2009 Physics Bowl Solutions

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

1. **D…** Converting units… $\frac{100\,yr}{1}\times\frac{365\,dy}{1\,yr}\times\frac{24\,hr}{1\,dy}\times\frac{60\min}{1\,hr}\times\frac{60\,s}{1\min}=3.15\times10^9\ s\ \sim 10^9\ s$

2. **B…** Converting units… $\frac{25\,m^2}{1}\times\frac{100\,cm}{1\,m}\times\frac{100\,cm}{1\,m}=250000\,cm^2$

3. **A…** From Newton, we have $F_{net}=ma$. The MKS units of mass are kg with m/s^2 as the MKS unit of acceleration. Putting them together gives us that the unit of force can be written as $\frac{kg\cdot m}{s^2}$.

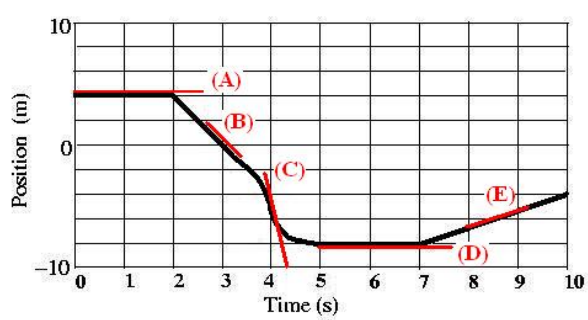
4. **C…** In a measurement, all non-zero values are significant, as well as any zeroes at the *end* of a measurement *after* the decimal. Therefore, the significant digits are bolded: 0.0**1230**

5. **D…** Kinetic energy is computed as $\frac{1}{2}mv^2=\frac{1}{2}(0.5\,kg)(4.0\,m/s)^2=4.0\ J$

6. **D…** Antinodes are separated by a distance of one-half of a wavelength. Hence, the wavelength is $\lambda=40\,cm$ here. For waves on a string, we compute $v=f\lambda\Rightarrow f=v/\lambda=\frac{1200\,cm/s}{40\,cm}=30\,Hz$

7. **B…** The resistors in the circuit are connected in parallel. Hence,
$$\frac{1}{R_{eq}}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}=\frac{1}{4.00\Omega}+\frac{1}{3.00\Omega}+\frac{1}{2.00\Omega}=1.08\frac{1}{\Omega}\Rightarrow R_{eq}=\frac{1}{1.08}\Omega=0.923\Omega$$

8. **C…** The speed of the object is greatest when the slope of the line tangent to the position vs. time graph has the greatest slope. This occurs at time $t=4.0\,s$. The graph shows tangent lines at the points of interest in the answers.



9. **A…** For the trajectory shown, the velocity is tangent to the path while the acceleration in the problem is that due to gravity (straight downward).

10. **E…** Using the conservation of linear momentum for the collision, we write $\vec{p}_{init}=\vec{p}_{final}\Rightarrow m_1\vec{v}_{1i}+m_2\vec{v}_{2i}=m_1\vec{v}_{1f}+m_2\vec{v}_{2f}$ where we identify $m_1=M$,

$m_2 = m_{truck} = X$ and call "to the West" as the positive direction. This gives

$M(-4V) + X(3V) = M(2V) + X(2V) \quad \rightarrow \quad 6MV = XV \quad \Rightarrow \quad X = 6M$

11. B… During a lunar eclipse, sunlight is blocked from the Moon by the Earth. Hence, the Earth is between the Sun and the Moon.

12. D… The gravitational force on the sphere by the Earth is $mg = (5.0\,kg)\left(10\,{}^{m}\!/_{s^2}\right) = 50\,N$. By Newton's Third Law, this is the magnitude of the gravitational force exerted on the Earth by the sphere.

13. E… Using constant acceleration kinematics, we write

$v^2 = v_0^2 + 2a\Delta x \rightarrow a = \dfrac{v^2 - v_0^2}{2\Delta x} = \dfrac{\left(2.5\,{}^{m}\!/_{s}\right)^2 - \left(5.0\,{}^{m}\!/_{s}\right)^2}{2(10\,m)} = -0.9375\,{}^{m}\!/_{s^2}$. The question asked for the magnitude (positive value) of the acceleration.

14. B… Work is done on the box for any displacement parallel to the direction of the applied force. Hence, since the force is applied to the left as it moves 8.0 meters to the left, then the work is positive (leftward force and leftward displacement) and has value $W = Fd_{\parallel} = (240\,N)(8.0\,m) = 1920\,J$

15. C… Using the ideal gas equation, we write $PV = nRT$ recognizing that $R = 0.0821\dfrac{L \cdot atm}{mol \cdot K}$ (see constants sheet) to utilize the pressure given in atmospheres and volume in liters. Also, the temperature must be in Kelvin. This leads to $n = \dfrac{PV}{RT} = \dfrac{(2.5\,atm)(6\,L)}{\left(0.0821\dfrac{L \cdot atm}{mol \cdot K}\right)(373\,K)} = 0.49\,mol$.

16. A… The expression $\Delta x = v_0 t + \frac{1}{2}at^2$ is only applicable when the linear acceleration is constant.

$\Delta\theta = \omega_0 t + \frac{1}{2}\alpha t^2$ is only applicable when the angular acceleration is constant.

17. D… Average speed is computed as distance divided by time. The total distance traveled is 3.0 meters for the first part and then an additional $\Delta x = v_0 t = \left(9\,{}^{m}\!/_{s}\right)(2\,s) = 18\,m$ for a total of $3 + 18 = 21\,m$.

Hence, the average speed is ${}^{21m}\!/_{3s} = 7.0\,{}^{m}\!/_{s}$.

18. E… The magnetic field associated with the current in the wire is directed out of the plane of the page at the location of the electron (Right-hand rule… right thumb along current, fingers wrap in the sense of the field). Using the right hand rule for the force on a charged particle in a field… right fingers point to the left (velocity), the fingers are curled toward the field (out of paper) and the right thumb points toward the top of the paper… except that since the charge is negative (electron), the hand is flipped 180 degrees giving the final direction of the force to be toward the bottom of the page.

19. B… Energy transfer from the bulk motion of a fluid is best related to the term convection.

20. C… This is a 2-D constant acceleration kinematics problem. Horizontally, there is no acceleration, so one has $\Delta x = v_{0x}t + \frac{1}{2}a_x t^2 \rightarrow (120\,m) = v_{0x}(4.0\,s) \Rightarrow v_{0x} = 30\,{}^{m}\!/_{s}$. By symmetry, the vertical component of the velocity is instantaneously zero halfway through the trip. Hence,

$v_y = v_{0y} + a_y t \rightarrow 0 = v_{0y} + \left(-10\,{}^{m}\!/_{s^2}\right)(2\,s) \Rightarrow v_{0y} = 20\,{}^{m}\!/_{s}$. Using the Pythagorean Theorem to find the total initial speed yields $v_0 = \sqrt{v_{0x}^2 + v_{0y}^2} = \sqrt{\left(30\,{}^{m}\!/_{s}\right)^2 + \left(20\,{}^{m}\!/_{s}\right)^2} = 36.1\,{}^{m}\!/_{s}$

21. C… Since the object didn't change its motion, it has an acceleration of zero. With only the applied force and friction acting on the mass horizontally, these forces must have equal size by $F_{net} = ma = 0$. The friction force is therefore $60\,N$.

22. D… The period of a simple pendulum is computed as $T = 2\pi\sqrt{\frac{L}{g}}$. By shortening the length of the string to $\frac{1}{4}L$, the period is now ½ as large because of the square root. The new period is $\frac{T}{2}$

23. C… Protons are confined to the nuclei of the atoms and are not mobile, so the charging is done via electron transfer. That the comb becomes negative means that electrons were accepted by the comb from the hair.

24. B… The kinetic energy of the mass is $KE = \frac{1}{2}mv^2 = 128 \rightarrow mv^2 = 256$. The net force acting on the object is found from Newton's Second Law as $F_{net} = \frac{mv^2}{r} = \frac{256}{8} = 32\,N$ since the acceleration is toward the center of circle and has magnitude $\frac{v^2}{r}$.

25. E… The momentum of a photon is directly related to the energy of the photon… the more energetic the photon, the more momentum it has. Of those listed, the gamma ray is the most energetic.

26. D… By adding the shorting wire, bulb 4 is now bypassed. This reduces the overall resistance of the circuit (check it: before short: $\frac{5}{3}R$, after short: $\frac{3}{2}R$). By decreasing the resistance, the current in the circuit increases. Using Ohm's Law, bulb 1 now has more current and therefore there is a larger power associated with it $\left(P = I^2R\right)$ and it burns more brightly. Bulb #2, however, dim using Kirchhoff's Loop Rule… the battery voltage is unchanged while bulb #1 has a larger voltage… meaning that the voltage across bulb 2 must decrease and it therefore is dimmer $\left(P = \frac{V^2}{R}\right)$. Finally, since there is a bit more current in the circuit and the branch with bulb 3 has a greatly reduced resistance… more of the current will be directed this way, thereby brightening bulb 3.

27. C… By the right-hand rule, there is a magnetic force on the proton directed into the plane. (Fingers point up the page, curl them to the right… thumb points inward). Since the proton is undeflected, there must be an electric force of equal size directed out of the plane of the page. Using $\vec{F} = q\vec{E}$, the direction of the force on the proton and the field that it is in must be in the same direction since the charge is positive. Hence, there is a component of electric field directed out of the page.

28. E… The ideal yellow pigment is reflecting the red and green light. Cyan is produced with green and blue filters. Consequently, when this light shines on the yellow pigment, the green light is reflected and the blue light is absorbed. The pigment appears green.

29. B… To transition to the $-12eV$ state with only two photon emissions, the only options are for the electron to make the following transitions: $-1eV \rightarrow -3eV \rightarrow -12eV$ giving us photons of energy $2eV$ and $9eV$ or $-1eV \rightarrow -7eV \rightarrow -12eV$ giving photons of energy $6eV$ and $5eV$. This means that the $4\ eV$ photon is not possible with only two transitions.

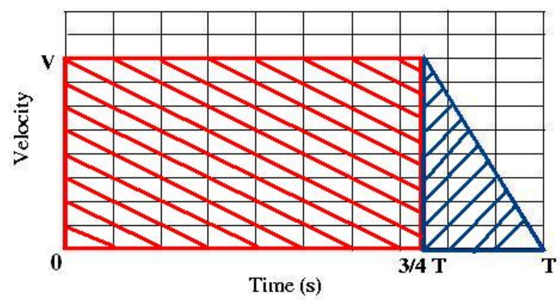
30. A… The most straight-forward approach is to use that the expression for power from a resistor in the form $R = \frac{P}{I^2}$ which yields units of $\frac{W}{A^2} = \frac{J/s}{A^2} = \frac{N \cdot m}{A^2 \cdot s} = \frac{\frac{kg \cdot m}{s^2}m}{A^2 \cdot s} = \frac{kg \cdot m^2}{A^2 \cdot s^3}$. Note that the base MKS unit is the Ampere and not the Coulomb.

31. A… There are a couple of options for solving this problem…

Method 1: Writing the constant acceleration kinematics expressions for each leg of the trip yields $\Delta x_1 = v_0 t + \frac{1}{2}a_1 t^2 \Rightarrow \Delta x_1 = V\left(\frac{3}{4}T\right)$. For the second leg, we have $\Delta x_2 = v_{02} t + \frac{1}{2}a_2 t^2 \Rightarrow \Delta x_1 = V\left(\frac{1}{4}T\right) + \frac{1}{2}\left(\frac{-V}{\frac{1}{4}T}\right)\left(\frac{T}{4}\right)^2 = \frac{1}{8}VT$ where the acceleration was computed during the interval as $a = \frac{\Delta v}{\Delta t} = \frac{0 - V}{\frac{1}{4}T}$. Putting this information together gives the ratio of the distances traveled as $\frac{\Delta x_1}{\Delta x_2} = \frac{\frac{3}{4}VT}{\frac{1}{8}VT} = \frac{24}{4} = \frac{6}{1}$.

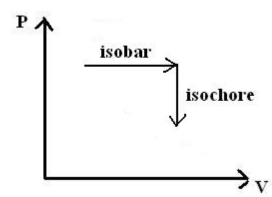
Method 2: Graph the motion as velocity vs. time. The area under the curve will give the change in position… and since this is purely a 1D problem, the size of the displacement is the distance traveled. So, the problem reduces to the ratio of the area of a rectangle to that of a triangle. That is,

$$\frac{\Delta x_1}{\Delta x_2} = \frac{LW}{\frac{1}{2}bh} = \frac{\left(\frac{3}{4}T\right)(V)}{\frac{1}{2}\left(\frac{1}{4}T\right)(V)} = \frac{24}{4} = \frac{6}{1}$$



32. E… By placing the cube in water and drawing the free body diagram, we have only a gravitational force and buoyancy. Equating these gives $\rho_{water} g V_{displace} = \rho_{cube} V_{cube} g \rightarrow \frac{V_{displace}}{V_{cube}} = \frac{\rho_{cube}}{\rho_{water}} = 0.60$. So, the density of the cube is found to be $600 \, kg/m^3$. Using this same logic for the cube in the oil, we find $\frac{V_{displace}}{V_{cube}} = \frac{\rho_{cube}}{\rho_{oil}} = \frac{600}{800} = 0.75$. 75% of the cube is submerged in the oil.

33. A… The PV diagram shows qualitatively what the processes of interest look like. Since the first process is constant pressure, the constant volume cooling reduces the pressure from the initial value, making (A) true. The volume clearly increases, making (B) wrong. The temperature could end up greater, less than, or the same as it started depending on the exact nature of the processes. The same is true of the total heat associated with the processes. Finally, the internal energy is not changed ONLY if the initial and final temperatures are exactly the same.



34. E… Looking at the light Medium 2, we use Snell's Law to see that the index of refraction is greater in Medium 2 than in either Medium 3 or 1. Since the light bends so severely away from the normal in Medium 3, the index is much lower than it is in Medium 1. So, $n_3 < n_1 < n_2$. The speed of light in these media is therefore expressed as $v_2 < v_1 < v_3$ since $v = c/n$. This also means that the wavelengths are ordered as $\lambda_2 < \lambda_1 < \lambda_3$ as the frequency of the light is the same in all of the media.

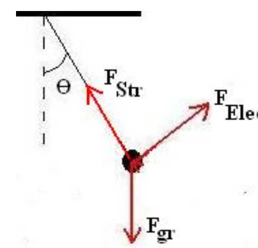
35. A… The continuity equation is needed as the total fluid moving through Region I must equal the fluid through Region II. Hence, we have $A_I v_I = A_{II} v_{II}$. Since the area in region I is **4** times the area in region II (double the radius… area is πr^2), then the fluid speed is greater in region II by a factor of 4.

36. D… Using Kirchhoff's Loop Rule for the circuit, we have

$$\Delta V_B + \Delta V_C + \Delta V_R = 0 \rightarrow (+12v) + \Delta V_C + (-IR) = 0 \ \rightarrow \Delta V_C = (-12v) + (0.5A)(10\Omega) = -7v$$

The potential difference across the capacitor is -7 volts giving the size of the voltage as 7 volts.

37. A… Conventional current in the left-hand circuit is directed clockwise. By a right-hand rule, the magnetic field interior to the loop with current is therefore INTO the page. Since magnetic field lines form closed loops, outside the current-carrying loop, the field has a component directed OUT of the plane of the page. Since the resistance in the left-hand circuit is increasing, there is a decrease in the current and hence a decrease in the magnetic field strength. By Lenz's Law in the right-hand circuit, there is an induced current in the wires to generate a field directed out of the plane of the page. This means that there is a counterclockwise current in the wire and the current is from B to A through the resistor in the diagram.



38. B… There are 3 forces acting on the mass… a gravitational force, the force from the string, and an electric force (see the FBD to the right). Using Newton's Second Law in equilibrium, we have $\vec{F}_{gr} + \vec{F}_{Str} + \vec{F}_{Elec} = 0 \Rightarrow \vec{F}_{gr} + \vec{F}_{Elec} = -\vec{F}_{Str}$. That is, the sum of the gravitational and electric forces is equal and opposite to the force from the string. By removing the string, there is therefore a net force directed oppositely to the string force. This gives the direction of the constant acceleration acting on the object and since it starts from rest, the mass will move in a straight line.

39. D… Efficiency can be computed as "what you get" divided by "what you paid for". Here, we got the mass to rise to the top of the incline. We paid for it by applying a force over some distance and putting work into the system. Writing this mathematically, we have

$$e = \frac{W_{out}}{W_{in}} = \frac{(mg)d}{F\ \ h} = \frac{mg}{F}\sin 30^\circ = \frac{(10\,kg)(10\,m/s^2)}{75\,N}\sin 30^\circ = \frac{4}{3}\cdot\frac{1}{2} = \frac{2}{3}.$$

Note, we took the height of the incline to be d and the hypotenuse (how far we applied a force) as h leading to $\sin 30^\circ = \frac{d}{h}$.

40. C… Conservation of mechanical energy can be employed here. This gives $\Delta KE + \Delta PE = 0$ and we note that we have two forms of kinetic energy (translational and rotational). Incorporating both, we write $\Delta KE_{tr} + \Delta KE_{rot} + \Delta PE = 0 \rightarrow \left(\frac{1}{2}mv_f^2 - 0\right) + \left(\frac{1}{2}I\omega_f^2 - 0\right) + \left(0 - \frac{1}{2}kx_i^2\right) = 0$. Noting from the equation sheet that $I_{cyl} = \frac{1}{2}MR^2$, we can write, using $v = r\omega$, that

$$\tfrac{1}{2}mv_f^2 + \tfrac{1}{2}\left(\tfrac{1}{2}MR^2\right)\omega^2 = \tfrac{1}{2}kx_i^2 \ \rightarrow \ mv^2 + \tfrac{1}{2}mv^2 = kx_i^2 \Rightarrow v_{cm} = \sqrt{\tfrac{4}{3}\tfrac{k}{m}}\ x_i = 1.15\,m/s$$

41. E… This is a question of time constant. The circuit with the smallest time constant will charge to 90% the fastest. The time constants are RC, RC, 2RC, RC, and ½ RC for the circuits given.

42. D… When the objects come together, there is conservation of angular momentum (no net external torque). Hence, we write $L_i = L_f \Rightarrow I_1\omega_0 = (I_1 + I_2)\omega$ where $I = \frac{1}{2}mr^2$ leading to

$$\omega = \left(\frac{I_1}{I_1 + I_2}\right)\omega_0 = \left(\frac{\tfrac{1}{2}MR^2}{\tfrac{1}{2}MR^2 + \tfrac{1}{2}(2M)\left(\tfrac{R}{2}\right)^2}\right)\omega_0 = \left(\frac{\tfrac{1}{2}}{\tfrac{3}{4}}\right)\omega_0 = \left(\frac{2}{3}\right)\omega_0$$

43. **B…** Because the object is placed outside the focus of the lens, the image formed will be real for this real object. The magnification, though, is unknown. If the object is placed between the center of curvature and the focus, then the image is larger. If the object is located at the center of curvature, then the image is the same size as the object. Finally, placing the object outside of the center of curvature results in a minified image.
44. **C…** The LC circuit has charge oscillate as a simple harmonic oscillator. Consequently, it is ¼ of a period for energy to switch from the inductor to the capacitor.
45. **A…** It was Pauli who conjectured the existence of the neutrino (Fermi later worked out the theory of beta decay and named the particle).
46. **D…** In order for the 6 electric fields to completely cancel, one can draw a unit circle $(2\pi\, rad)$and divide it equally into 6 pieces. Doing so gives an angle of $\pi/3$ for each piece. This is the phase difference for each of the fields so that when added together (in a phasor diagram), the total field will be zero. Consider that $\cos(0\pi/3)+\cos(\pi/3)+\cos(2\pi/3)+\cos(3\pi/3)+\cos(4\pi/3)+\cos(5\pi/3)=0$.
47. **E…** The time-changing electric field induces a magnetic field. Since the electric field is out of the page and increasing in time, then by the right-hand rule, the time-changing field acts like a current (a displacement current) and the magnetic field associated with a current out of the plane of the page is directed in a counterclockwise manner around the circular region. At the location of the proton, there is a magnetic force therefore directed into the page (fingers point to the right, curl down the page, the right thumb point into the page).
48. **B…** A traveling wave has the form $f(kr \pm \omega t)$ where the direction of wave travel would be $\mp r$. For the field given, this means that the wave is traveling in the $+x$ direction.
49. **C…** The direction of energy flow is computed by the Poynting Vector which is related to the cross product of the electric and magnetic fields. At the origin at time $t = 0$, the electric field has value $6.0\,\hat{z}$. We must therefore solve the problem $\hat{x} = \hat{z} \times ??$. The magnetic field is perpendicular to the electric field and from the rules of cross products, $\hat{z} \times (-\hat{y}) = \hat{x}$. The magnetic field is directed along $-y$.
50. **D...** Using classical physics, we compute

$KE = \frac{1}{2}mv^2 \Rightarrow 3.20\times10^{-13} = \frac{1}{2}(9.1\times10^{-31})v^2 \Rightarrow v = 8.4\times10^{8}\ m/s = 2.8c$ That is**,** the electron is moving at 2.8 times the speed of light!!! Conclusion… we need relativistic physics to answer this question. So, we approach it as either...

Method #1: $KE = (\gamma - 1)m_o c^2 \rightarrow 3.2\times10^{-13} = (\gamma-1)(9.1\times10^{-31})(3\times10^{8})^2$ Solving for $\gamma = \dfrac{1}{\sqrt{1-\beta^2}}$ yields $\gamma - 1 = 3.907 \rightarrow \gamma = \dfrac{1}{\sqrt{1-\beta^2}} = 4.907 \rightarrow 24.08(1-\beta^2) = 1 \rightarrow \beta = 0.979$.

$\beta = v/c$ so we can finally write $p = \gamma m_0 v = (4.907)(9.1\times10^{-31})(.979c) = 1.3\times10^{-21}\ kg\ m/s$.

Method #2: Using Einstein's equation for energy, we can write

$E^2 = (\gamma m_0 c^2)^2 = (KE + m_o c^2)^2 = p^2c^2 + m_o^2 c^4 \rightarrow KE^2 + 2(KE)(m_0 c^2) + m_0^2 c^4 = p^2c^2 + m_0^2c^4$.

Simplifying this expression gives us

$$p = \frac{KE}{c}\sqrt{1 + 2\left(\frac{m_0 c^2}{KE}\right)} \rightarrow p = \left(\frac{3.2\times10^{-13}}{3\times10^{8}}\right)\sqrt{1 + \frac{2(9.1\times10^{-31})(3\times10^{8})^2}{3.2\times10^{-13}}} = 1.3\times10^{-21}\ kg\ m/s$$