving for the lengths… $\dfrac{v}{2L_1} = \dfrac{v}{4L_2} \rightarrow L_2 = {}^{1}\!/_{2}\,L_1$.

28. B… Diverging lenses always produce virtual images of real objects that are smaller and upright.



29. C… As the magnet moves away from the circuit, the field directed to the left through the solenoid (toward the South Pole of the magnet) is decreasing. This means that there is an induced electric field in the vicinity of the solenoid to produce a magnetic field directed to the left. Using the right-hand rule for a solenoid, the current through the solenoid must be directed upward "in front" of the solenoid… meaning that the current is directed from A to B through the resistor (the induced current and magnetic field are shown in the figure). The induction takes place to "fight the change" of the moved magnet, meaning that there is a force on the magnet trying to pull it back. We can model the magnet of the solenoid as having a North Pole on the left side, thereby attracting the magnet to the right.

30. **E…** There is no phase change for transmitted waves, but when light bounces off a material which has a higher index of refraction, there is a phase shift of 180°.

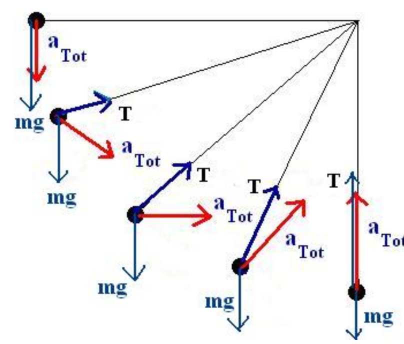
31. **D…** Once equilibrium is established in the circuit, there is no current to the capacitor. This means that the only current is through the branches with resistors. For the left-hand branch, we write Kirchhoff's Loop Rule to find $\xi + \Delta V_7 + \Delta V_3 = 0 \Rightarrow 6 - I_{left}(7) - I_{left}(3) = 0 \to I_{left} = 0.6\,A$. For the right branch of resistors, we can write a loop rule of $\xi + \Delta V_6 + \Delta V_{12} = 0 \Rightarrow\ 6 - I_{right}(6) - I_{right}(12) = 0 \to I_{right} = 0.33\,A$. Now, writing a Loop through the capacitor with resistors R_1 and R_3, we have
$$-I_{left}(7) + \Delta V_{cap} + I_{right}(6) = 0 \to -(0.6)(7) + \Delta V_{cap} + (0.33)(6) = 0 \Rightarrow |\Delta V_{cap}| = 4.2 - 2.0 = 2.2\,v$$

32. **B…** When there is a total lunar eclipse, the Moon passes into the shadow of the Earth… which means that the Moon is Full.

33. **E…** The electric potential of a point charge is a scalar computed as kQ/r. In order for the potential to be zero in this configuration, one needs to be closer to the smaller charge. As a result, there is no place in Region I where the potential is zero as all points in that region are closer to the larger charge. There are locations, however, in both Regions II and III for which the total potential is zero.

34. **B…** Again, one must be closer to the smaller charge in order for the fields to cancel. This rules out Region I. Here, though, there is a direction associated with the field. In region II, the field from the +3Q charge is to the right, whereas the field from the –Q charge is also to the right. These fields cannot cancel. In Region III, the fields are in opposite directions and there is a place on the axis at which the fields from the two charges have equal magnitude.

35. **A…** The acceleration at $\theta = 0^\circ$ is straight down whereas the acceleration at $\theta = 90^\circ$ is straight upward. In transitioning between these angles, the sum of the two forces acting on the mass effectively rotates by 180°. As a result, the acceleration undergoes a transition like that shown in the figure (not quite drawn to scale) here (the red vector is the total acceleration). One notes that this result holds whether the angle θ increases (mass falling) or decreases (mass rising) and that the total acceleration is directed along the string only at $\theta = 90^\circ$, outside the range of angles allowed in the problem.



36. **C…** Using the right-hand rule in Region II… fingers point along the velocity (to the right initially) and if the fingers are curled upward out of the page, then the right thumb points down the page… but since this is an electron, we flip our hand over to find the direction of the force. Hence, the field in Region II is out of the page. In region I, the electric force on the electron is directed OUT of the page $(\vec{F} = q\vec{E})$ with the electric field pointing into the page. Hence, we need a magnetic force INTO the page. In order to do this, we use the right-hand rule again and with the fingers pointing to the right, with the magnetic field UP the plane, then the right thumb points out of the page… but again, since this is an electron, the hand is flipped to find the force direction.

37. **E…** Balancing torques about the pivot point (the stick is in static equilibrium), one uses the distance for the 45 gram mass to be $42.5 - 20 = 22.5\,cm$ and since the meter stick is uniform, the mass acts its center, leading to a value of $d_{mg} = 50 - 42.5 = 7.5\,cm$. Hence, we have that
$$\tau_{CW} + \tau_{CCW} = 0 \to F_{45}d_{45} + (-(mg)d_{mg}) = 0 \to$$
$$(45\,g)g(22.5\ cm) = mg(7.5\ cm)\ \to m = \frac{45(22.5)}{7.5} = 135\,g$$

38. A… Using Newton's Second Law, we have $F_{net} = ma = m\frac{v^2}{r} = (1200)\frac{5000^2}{7.5\times10^7} = 400\,N$. Even though the mass of the planet is unknown, there is enough information about the satellite to determine the total gravitational force acting on it.

39. B… The average speed of molecules (rms-speed effectively) is dependent on temperature. With the temperature constant, there is no change in the speeds of the molecules. Hence, with a smaller volume, the distance that a particle has to travel in order to collide with the walls of the container is greatly decreased… hence there is an increase in the frequency with which particles hit the wall. This is reason for the pressure increase.

40. C… We are interested in the speed of the particle and the end-of-rod to which it is attached immediately after the collision. Because of the presence of the pivot, there is an external force on this system, meaning that linear momentum is not conserved. In order to analyze this problem, one uses angular momentum conservation about the pivot point. This gives:

$\Delta L = 0 \rightarrow (L_{part})_i = (L_{rod} + L_{part})_f$. Hence, we have $mVL = \left(\frac{1}{3}ML^2\right)\omega_f + mV_f L$ where $V_f = \omega_f L$ for the end of the rod. This gives

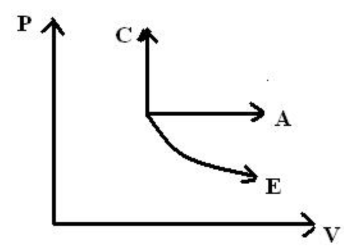
$$mVL = \left(\frac{1}{3}(2m)L^2\right)\frac{V_f}{L} + mV_f L \rightarrow mV = \frac{2}{3}mV_f + mV_f \rightarrow V = \frac{5}{3}V_f \rightarrow V_f = \frac{3}{5}V$$

41. E… When the switch is opened, the current through the branch with resistor R_2 drops to zero. At the instant before the switch is opened, the current through the inductor is 4.5 A (3.0 A through R_1 and 1.5 A through R_2). This current is maintained for the first instant after moving the switch, which means that a full 4.5 A is through resistor R_1. Writing Kirchhoff's Loop Rule around the branch with current, one has $\xi + \Delta V_L + \Delta V_{R_1} = 0 \rightarrow 12 + \Delta V_L - (4.5A)(4.0\,\Omega) = 0 \Rightarrow \Delta V_L = +6\,v$. Since the voltage increased across the inductor using a clockwise loop, point B must be at a higher potential than point A.

42. D… Since the battery remains connected, the voltage across the capacitor is unchanged. Since the geometry of the capacitor changes, so does the capacitance. From $C = \varepsilon_0 \, {}^{A}\!/_{d}$, doubling the distance between the plates halves the capacitance. Consequently, the total energy stored by the capacitor, given by $U = \frac{1}{2}CV^2$, is also cut in half.

43. A… By Malus' Law, the intensity of the light out of the analyzer has intensity $I_{in}\cos^2 30^\circ = \frac{3}{4}I_{in}$. The polarizer through which the unpolarized light initially shines reduces the intensity by a factor of 2, meaning that the total intensity of light out of the analyzer is given as $\frac{3}{4}\left(\frac{1}{2}I_o\right) = \frac{3}{8}I_0$.

44. A… The adiabatic processes have no heat exchanged with the surroundings. Of the remaining processes, consider the First Law of Thermodynamics $\Delta U = Q + W$ with the ideal gas equation and that the internal energy of the gas depends on temperature only.



Method 1: For process (C), since the volume is constant in doubling the temperature, one can write $Q_C = nc_v\Delta T = (1)\left(\frac{3}{2}R\right)(T) = \frac{3}{2}RT$.

For process (A), one can write $Q_A = nc_p\Delta T = (1)\left(\frac{5}{2}R\right)(T) = \frac{5}{2}RT$. Lastly, for the isothermal process, there is no change in the internal energy, so the heat is completed related to the work done on the gas. Since the work done is LESS during this process compared to that in process (A) (consider the area under the curve), the heat added is less.

Method 2: The internal energy change of the gases are

$\Delta U = \frac{3}{2}nR\Delta T \rightarrow \Delta U_A = \Delta U_C = \frac{3}{2}RT$; $\Delta U_E = 0$. From the First Law, since $W = -P\Delta V$ is larger for process A than process C, there is more heat for A from $\Delta U = Q + W$. In addition, with more work done in process A than process E, the heat for E is much less than that of process A.

45. E… Relativistic kinetic energy is $(\gamma - 1)m_o c^2$ where $\gamma = 1\Big/\sqrt{1-\left(v/c\right)^2}$. Computing the ratio gives

$$\frac{KE_2}{KE_1} = \frac{\gamma_2 - 1}{\gamma_1 - 1} = \frac{1\Big/\sqrt{1-.6^2} - 1}{1\Big/\sqrt{1-.3^2} - 1} = \frac{0.25}{0.048} = 5.18\,.$$

46. B… For a traveling wave, the general form is $y(x,t) = A\sin(kx - \omega t)$ so that the period of the wave is found as $T = \frac{2\pi}{\omega} = \frac{2\pi}{5} = 1.26\,s$.

47. C... The expression for radioactive decay is $N = N_0 e^{-\lambda t}$. This yields an expression for λ as $1/2 = e^{-\lambda(2)} \Rightarrow \lambda = -\frac{1}{2}\ln\left(1/2\right)$. Therefore, to find the time for 1/3 of the sample to remain, we have $1/3 = e^{-\lambda t} \Rightarrow t = -\frac{1}{\lambda}\ln\left(1/3\right) = 2\left(\ln\left(1/3\right)\Big/\ln\left(1/2\right)\right) = 3.2\ yr$.

48. C… The initial potential energy of the mass-spring system will be transformed entirely into thermal energy (and sound, etc.) from the friction. Hence, the condition we seek is to find the coefficient of friction which returns the mass back to equilibrium with no speed. That is,

$\frac{1}{2}kx^2 = \mu nx = \mu(Mg)x \Rightarrow \mu_{\min} = \frac{kx}{2Mg}$

49. B… Inductors have a voltage related to change… as driving frequency increases, the inductor reacts more strongly. Hence, the circuit is said to be more inductive. From AC circuit theory, a higher frequency increases the inductive reactance and makes the phase angle more positive. As the reactance increases, the impedance must be increasing as the current decreases, and the current decreases, so does the power associated with the resistor (and hence the source).

50. E… Since the field is directed into the plane and is decreasing, there is an induced electric field oriented clockwise in space from the solenoid. The switch is open in the circuit, so there is no current in the branch of the circuit with the battery once equilibrium is established. Considering the loop around the solenoid with the three resistors in a clockwise manner, one has

$\xi - IR - IR - IR = 0 \Rightarrow IR = \xi/3$. In looking at a loop around the circuit with the battery, the bulb down the middle branch, and the switch, one has

$\xi + \Delta V_R + \Delta V_S = 0 \rightarrow \xi + \xi/3 + \Delta V_S = 0 \Rightarrow \Delta V_S = \frac{4}{3}\xi$. We have a $+\xi/3$ from the resistor since we cross the resistor against the direction of the current through it.