Chapter 11 Solutions to Chapter Review Questions

CHAPTER 3: THERMODYNAMICS REVIEW QUESTIONS

Section I: Multiple Choice

1. **B** Because the average kinetic energy of a molecule of gas is directly proportional to the temperature of the sample, the fact that the gases are at the same temperature—since they're in the same container at thermal equilibrium—tells you that the molecules have the same average kinetic energy. The ratio of their kinetic energies is therefore equal to 1.

2. **A** P–V diagrams have pressure on the vertical axis and volume on the horizontal axis. You know volume is changing, so the graph will have to show a change in the horizontal axis, so you can eliminate (B). Then, from the Ideal Gas Law, $PV = nRT$, you see that pressure is unchanged if the volume and temperature are both doubled. The vertical value of the P–V diagram remains constant, resulting in a horizontal line on the graph.

3. **A** The work done on the gas during a thermodynamic process is equal to the area of the region in the P–V diagram above the V-axis and below the path the system takes from its initial state to its final state. Since the area below path 1 is the greatest, the work done on the gas during the transformation along path 1 is the greatest.

4. **C** During an isothermal change, ΔU is always zero.

5. **B** There is no way to measure a pressure of 0 Pa, so you can eliminate (A) and (C) as answers. The Ideal Gas Law states $PV = nRT$, so a graph of P versus n will be linear when V and T are both held constant, so you can eliminate (D).

6. **D** In order for the temperature of the gas to remain constant, the added energy from the additional gas needs to be removed. One way to do this is to have heat leave the system. By the Ideal Gas Law, a decrease in pressure would not match with an increase in the amount, n, so (A) is eliminated. Since the volume of the gas is constant in this experiment, no work can be done, so (B) and (C) are eliminated.

7. **A** By convention, work done *on* the gas sample is designated as positive, so in the First Law of Thermodynamics, $\Delta U = Q + W$, you must write $W = +320$ J. Therefore, $Q = \Delta U - W = 560\text{ J} - 320\text{ J} = +240$ J. Positive Q denotes heat *in*.

8. **C** No work is done during the step from state a to state b because the volume doesn't change. Therefore, the work done from a to c is equal to the work done from b to c. Since the pressure remains constant (this step is isobaric), find that

$$W = -P\Delta V = -(3.0 \times 10^5\text{ Pa})[(10 - 25) \times 10^{-3}\text{ m}^3] = 4500\text{ J}$$

9. **C** Choice (A) is wrong because *no heat is exchanged between the gas and its surroundings* is the definition of *adiabatic*, not *isothermal*. Choice (B) cannot be correct since the step described in the question is isothermal; by definition, the temperature does not change. This also eliminates (D) and supports (C). If the sample could be brought back to its initial state *and* have a 100% conversion of heat to work, *that* would violate the Second Law of Thermodynamics, which states that heat cannot be completely converted to work with no other change taking place. In this case, there are changes taking place: the pressure decreases and the volume increases.

10. **C** The Second Law of Thermodynamics indicates that energy will flow from a hot object to a cool object, making the final temperature of the hot object cooler and the cold object warmer.

Section II: Free Response

1. A. First, calculate ΔU_{acb}. Using path *acb*, the question tells you that $Q = +70$ J and $W = -30$ J (W is negative here because it is the *system* that does the work). The first law, $\Delta U = Q + W$, tells you that $\Delta U_{acb} = +40$ J. Because $\Delta U_{a \to b}$ does not depend on the path taken from *a* to *b*, you must have $\Delta U_{ab} = +40$ J, and $\Delta U_{ba} = -\Delta U_{ab} = -40$ J. Thus, $-40 \text{ J} = Q_{ba} + W_{ba}$, where Q_{ba} and W_{ba} are the values along the curved path from *b* to *a*. Since $Q_{ba} = -60$ J, it follows that $W_{ba} = +20$ J. Therefore, the surroundings do 20 J of work on the system.

   B. Again, using the fact that $\Delta U_{a \to b}$ does not depend on the path taken from *a* to *b*, you know that $\Delta U_{adb} = +40$ J, as computed above. Writing $\Delta U_{adb} = QW_{adb} + W_{adb}$, if $W_{adb} = -10$ J, it follows that $Q_{adb} = +50$ J. That is, the system absorbs 50 J of heat.

   C. For the process *db*, there is no change in volume, so $W_{db} = 0$. Therefore, $\Delta U_{db} = Q_{db} + W_{db} = Q_{db}$. Now, since $U_{ab} = +40$ J, the fact that $U_a = 0$ J implies that $U_b = 40$ J, so $\Delta U_{db} = U_b - U_d = 40 \text{ J} - 30 \text{ J} = 10$ J. Thus, $Q_{db} = 10$ J. Now, let's consider the process *ad*. Since $W_{adb} = W_{ad} + W_{db} = W_{ad} + 0 = W_{ad}$, the fact that $W_{adb} = -10$ J [computed in part (b)] tells you that $W_{ad} = -10$ J. Because $\Delta U_{ad} = U_d - U_a = 30$ J, it follows from $\Delta U_{ad} = Q_{ad} + W_{ad}$ that $Q_{ad} = \Delta U_{ad} - W_{ad} = 30 \text{ J} - (-10 \text{ J}) = 40$ J.

   D. The process *adbca* is cyclic, so ΔU is zero. Because this cyclic process is traversed *counterclockwise* in the P–V diagram, you know that W is *positive*. Then, since $\Delta U = Q + W$, it follows that Q must be negative.

2. A. i. Use the Ideal Gas Law:

$$T_a = \frac{P_a V_a}{nR} = \frac{(2.4 \times 10^5 \text{ Pa})(12 \times 10^{-3} \text{ m}^3)}{(0.4 \text{ mol})(8.31 \text{ J/mol} \cdot \text{K})} = 870 \text{ K}$$

   ii. Since state *b* is on the isotherm with state *a*, the temperature of state *b* must also be 870 K.

   iii. Use the Ideal Gas Law:

$$T_c = \frac{P_c V_c}{nR} = \frac{(0.6 \times 10^5 \text{ Pa})(12 \times 10^{-3} \text{ m}^3)}{(0.4 \text{ mol})(8.31 \text{ J/mol} \cdot \text{K})} = 220 \text{ K}$$

B. There is heat flow into the system during step *ab*. As the volume expands, the system does work on the surroundings (uses up some of its internal energy). As a result, the system would drop in temperature if no heat flowed into the gas to make up for this use of energy. During an isothermal process, $\Delta T = 0$ K, so the change in internal energy of the gas, $\Delta U = \frac{3}{2} Nk_b\Delta T$, is zero. From the First Law of Thermodynamics, $\Delta U = W + Q$, any energy that is used by expanding (work done by the system on the surroundings) must be replaced by heat flowing into the system.

C. Using the equation given, find that

$$W_{ab} = -nRT \cdot \ln \frac{V_b}{V_a} = -(0.4 \text{ mol})(8.31 \text{ J/mol} \cdot \text{K})(870 \text{ K}) \cdot \ln \frac{48 \times 10^{-3} \text{ m}^3}{12 \times 10^{-3} \text{ m}^3}$$
$$= -4000 \text{ J}$$

D. The total work done over the cycle is equal to the sum of the values of the work done over each step:

$$\begin{aligned} W_{\text{cycle}} &= W_{ab} + W_{bc} + W_{ca} \\ &= W_{ab} + W_{bc} \\ &= (-4000 \text{ J}) + (2200 \text{ J}) \\ &= -1800 \text{ J} \end{aligned}$$

CHAPTER 4: ELECTRIC FORCES AND FIELDS REVIEW QUESTIONS

Section I: Multiple Choice

1. **D** Electrostatic force obeys an inverse-square law: $F_E \propto 1/r^2$. Therefore, a plot should be made of F versus the inverse square of r to get a line.

2. **C** The strength of the electric force is given by kq^2/r^2, and the strength of the gravitational force is Gm^2/r^2. Since both of these quantities have r^2 in the denominator, you simply need to compare the numerical values of kq^2 and Gm^2. There's no contest. Since

$$kq^2 = (9 \times 10^9 \text{ N·m}^2/\text{C}^2)(1 \text{ C})^2 = 9 \times 10^9 \text{ N·m}^2$$

and

$$Gm^2 = (6.7 \times 10^{-11} \text{ N·m}^2/\text{kg}^2)(1 \text{ kg})^2 = 6.7 \times 10^{-11} \text{ N·m}^2$$

you can see that $kq^2 >> Gm^2$, so F_E is much stronger than F_G.

3. **C** If the net electric force on the center charge is zero, the electrical repulsion by the $+2q$ charge must balance the electrical repulsion by the $+3q$ charge:

$$\frac{1}{4\pi\varepsilon_0}\frac{(2q)(q)}{x^2}=\frac{1}{4\pi\varepsilon_0}\frac{(3q)(q)}{y^2} \Rightarrow \frac{2}{x^2}=\frac{3}{y^2} \Rightarrow \frac{y^2}{x^2}=\frac{3}{2} \Rightarrow \frac{y}{x}=\sqrt{\frac{3}{2}}$$

4. **D** Since P is equidistant from the two charges, and the magnitudes of the charges are identical, the strength of the electric field at P due to $+Q$ is the same as the strength of the electric field at P due to $-Q$. The electric field vector at P due to $+Q$ points away from $+Q$, and the electric field vector at P due to $-Q$ points toward $-Q$. Since these vectors point in the same direction, the net electric field at P is (E to the right) + (E to the right) = ($2E$ to the right).

5. **C** The acceleration of the small sphere is

$$a=\frac{F_E}{m}=\frac{1}{4\pi\varepsilon_0}\frac{Qq}{mr^2}$$

As r increases (that is, as the small sphere is pushed away), a decreases. However, since a is always positive, the small sphere's speed, v, is always increasing.

6. **B** Since $\mathbf{F}_E$ (on q) = $q\mathbf{E}$, it must be true that $\mathbf{F}_E$ (on $-2q$) = $-2q\mathbf{E} = -2\mathbf{F}_E$.

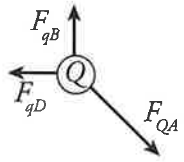
7. **C** All excess electric charge on a conductor resides on the outer surface.

Section II: Free Response

1. A. i. The force from the charge at A will be repulsive and must act at a 45° angle because the force acts along the bisector of the square. The balancing forces from the charges q will be at right angles to one another, and so each must balance a component of the force from Q alone. Since sin(45°) = cos(45°), the forces from each q must be equal, and therefore the charges must also be equal.

ii. In order for the force on C to be 0, the repulsive force from charge A must be balanced by an attractive force from each q, so the charges at positions B and D must have a negative sign.

A free body diagram of the charge at point C is drawn below.



The distance between opposite vertices of a square of side length s is $s\sqrt{2}$. You can look at either the x- or y-components because the equations each direction yields are identical. From the x direction, $F_{QA}\sin(45°) = F_{qD}$. Therefore, $F_{qD} = k\dfrac{Q^2}{(s\sqrt{2})^2} \times \dfrac{\sqrt{2}}{2}$.

$$F_{qD} = k\frac{\sqrt{2}Q^2}{4s^2}$$

Now that you know the force from the charge at D, use Coulomb's Law to determine q.

$$F_{qD} = k\frac{Qq}{s^2} = k\frac{\sqrt{2}Q^2}{4s^2}$$

$$Qq = \frac{\sqrt{2}Q^2}{4}$$

$$q = \frac{\sqrt{2}Q}{4}$$

B. Within the square, the field from the charge Q at position A will point into the fourth quadrant (the x-component will be positive and the y-component will be negative). With the charges positive, within the square the field from D will point into the first quadrant (the x-component will be positive and the y-component will be positive), and from B will point into the third quadrant (the x-component will be negative and the y-component will be negative). To cancel the fields, the x-coordinate would have to be closer to point B than to point D, and the y-coordinate would have to be closer to D than to B. Some point which satisfies these two requirements will have a field of 0 N/C.

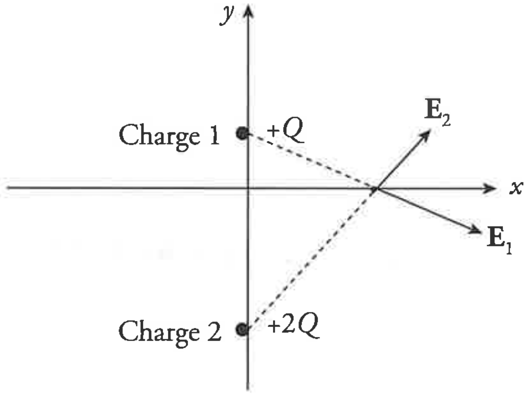
C. At the center of the square, the net electric field is the vector sum of the contributions from the four charges. The field from the charges at A and C will always balance one another as long as those charges have the same sign, regardless of that sign. First, the charges are equidistant from the center of the square, so r will be equal regardless of the sign or magnitude of the charges. If they are both positive, the field from A will be in the fourth quadrant and the field from C will be in the second quadrant. If both charges are negative, then the field from C will be in the fourth quadrant and the field from A will be in the second quadrant. Therefore, regardless of the magnitude or sign of the charges, the contributions from the charges Q will cancel one another. An identical argument can be made for the charges q showing that their fields will also cancel with one another. Therefore, the net field at the center of the square must be 0 N/C regardless of the signs or magnitudes of Q or q.

2. A. The electric force on Charge 1 is $F_1 = k\frac{Q \cdot 2Q}{(a + 2a)^2} = k\frac{2Q^2}{9a^2}$. The force between the charges is repulsive, so the charge at 1 is pushed upward.

B. $\overrightarrow{E_{net}} = \overrightarrow{E_1} + \overrightarrow{E_2} = k\frac{Q}{a^2}$ down $+ k\frac{2Q}{(2a)^2}$ up. Making upward positive results in $E_{net} = k\frac{Q}{2a^2} - k\frac{Q}{a^2} = -k\frac{Q}{a^2}$.

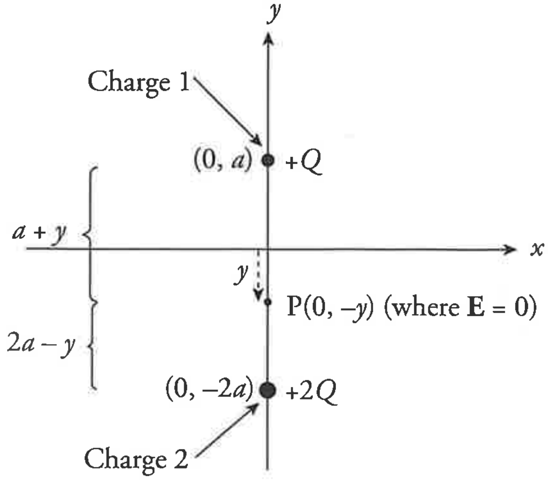
The net field is $k\frac{Q}{2a}$ in the downward direction.

C. No. The only point on the x-axis where the individual electric field vectors due to each of the two charges point in exactly opposite directions is the origin (0, 0). But at that point, the two vectors are not equal and thus do not cancel.



Therefore, at no point on the x-axis could the total electric field be zero.

D. Yes. There will be a Point P on the y-axis between the two charges,



where the electric fields due to the individual charges will cancel each other out.

$$E_1 = E_2$$

$$\frac{1}{4\pi\varepsilon_0}\frac{Q}{(a+y)^2} = \frac{1}{4\pi\varepsilon_0}\frac{2Q}{(2a-y)^2}$$

$$\frac{1}{(a+y)^2} = \frac{2}{(2a-y)^2}$$

$$(2a-y)^2 = 2(a+y)^2$$

$$0 = y^2 + 8ay - 2a^2$$

$$y = \frac{-8a \pm \sqrt{(8a)^2 - 4(-2a^2)}}{2}$$

$$= (-4 \pm 3\sqrt{2})a$$

Disregarding the value $y = (-4 - 3\sqrt{2})a$ (because it would place the point P below Charge 2 on the y-axis, where the electric field vectors do not point in opposite directions), you find that $\mathbf{E} = 0$ at the point $P = (0, -y) = (0, (4 - 3\sqrt{2})a)$.

CHAPTER 5: ELECTRIC POTENTIAL AND CAPACITANCE REVIEW QUESTIONS

Section I: Multiple Choice

1. **B** For a point particle, which a uniform sphere will behave like, the relationship between the electric potential and the distance is $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$. So, with V on the vertical axis and $\frac{1}{r}$ on the horizontal axis, a graph will be produced which is a straight line whose slope is $\frac{1}{4\pi\varepsilon_0}q$.

2. **B** Use the definition $\Delta V = -W_E/q$. If an electric field accelerates a negative charge doing positive work on it, then $W_E > 0$. If $q < 0$, then $-W_E/q$ is positive. Therefore, ΔV is positive, which implies that V increases.

3. **D** Equipotential curves for a parallel-plate capacitor are horizontal lines. Both (A) and (B) are at the same potential, so their potential difference is 0 V. As one moves closer to the $+Q$ plate, the potential will increase, so (D) is correct.

4. **D** By definition,

$$V_{A\to B} = \Delta U_E/q, \text{ so } V_B - V_A = \Delta U_E/q$$

5. **B** Because **E** is uniform, the potential varies linearly with distance from either plate ($\Delta V = Ed$). Since Points 2 and 4 are at the same distance from the plates, they lie on the same equipotential. (The equipotentials in this case are planes parallel to the capacitor plates.)

6. **B** The charge Q must be positive because the potential decreases as the distance from the charge increases. A negative charge will be attracted to a positive charge. This means that the electric field of Q would do positive work if q were brought closer, and it would do negative work if q were moved farther away.

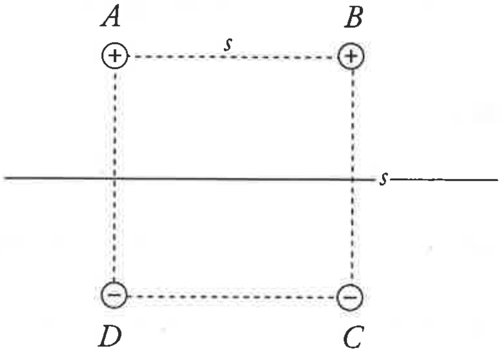
Section II: Free Response

1. A. Greatest *A* and *B* *A* *A*, *B*, and *C* All four Least

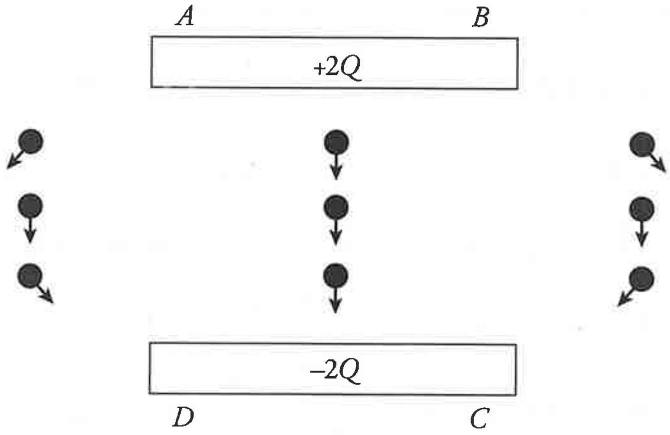
The work required to move a charge through an existing electric field can be related to the voltage of that field at the initial and final positions of the charge. All voltages are defined to be 0 when the charges are very far away from one another, so V_i is always 0 V. Charge *A* is placed first and there is no electric field that charge *A* is moved through, so the charge distribution has no energy. At location *B*, in the presence of charge *A*, there is an electric field and you can calculate the voltage at point *B* as $V_B = \frac{+kQ}{s}$. Moving the charge to point *B* adds $W = \frac{kQ^2}{s}$ to the charge distribution. At location *C*, in the presence of charges at *A* and *B*, calculate the voltage as the sum of the contributions from *A* and *B* as $V_C = \frac{kQ}{\sqrt{2}s} + \frac{kQ}{s}$. Charge *C* is negative, so putting it at position *C* removed $W = \frac{kQ^2}{s} + \frac{kQ^2}{\sqrt{2}s}$, making the energy of the distribution $-\frac{kQ^2}{\sqrt{2}s} = -\frac{\sqrt{2}kQ^2}{2s}$. Finally, the voltage at position *D* from the charges at *A*, *B*, and *C*, respectively, is $V_D = \frac{kQ}{s} + \frac{kQ}{\sqrt{2}s} - \frac{kQ}{s} = \frac{kQ}{\sqrt{2}s}$. Charge *D* is negative, so putting it at position *D* removed $W = \frac{kQ^2}{\sqrt{2}s}$ from the distribution. The energy in the distribution of all four charges is $U_E = -\frac{2kQ^2}{\sqrt{2}s} = -\frac{2\sqrt{2}kQ^2}{2s}$.

B. At the exact center of the square, this distance from each charge is *d*, where from the Pythagorean Theorem, $d^2 = \left(\frac{s}{2}\right)^2 + \left(\frac{s}{2}\right)^2$, so $d = \frac{\sqrt{2}s}{2}$. The voltage at the center is then the sum of the voltages from each charge: $V_{center} = V_A + V_B + V_C + V_D = \frac{+kQ}{d} + \frac{+kQ}{d} + \frac{-kQ}{d} + \frac{-kQ}{d} = 0\text{ V}$.

C. The equipotential will be described as always the same distance from the pair at *AD* as well as the same distance from the pair at *BD*. Thus, the equipotential line is a horizontal line through the square.



D. The electric field along the center line will be uniform because any diminishment from the influence of the top plate is counteracted by an increased influence from the lower plate. However, at a position not between the plates, this is no longer true, and so for the bottom dots, the lower plate is more influential. This causes the electric field at these locations to tend to point toward the negatively charged plate.



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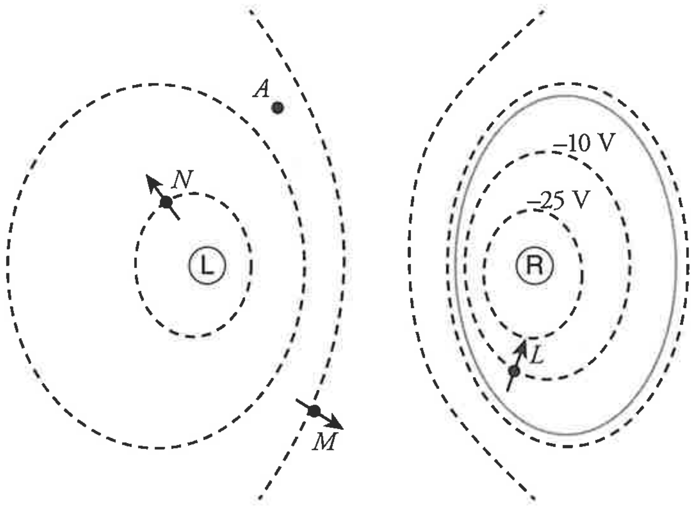


A. Because the potential difference between adjacent lines is $\Delta V = 15$ V and the potential is going from –25 V to –10 V on the two lines closest to R, the 0 V isoline must be in between the line labeled –10 V and the next line in the image. The light gray solid line is the line where the potential is 0 V.

B. 42.5 V

C. i. The potential is increasing as the isolines get farther away from R, so R must be negative and L must be positive.

ii. R carries the greater magnitude of charge, as the isolines are closer together in the neighborhood of R, which indicates a stronger magnitude of electric field.

D. i. See image above.

ii. $L > M > N$. At L, the isolines are closest together, and at N, they are farthest apart.

E. L carries positive charge, and potential is larger (relative to positions near negative charges) at positions near positive charges. Making L negatively charged would therefore make the potential at point N lower than it is when L is positive.

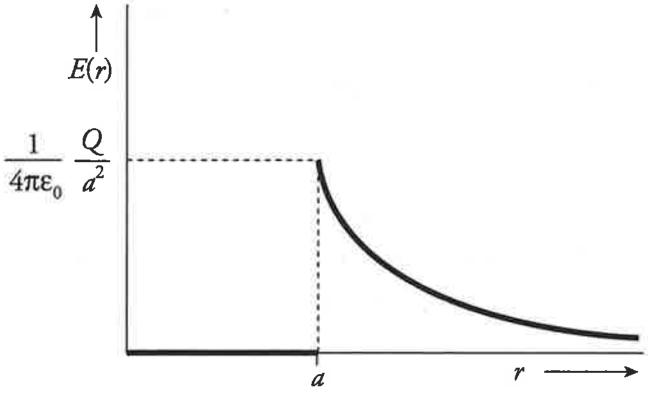
3. A. Outside the sphere, the sphere behaves as if all the charge were concentrated at the center. Inside the sphere, the electrostatic field is zero:

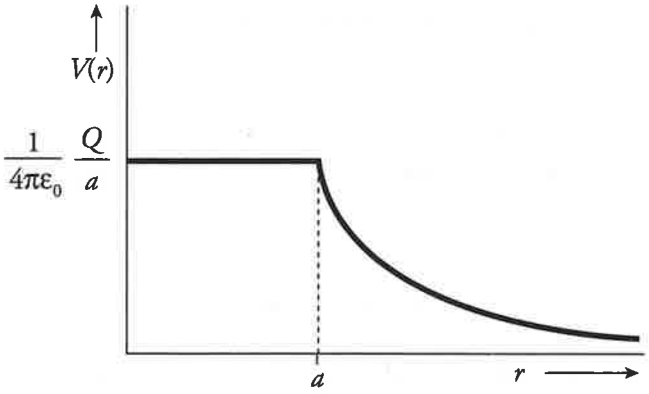
$$E(r) = \begin{cases} 0 & (r < a) \\ \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q}{r^2} & (r > a) \end{cases}$$

B. On the surface and outside the sphere, the electric potential is $\left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{Q}{r}\right)$. Within the sphere, V is constant (because $E = 0$) and equal to the value on the surface. Therefore,

$$V(r) = \begin{cases} \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q}{a} & (r \le a) \\ \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q}{r} & (r > a) \end{cases}$$

C. See diagrams:





CHAPTER 6: ELECTRIC CIRCUITS REVIEW QUESTIONS

Section I: Multiple Choice

1. **A** Let ρ_S denote the resistivity of silver and let A_S denote the cross-sectional area of the silver wire. Then

$$R_B = \frac{\rho_B L}{A_B} = \frac{(5\rho_S)L}{4^2 A_S} = \frac{5}{16}\frac{\rho_S L}{A_S} = \frac{5}{16}R_S$$

2. **C** The equation $I = V/R$ implies that increasing V by a factor of 2 will cause I to increase by a factor of 2.

3. **D** Initially the uncharged capacitor will have no voltage across it and will therefore have essentially zero resistance. This means the charge flows freely through it and all the current will flow through the path with the capacitor rather than the path with the resistor. After a long time, the capacitor will become fully charged and will not allow any more charge to add to or leave the plates, so it essentially has infinite resistance. Therefore, none of the current will flow through that path and all of the current flows through the path with the resistor.

4. **C** The resistivity ρ is found from the resistance $R = \rho L/A$. To find the resistance, Ohm's Law $V = IR$ is needed. In addition to V and L, you need to find both I and A. The ammeter will yield I, and the diameter of the wire will allow you to determine A.

5. **C** Because the voltage has been applied for a long time, the capacitor will be fully charged, so it behaves like an open switch. This puts the 4 Ω resistor and the top 3 Ω resistor in series with one another, making an equivalent resistor of 7 Ω. That combination is in parallel with the other 3 Ω resistor, so $\frac{1}{R_{eq}} = \frac{1}{7\,\Omega} + \frac{1}{3\,\Omega} \rightarrow \frac{1}{R_{eq}} = \frac{0.48}{\Omega} \rightarrow R_{eq} = 2.1\,\Omega$.

6. **C** If each of the identical bulbs has resistance R, then the current through each bulb is ε/R. This is unchanged if the middle branch is taken out of the parallel circuit. (What *will* change is the total amount of current supported by the battery.)

7. **B** The three parallel resistors are equivalent to a single 2 Ω resistor, because $\frac{1}{8\,\Omega} + \frac{1}{4\,\Omega} + \frac{1}{8\,\Omega} = \frac{1}{2\,\Omega}$. This 2 Ω resistance is in series with the given 2 Ω resistor, so their equivalent resistance is 2 Ω + 2 Ω = 4 Ω. Therefore, three times as much current will flow through this equivalent 4 Ω resistance in the top branch as through the parallel 12 Ω resistor in the bottom branch, which implies that the current through the bottom branch is 3 A, and the current through the top branch is 9 A. The voltage drop across the 12 Ω resistor is therefore $V = IR = (3\text{ A})(12\,\Omega) = 36\text{ V}$.

8. **A** Ohm's Law states that $V = IR$, so a graph of V versus I will have a slope equal to the resistance. If the battery has an internal resistance, then the circuit will have a larger resistance than anticipated, which will lead to a steeper slope. The graph, however, will still show a directly proportional relationship between V and I.

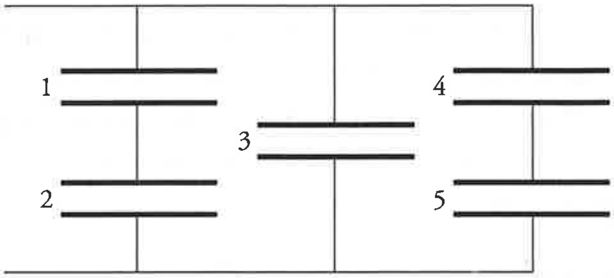
9. **D** The equation $P = I^2R$ gives

$$P = (0.5\ \text{A})^2(100\ \Omega) = 25\ \text{W} = 25\ \text{J/s}$$

Therefore, in 20 s, the energy dissipated as heat is

$$E = Pt = (25\ \text{J/s})(20\ \text{s}) = 500\ \text{J}$$

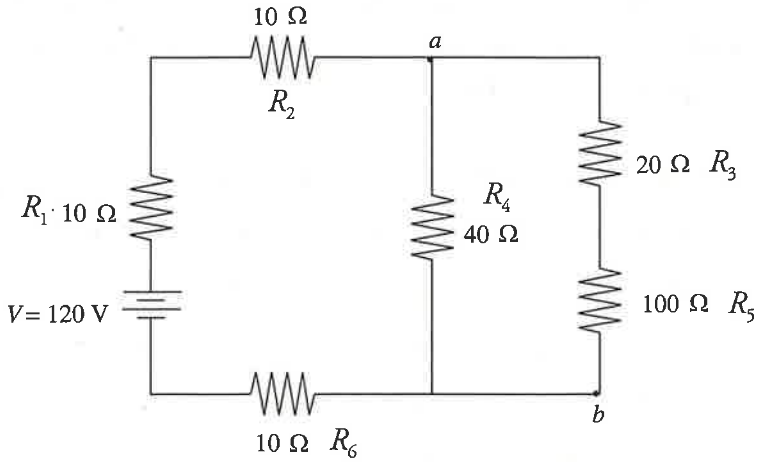
10. **D**



Capacitors 1 and 2 are in series, so their equivalent capacitance is $C_{1\text{-}2} = C/2$. (This is obtained from the equation $1/C_{1\text{-}2} = 1/C_1 + 1/C_2 = 1/C + 1/C = 2/C$.) Capacitors 4 and 5 are also in series, so their equivalent capacitance is $C_{4\text{-}5} = C/2$. The capacitances $C_{1\text{-}2}$, C_3, and $C_{4\text{-}5}$ are in parallel, so the overall equivalent capacitance is $(C/2) + C + (C/2) = 2C$.

Section II: Free Response

1. Begin by labeling each resistor and making a chart of the resistance, voltage, current, and power for each resistor.



	Resistance (Ω)	Voltage (V)	Current (A)	Power (W)
R_1	10			
R_2	10			
R_3	20			
R_4	40			
R_5	100			
R_6	10			
Entire Circuit		120		

The two parallel branches, the one containing the 40 Ω resistor and the other a total of 120 Ω, are equivalent to a single 30 Ω resistance. This 30 Ω resistance is in series with the three 10 Ω resistors, giving an overall circuit resistance of 10 Ω + 10 Ω + 30 Ω + 10 Ω = 60 Ω.

	Resistance (Ω)	Voltage (V)	Current (A)	Power (W)
R_1	10			
R_2	10			
R_3	20			
R_4	40			
R_5	100			
R_6	10			
Entire Circuit	**60**	120	120/60 = 2	$120^2/60 = 240$

R_1, R_2, and R_6 are all in series with the battery, so they all have the same current as the current supported by the battery.

	Resistance (Ω)	Voltage (V)	Current (A)	Power (W)
R_1	10	2 * 10 = 20	**2**	$2^2 * 10 = 40$
R_2	10	2 * 10 = 20	**2**	$2^2 * 10 = 40$
R_3	20			
R_4	40			
R_5	100			
R_6	10	2 * 10 = 20	**2**	$2^2 * 10 = 40$
Entire Circuit	60	120	2	240

There is a loop $V - V_1 - V_2 - V_4 - V_6 = 0$, so $120 - 20 - 20 - V_4 - 20 = 0$ and $V_4 = 60$ V.

	Resistance (Ω)	**Voltage (V)**	**Current (A)**	**Power (W)**
R_1	10	20	2	40
R_2	10	20	2	40
R_3	20			
R_4	40	**60**	60/40 = 1.5	$60^2/40 = 90$
R_5	100			
R_6	10	20	2	40
Entire Circuit	60	120	2	240

Finally, you know that 2 A of current flows into the junction point labeled *a* and 1.5 A flows into R_4, which leaves 2 A – 1.5 A = 0.5 A to travel down the other branch.

	Resistance (Ω)	**Voltage (V)**	**Current (A)**	**Power (W)**
R_1	10	20	2	40
R_2	10	20	2	40
R_3	20	0.5 * 20 = 10	**0.5**	$0.5^2 * 20 = 5$
R_4	40	60	1.5	90
R_5	100	0.5 * 100 = 50	**0.5**	$0.5^2 * 100 = 25$
R_6	10	20	2	40
Entire Circuit	60	120	2	240

Check the power sum: 40 + 40 + 5 + 90 + 25 + 40 = 240 is correct. Use the completed chart to answer the questions.

A. The battery delivers 240 W of power.

B. There is 1.5 A of current through the 40 Ω resistor.

C. i. The potential difference between points *a* and *b* is the voltage across R_4, so it is 60 V.

ii. The higher potential is near the long pole of the battery in the diagram, so *a* is 60 V higher in potential than *b*.

D. Using $R = \rho L/A$ gives $100 = 0.45(0.04)/\pi r^2$ so $r = \sqrt{\dfrac{0.45(0.04)}{100\pi}} = 0.0076\text{ m}$.

E. In order for there to be no current flow supported by the battery after the capacitor is fully charged, the capacitor would have to be in series with the battery. Then, once the capacitor is full, it would have the same voltage drop as the battery supplies and the current in the circuit would go to 0 A. This happens if you replace any of the 10 Ω resistors with a capacitor.

2. Begin by making a chart of the resistance, voltage, current, and power for each resistor.

	Resistance (Ω)	**Voltage (V)**	**Current (A)**	**Power (W)**
R_1	10			
R_2	60			
R_3	20			
R_4	40			
R_5	60	$0.5 * 60 = 30$	0.5	$0.5^2 * 60 = 15$
Entire Circuit				

To calculate the equivalent resistance of the entire circuit, there are three parallel branches each with a resistance of 60 Ω. Those are equivalent to a single 20 Ω resistor. That is in series with a 10 Ω resistor.

	Resistance (Ω)	**Voltage (V)**	**Current (A)**	**Power (W)**
R_1	10			
R_2	60			
R_3	20			
R_4	40			
R_5	60	30	0.5	15
Entire Circuit	**30**			

As the standard approach did not result in a row with two entries in a column, you must examine the circuit to see whether the Loop Rule or Junction Rule will be more useful as the next step. You can see that the three parallel branches all have the same resistance, and therefore they must all have the same current of 0.5 A flowing through them. This is a result of the Loop Rule stating that parallel branches must have equal voltages.

	Resistance (Ω)	**Voltage (V)**	**Current (A)**	**Power (W)**
R_1	10			
R_2	60	$0.5 * 60 = 30$	**0.5**	$0.5^2 * 60 = 15$
R_3	20	$0.5 * 20 = 10$	**0.5**	$0.5^2 * 20 = 5$
R_4	40	$0.5 * 40 = 20$	**0.5**	$0.5^2 * 40 = 10$
R_5	60	30	0.5	15
Entire Circuit	30			

As you just used the Loop Rule, you can now use the Junction Rule to see that $I_1 = I_2 + I_3 + I_5 = 1.5$ A. Also, since R_1 is in series with the battery, you can complete the chart.

	Resistance (Ω)	Voltage (V)	Current (A)	Power (W)
R_1	10	1.5 * 10 = 15	**1.5**	1.5^2 * 10 = 22.5
R_2	60	30	0.5	15
R_3	20	10	0.5	5
R_4	40	20	0.5	10
R_5	60	30	0.5	15
Entire Circuit	30	1.5 * 30 = 45	**1.5**	1.5^2 * 30 = 67.5

A., B., C. The answers can now simply be read off the chart.

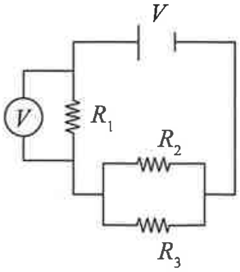
D. i. When the capacitor is uncharged, the rightmost 60 Ω resistor (along with the 20 Ω and 40 Ω series combination) will be shorted out and will have a current of 0 A flowing through them.

ii. The current will be greater than 0.5 A. The full capacitor acts like a resistor with infinite resistance, which essentially removes a parallel branch from the circuit. Removing a parallel branch lowers the current throughout the circuit, so it lowers the voltage drop across the 10 Ω resistor and increases the voltage drop across the remaining parallel branches. Thus, it increases the current through the remaining 60 Ω resistor.

3. A. First, find the equivalent resistance for the whole circuit. First, the total resistance of the two parallel resistors can be found by using $\frac{1}{R_T} = \frac{1}{R_2} + \frac{1}{R_3} = \frac{R_2 + R_3}{R_2 R_3}$, which means $R_T = \frac{R_2 R_3}{R_2 + R_3}$. Then this would be in series with the first resistor, so the equivalent resistance of the whole circuit, R_{eq}, would be $R_{eq} = R_1 + R_T = R_1 + \frac{R_2 R_3}{R_2 + R_3} = \frac{R_1 R_2 + R_1 R_3 + R_2 R_3}{R_2 + R_3}$.

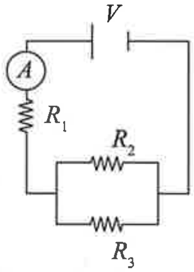
Next, you know from Ohm's Law that $V = IR$, so you can say $I = V/R = \dfrac{V}{\frac{R_1 R_2 + R_1 R_3 + R_2 R_3}{R_2 + R_3}} = \frac{V(R_2 + R_3)}{R_1 R_2 + R_1 R_3 + R_2 R_3}$. This will be the total current of the circuit. Because there are no branches before R_1, this will also be the current flowing through that resistor. So the voltage drop of that resistor, V_1, can be found by again using Ohm's Law for that location rather than the whole resistor. This gives $V_1 = I_1 R_1 = \frac{V(R_2 + R_3)}{R_1 R_2 + R_1 R_3 + R_2 R_3} R_1$.

B. The diagram should look like this:



In order to measure the voltage loss of a particular resistor, the voltmeter must be arranged in parallel with that resistor. This is because parallel elements always have equal voltage drops. Thus, whatever voltage drop the device measures will be the same as the voltage drop in the resistor being measured.

C. The diagram should look like this:



In order to measure the current passing through a particular resistor, the ammeter must be arranged in series with that resistor. This is because elements in series always have equal currents. Thus, whatever current the device measures will be the same as the current flowing through the resistor being measured.

D. For the voltmeter, infinite resistance would be ideal. As in all measurements, you don't want to disturb the system in any way as you take the measurement. Otherwise, your readings would not be accurate for the original system. Thus, in order to leave the circuit as it was, you need to maintain the flow of current that existed before you started your measurement. Having an infinite resistance would ensure no current flows into the voltmeter, leaving it all on its original path.

For the ammeter, 0 resistance would be ideal. Again, you want to have minimal disturbance on the system. If the ammeter did have resistance, then it would be a source of voltage loss that did not previously exist. In essence, it would be an additional resistor that would need to be considered, forcing you to recalculate everything from the ground up.

CHAPTER 7: MAGNETISM AND ELECTROMAGNETISM REVIEW QUESTIONS

Section I: Multiple Choice

1. **B** Because the current in wire 1 is stronger, you'll need to be further from that wire so that the magnitudes of the fields end up equal. This eliminates (A) and (C). Current-carrying wires produce fields which are circles around the wire. If the currents in each wire are going opposite directions, then in between the wires, the magnetic fields would go the same direction. Therefore, the currents must be in the same direction so that the magnetic fields in between the wires are in the opposite directions and (D) is also eliminated.

2. **D** The magnetic field strength for a current-carrying wire is given by $\mathbf{B} = \frac{\mu_0}{2\pi}\frac{I}{r}$. A graph of **B** versus I will give a line with a slope of $\frac{\mu_0}{2\pi}\frac{1}{r}$.

3. **B** All of the conditions for the second particle have the same magnitude of force as the original. In order to have the new experiment result in the same magnitude of the force, $F_B = |q||\mathbf{v}||\mathbf{B}| \sin(\theta)$ must be unchanged. Changing the signs of q, **v**, or **B** does not change the strength of the force. Rotating **v** and **B** by the same amount leaves θ unchanged, and rotating **B** by 180° results in the same value for $\sin(\theta)$. Thus, the invalid conditions must have a different direction of the magnetic force. Using the Right-Hand Rule, rotating your thumb and fingers by 90° into the plane of the paper causes the magnetic force to rotate from the original direction out of the plane (recalling q is negative) to finally point to the left.

4. **C** Relative to a current-carrying wire, the measured value of the magnetic field is directly proportional to the current and inversely proportional to the distance the measurement is taken. Therefore, a large current at a small distance will result in the largest measured magnetic field value.

5. **D** The strength of the magnetic field at a distance r from a long, straight wire carrying a current I is given by the equation $B = (\mu_0/2\pi)(I/r)$. Therefore, the strength of the magnetic field at Point P due to either wire is $B = (\mu_0/2\pi)(I/\frac{1}{2}d)$. By the Right-Hand Rule, the direction of the magnetic field at P due to the top wire is into the plane of the page and the direction of the magnetic field at P due to the bottom wire is out of the plane of the page. Since the two magnetic field vectors at P have the same magnitude but opposite directions, the net magnetic field at Point P is zero.

6. **C** Use the Right-Hand Rule for wires. If you point your thumb to the right and wrap your fingers along the wire, you will note that the magnetic field goes into the page below the wire and comes out of the page above the wire. This allows you to eliminate (A) and (B). Because $B = \frac{\mu_o I}{2\pi r}$, the closer you are to the wire, the stronger the magnetic field. Choice (C) is closer, so it is the correct answer.

7. **C** Magnetic fields point from north to south. Therefore, the magnetic field between the two magnets is toward the right of the page. Use the Right-Hand Rule. Because the B field is to the right and the charges through the wire flow to the bottom of the page, the force must be out of the page.

8. **C** Since **v** is upward and **B** is into the page, the direction of $\mathbf{v} \times \mathbf{B}$ is to the left. Therefore, free electrons in the wire will be pushed to the right, leaving an excess of positive charge at the left. Therefore, the potential at point a will be higher than that at point b, by $\varepsilon = BLv$.

9. **A** The magnitude of the emf induced between the ends of the rod is $\varepsilon = B\ell v = (0.5\text{ T})(0.2\text{ m})(3\text{ m/s}) = 0.3\text{ V}$. Since the resistance is 10 Ω, the current induced will be $I = \varepsilon / R = (0.3\text{ V})/(10\ \Omega) = 0.03\text{ A}$. To determine the direction of the current, note that since positive charges in the rod are moving to the left and the magnetic field points into the plane of the page, the Right-Hand Rule states that the magnetic force, $q\boldsymbol{v} \times \boldsymbol{B}$, points downward. Since the resulting force on the positive charges in the rod is downward, so is the direction of the induced current.

10. **C** First, you can eliminate (A) and (B). By definition, magnetic field lines emerge from the north pole and enter at the south pole. The magnetic field from the bar magnet will always point toward a viewer who is looking down at the loop from above. As the north pole gets closer to the loop, the field at the loop grows in strength, but as the south pole recedes from the loop, the magnetic field strength shrinks. Because of this, the flux changes from growing to shrinking as the magnet passes through the loop and the induced current must also change directions. Therefore, (A) and (B) are wrong. To determine whether (C) or (D) is correct, look at the first half of the motion. As the north pole gets closer to the loop, the magnetic flux increases. To oppose an increasing flux, the direction of the magnetic field generated by induced current must be downward. Looking from above, a clockwise induced current generates a downward magnetic field. Therefore, (C) is correct.

11. **C** An induced emf requires that the magnetic flux through a loop of wire change over time. Changing the area of the loop of wire will always cause the flux to change. Choice (B) can cause an emf, but will not necessarily, depending on the axis of rotation. Choice (D) is also incorrect because while a time varying field will cause an emf, it is not necessary to have such a field to produce an emf.

Section II: Free Response

1. A. The acceleration of an ion of charge q is equal to F_E/m. The electric force is equal to qE, where $E = V/d$. Therefore, $a = qV/(dm)$.

   B. Using $a = qV/(dm)$ and the equation $v^2 = v_0^2 + 2ad = 2ad$, you get

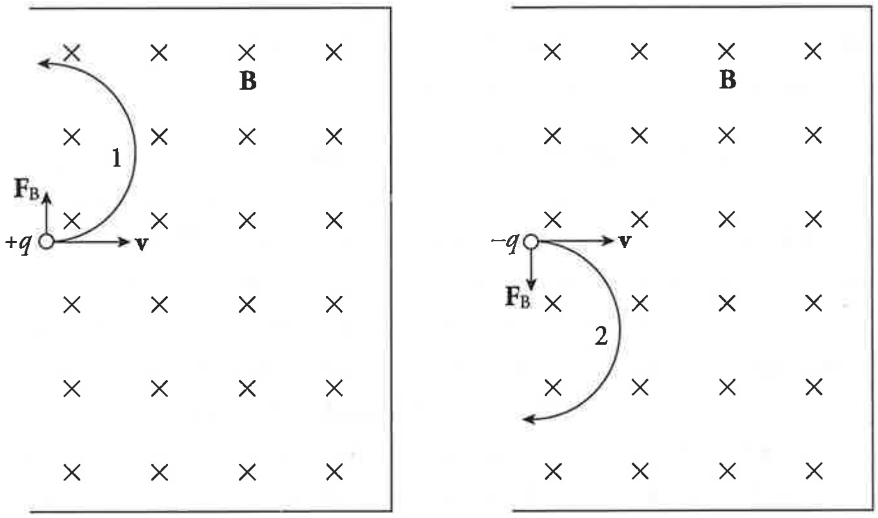
$$v^2 = 2\frac{qV}{dm}d \quad \Rightarrow \quad v = \sqrt{\frac{2qV}{m}}$$

As an alternate solution, notice that the change in the electrical potential energy of the ion from the source S to the entrance to the magnetic-field region is equal to qV; this is equal to the gain in the particle's kinetic energy.

Therefore,

$$qV = \frac{1}{2}mv^2 \quad \Rightarrow \quad v = \sqrt{\frac{2qV}{m}}$$

C. i. and ii. Use the Right-Hand Rule. Since **v** points to the right and **B** is into the plane of the page, the direction of **v** × **B** is upward. Therefore, the magnetic force on a positively charged particle (cation) will be upward, and the magnetic force on a negatively charged particle (anion) will be downward. The magnetic force provides the centripetal force that causes the ion to travel in a circular path. Therefore, a cation would follow Path 1 and an anion would follow Path 2.



D. Since the magnetic force on the ion provides the centripetal force,

$$qvB = \frac{mv^2}{r} \quad \Rightarrow \quad qvB = \frac{mv^2}{\frac{1}{2}y} \quad \Rightarrow \quad m = \frac{qBy}{2v}$$

Now, by the result of part B,

$$m = \frac{qBy}{2\sqrt{\frac{2qV}{m}}} \quad \Rightarrow \quad m^2 = \frac{q^2B^2y^2}{\frac{8qV}{m}} \quad \Rightarrow \quad m^2 = \frac{mq^2B^2y^2}{8qV} \quad \Rightarrow \quad m = \frac{qB^2y^2}{8V}$$

E. Since the magnetic force cannot change the speed of a charged particle, the time required for the ion to hit the photographic plate is equal to the distance traveled (the length of the semicircle) divided by the speed computed in part B:

$$t = \frac{s}{v} = \frac{\pi \cdot \frac{1}{2}y}{\sqrt{\frac{2qV}{m}}} = \frac{1}{2}\pi y\sqrt{\frac{m}{2qV}}$$

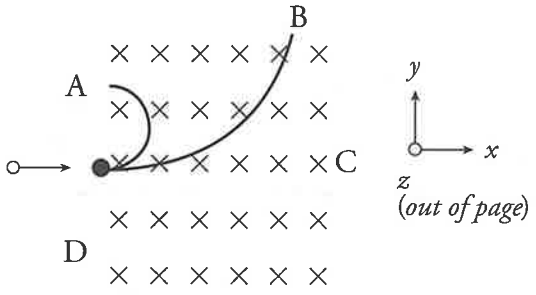
F. Since the magnetic force $\mathbf{F}_B$ is always perpendicular to a charged particle's velocity vector **v**, it can do no work on the particle. Thus, the answer is zero.

2. A. The force is directed in the $+y$ direction. The particle is charged positively and is moving in the $+x$ direction, so the thumb points to the right. With your fingers facing inward toward the paper, your palm is toward the top of the paper.

B. i. The new speed is equal to the old speed because the magnetic force cannot do work, and therefore is unable to change the kinetic energy, and thus the speed, of the particle.

ii. The new velocity is different from the old velocity as the direction has changed. The particle is traveling along a circular arc, and at any instant the velocity direction will be tangential to that arc. The new velocity will have the same magnitude as the initial velocity, but its x-component will be smaller as the y-component becomes larger. If the particle passes through 90° of the circular arc, the y-component will again begin to shrink as the x-component grows.

C. Both A and B could be exit points from the magnetic field region.



3. A. $\varepsilon = B\ell v = (2\text{ T})(0.4\text{ m})(1\text{ m/s}) = 0.8\text{ V}$

B. $V = IR$ becomes $I = \frac{V}{R} = \frac{0.8\text{ V}}{20\,\Omega} = 0.04\text{ A}$. The direction is given by Lenz's Law. Current flows in order to oppose the change in the magnetic flux. Because there is suddenly a new flux "in," current flows to produce an outward flux. This would be in the counterclockwise direction.

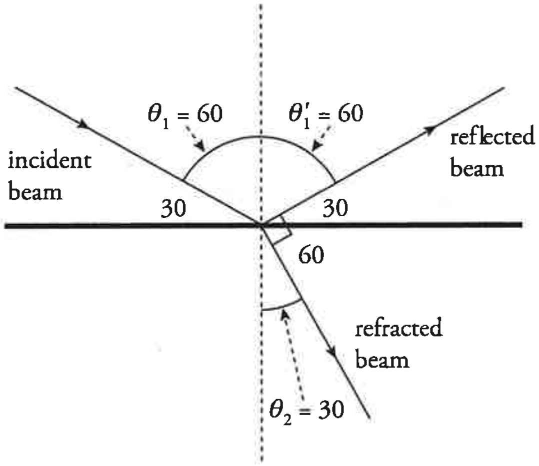
C. As the edge of the loop first encounters the magnetic field region, the induced current is established at 0.04 A, counterclockwise (found in part B). This continues as long as the flux is changing, which occurs until the left edge of the loop enters the magnetic field region. During the time the entire loop is within the region of the magnetic field, the flux is constant and the emf and current are both 0. Once the loop begins to leave the region of the magnetic field, the flux begins to change again and an induced current is established at 0.04 A. As the loop leaves the region of the magnetic field, the flux is shrinking instead of growing, so the current must be clockwise as the loop exits the magnetic field region.

D. The only thing that has changed is that the length of the wire at the leading edge has decreased. Thus, to maintain the same induced current, the speed at which the wire is pulled would have to increase. Moreover, as the length is halved, the speed would need to double in order for the induced current to remain constant.

CHAPTER 8: GEOMETRIC OPTICS REVIEW QUESTIONS

Section I: Multiple Choice

1. **B** As light travels into an optically dense medium, it will refract in toward the normal and away from the surface. So, the light in the glass will always be at a greater angle from the surface than the light in the air, so (B) is correct. Note that total internal reflection, (C), will not occur in this situation because it happens only with the initial medium being more optically dense.



2. **B** Replacing the lens with one of higher index will mean that the light will bend more as it passes through the lens. This has the effect of shortening the focal length. A virtual image can only be made by having the object closer than the focal length of the lens, so shortening the focal length will not cause it to become virtual and (D) is eliminated. Shortening the focal length with the same d_o also means that d_i will have to be smaller by the lens equation $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$, so (B) is correct.

3. **D** Choice (A) is false because a change in speed at an interface does not cause intensity to change. Choice (B) is false because had there been total internal reflection, the light would have remained in Medium 1. Choice (C) is false because the problem states that Medium 2 has a lower index of refraction, and from Snell's Law, $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$, if $n_2 < n_1$, then $\sin(\theta_2) > \sin(\theta_1)$ and the angles are not equal. Choice (D) is true because when light arrives at an interface, it must be absorbed, reflected, or transmitted. Therefore, any intensity not detected as transmitted into Medium 2 was either reflected back into Medium 1 or absorbed.

4. **A** The critical angle for total internal reflection is computed as follows:

$$n_1 \sin \theta_c = n_2 \sin 90°$$

$$\sin \theta_c = \frac{n_2}{n_1} = \frac{1.45}{2.90} = \frac{1}{2} \quad \Rightarrow \quad \theta_c = 30°$$

Total internal reflection can happen only if the incident beam originates in the medium with the higher index of refraction, and therefore the beam must originate in the solid. The refracted ray must strike the interface of the other medium at an angle of incidence greater than the critical angle.

5. **C** Every ray, regardless of whether it is a principal ray or not, which originates at the tip of an object and strikes a mirror, will converge at the tip of the image.

6. **A** All of the rays which originate at the tip of the image and travel along paths that remain above the optic axis will be blocked. However, all of the rays that originate at the tip of the image and travel along paths that are below the optic axis at the plane of the block will be unaltered. As a result, fewer rays will converge at the image location, resulting in a less bright image.

7. **D** Diverging lenses always create virtual images.

Section II: Free Response

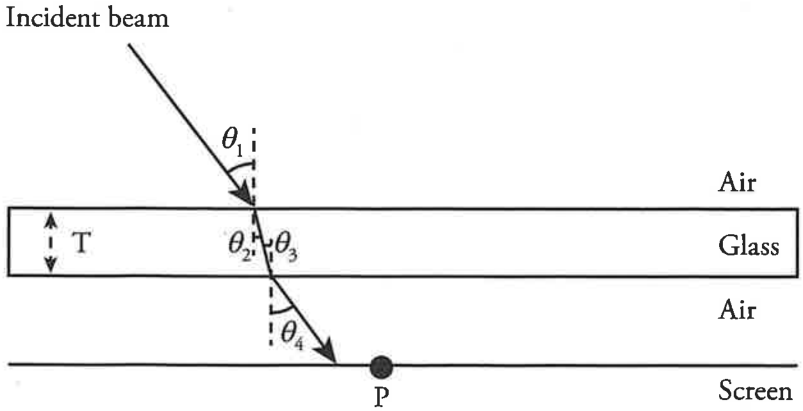
1. A. i. Student 1 is correct that "According to Snell's Law, the light will bend at the first interface" and also "unbend at the second interface and travel parallel to its original path."

ii. Student 2 is correct that "Snell's Law is $n_{in} \sin(\theta_{in}) = n_{out} \sin(\theta_{out})$" and that "$\theta_{out}$ is different from θ_{in} at the first interface."

iii. Student 1 is incorrect that "The spot on the screen will still be at point P."

iv. Student 2 is incorrect that "The beam after the glass cannot be parallel to the beam before the glass."

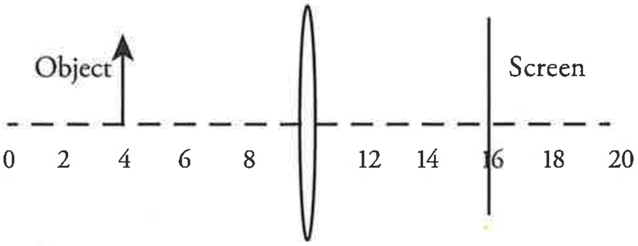
B.



Here, $\theta_1 = \theta_4$ and $\theta_2 = \theta_3$.

C. If the area between the glass and screen were filled with water, it would still be the case that $\theta_2 = \theta_3$ because there is no change to the glass. However, upon leaving the glass and entering the water, the amount that the light would bend away from the normal would be less than in the case of air because the difference in the indices of refraction is smaller with glass-to-water than glass-to-air. As a result, the beams in air and water would not be parallel and the spot that would appear on the screen would be even farther away from point P than in the original experiment.

2. A.



In order for the object and image to be the same size, the magnitude of the magnification must be 1, so $|M| = \left|\left(\frac{s_i}{s_o}\right)\right| = 1$ and therefore $|s_o| = |s_i|$. The only way to satisfy the equation $\frac{1}{f} = \frac{1}{s_i} + \frac{1}{s_o}$ when the image distance is equal to the object distance is for both to be $2f$. The object should be placed $2f$ before the lens and the screen should be placed $2f$ after the lens. The image will be below the optical axis in this case, so the part of the screen where the image forms needs to also be placed below the optic axis. Note: switching the positions of the object and screen (so that the object is on the right and the screen is on the left) is also correct.

B. A converging lens is similar to a convex mirror, but with the mirror, the light always stays on one side of the mirror. Both the object and the screen should be placed at the 4 cm mark. The image will be below the optical axis in this case.

C. A virtual image is a position in space where the light rays appear to have converged, although no light is actually present at the "image position." Ray tracing can yield a set of non-converging rays. Tracing those rays "backward" to the point where the lines do converge results in the virtual image position. In order to experimentally verify that a virtual image exists, the virtual image location may be used as the object location for a second imaging system. The second imaging system may then produce a real image on a screen of the virtual image that was its object.

CHAPTER 9: WAVES, SOUND, AND PHYSICAL OPTICS REVIEW QUESTIONS

Section I: Multiple Choice

1. **C** From the equation $\lambda = v/f$, find that

$$\lambda = \frac{v}{f} = \frac{10 \text{ m/s}}{5 \text{ Hz}} = 2 \text{ m}$$

2. **C** The speed of a transverse traveling wave on a stretched rope is given by the equation $v = \sqrt{\frac{F_T}{m/L}}$. Therefore,

$$v = \sqrt{\frac{F_T}{m/L}} = \sqrt{\frac{80 \text{ N}}{(1 \text{ kg})/(5 \text{ m})}} = \sqrt{400 \text{ m}^2/\text{s}^2} = 20 \text{ m/s}$$

3. **C** The time interval from a point moving from its maximum displacement above $y = 0$ (equilibrium) to its maximum displacement below equilibrium is equal to one-half the period of the wave. In this case,

$$T = \frac{1}{f} = \frac{\lambda}{v} = \frac{8 \text{ m}}{2 \text{ m/s}} = 4 \text{ s}$$

so the desired time is $\frac{1}{2}(4 \text{ s}) = 2 \text{ s}$.

4. **D** The distance between successive nodes is always equal to $\frac{1}{2}\lambda$. If a standing wave on a string fixed at both ends has a total of 4 nodes, the string must have a length L equal to $3(\frac{1}{2}\lambda)$. If $L = 6$ m, then λ must equal 4 m.

5. **B** The previous question showed that $\lambda = 4$ m. Since $v = 40$ m/s, the frequency of this standing wave must be

$$f = \frac{v}{\lambda} = \frac{40 \text{ m/s}}{4 \text{ m}} = 10 \text{ Hz}$$

6. **A** In general, sound travels faster through solids than through gases. Therefore, when the wave enters the air from the metal rod, its speed will decrease. The frequency, however, will not change. Since $\lambda = v/f$ must always be satisfied, a decrease in v implies a decrease in λ.

7. **A** The distance from S_2 to P is 5 m (it's the hypotenuse of a 3-4-5 triangle), and the distance from S_1 to P is 4 m. The difference between the path lengths to Point P is 1 m, which is half the wavelength. Therefore, the sound waves are always exactly out of phase when they reach Point P from the two speakers, causing destructive interference there. By contrast, since Point Q is equidistant from the two speakers, the sound waves will always arrive in phase at Q, interfering constructively. Since there is destructive interference at P and constructive interference at Q, the amplitude at P will be less than at Q.

8. **B** An air column (such as an organ pipe) with one closed end resonates at frequencies given by the equation $f_n = nv/(4L)$ for odd integers n. The fundamental frequency corresponds, by definition, to $n = 1$. Therefore,

$$f_1 = \frac{v}{4L} = \frac{340\text{ m/s}}{4(0.17\text{ m})} = 500\text{ Hz}$$

9. **B** The speed of the chirp is

$$v = \lambda f = (8.75 \times 10^{-3}\text{ m})(40 \times 10^3\text{ Hz}) = 350\text{ m/s}$$

If the distance from the bat to the tree is d, then the wave travels a total distance of $d + d = 2d$ (round-trip distance). If T is the time for this round-trip, then

$$2d = vT \quad \Rightarrow \quad d = \frac{vT}{2} = \frac{(350\text{ m/s})(0.4\text{ s})}{2} = 70\text{ m}$$

10. **C** In the equation for a wave, $x = A\cos(\omega t)$, the amplitude A will always have the same units as the wave itself. This is because the value of $\cos(\omega t)$ is a number between –1 and 1 and has no units. An electric field, whether stationary or oscillating, is always measured in N/C (or equivalently V/m), so (B) and (D) are incorrect. In $\cos(\omega t)$, ω is the angular frequency, found using $\omega = 2\pi f$.

11. **C** Since the fringe is bright, the waves must interfere constructively. This implies that the difference in path lengths must be a whole number times the wavelength, eliminating (A) and (B). The central maximum is equidistant from the two slits, so $\Delta \ell = 0$ there. At the first bright fringe above the central maximum, you have $\Delta \ell = \lambda$.

12. **B** In the double-slit experiment, $y = \frac{m\lambda D}{d}$. Using a shorter wavelength, as in the second experiment, results in a decrease in the fringe spacing, so (C) and (D) are false. Using slits which are closer together causes the fringe spacing to increase, so (A) is false.

Section II: Free Response

1. A. The speed of a transverse traveling wave on a stretched rope is given by the equation $v = \sqrt{\frac{F_T}{m/L}}$. Therefore,

$$v^2 = \frac{F_T}{m/L} \quad \Rightarrow \quad F_T = \mu v^2 = (0.4\text{ kg/m})(12\text{ m/s})^2 = 58\text{ N}$$

B. Use the fundamental equation $\lambda = v/f$:

$$f = \frac{v}{\lambda} = \frac{12\text{ m/s}}{2\text{ m}} = 6\text{ Hz}$$

C. i. Because higher harmonic numbers correspond to shorter wavelengths, the harmonic number of the 3.2 m standing wave must be higher than that of the 4 m standing wave. You're told that these harmonic numbers are consecutive integers, so if n is the harmonic number of the 4 m standing wave, then $n + 1$ is the harmonic number of the 3.2 m wave. Therefore,

$$\frac{2L}{n} = 4\text{ m} \qquad \text{and} \qquad \frac{2L}{n+1} = 3.2\text{ m}$$

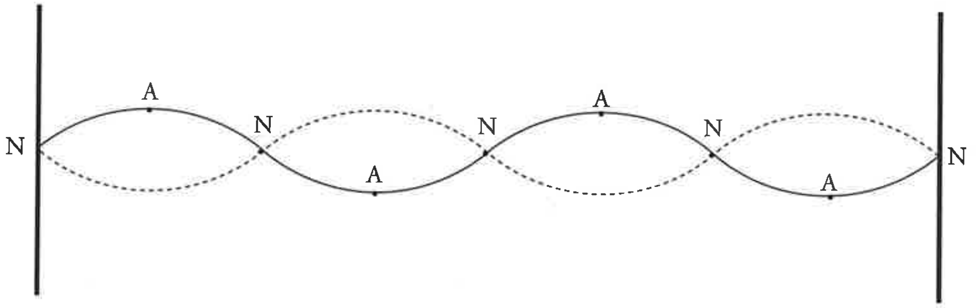
The first equation says that $2L = 4n$, and the second one says that $2L = 3.2(n + 1)$. Therefore, $4n$ must equal $3.2(n + 1)$; solving this equation gives $n = 4$. Substituting this into either one of the displayed equations then gives $L = 8$ m.

ii. Because the mass per unit length of the rope is 0.4 kg/m, the mass of the rope must be

$$m = \mu L = (0.4\text{ kg/m})(8\text{ m}) = 3.2\text{ kg}$$

D. You determined this in the solution to part C (i). The 4 m standing wave has harmonic number $n = 4$.

E.



2. A. Use the equation for the beat frequency:

$$f_{\text{beat}} = |f_1 - f_2| = |400\text{ Hz} - 440\text{ Hz}| = 40\text{ Hz}$$

B. As sound travels from air into water, the speed of sound will increase, as sound travels faster in liquids than in gases. By Wave Rule #2, when a wave passes into another medium, its speed changes but its frequency does not. By the equation $v = f\lambda$, it can be observed that if speed increases and frequency does not change, then the wavelength must increase.

C. As the sound source (tuning fork) is traveling toward the stationary detector (the student on the second floor), the observed frequency will be higher than the source frequency. However, the question is asking what happens to the observed frequency as the tuning fork travels upward. Due to acceleration from gravity, the speed of the tuning fork as it moves up will decrease. As the relative speed between the source and detector is decreasing, the impact of the Doppler effect will decrease. This will lead to a decrease in the observed frequency as the tuning fork travels upward (although the observed frequency will still be higher than the source frequency).

3. A. Interference effects can be observed only if the light is coherent. Using two independent light sources at the slits in Barrier 2 would generate incoherent light waves. The setup shown guarantees that the light reaching the two slits will be coherent.

   B. Maxima are located at positions given by the equation $y = m\lambda D/d$, where m is an integer ($y_0 = 0$ is the central maximum). The first-order maximum for red light occurs at

$$y_{1,\text{ red}} = \frac{1 \cdot \lambda_{\text{red}} D}{d} = \frac{1 \cdot (750 \times 10^{-9}\text{ m})(4.0\text{ m})}{0.50 \times 10^{-3}\text{ m}} = 0.006\text{ m} = 6.0\text{ mm}$$

   and the first-order maximum for violet light occurs at

$$y_{1,\text{ violet}} = \frac{1 \cdot \lambda_{\text{violet}} D}{d} = \frac{1 \cdot (400 \times 10^{-9}\text{ m})(4.0\text{ m})}{0.50 \times 10^{-3}\text{ m}} = 0.0032\text{ m} = 3.2\text{ mm}$$

   Therefore, the vertical separation of these maxima on the screen is $\Delta y = 6.0\text{ mm} - 3.2\text{ mm} = 2.8\text{ mm}$.

   C. Maxima are located at positions given by the equation $y = m\lambda D/d$, where m is an integer. Therefore, you want to solve the equation

$$\begin{gathered} y_{m,\text{ violet}} = x_{n,\text{ orange-yellow}} \\ \frac{m\lambda_{\text{violet}} D}{d} = \frac{n\lambda_{\text{orange-yellow}} D}{d} \\ m\lambda_{\text{violet}} = n\lambda_{\text{orange-yellow}} \\ m(400\text{ nm}) = n(600\text{ nm}) \end{gathered}$$

   The smallest integers that satisfy this equation are $m = 3$ and $n = 2$. That is, the third-order maximum for violet light coincides with the second-order maximum for orange-yellow light. The position on the screen (relative to the central maximum at $x = 0$) of these maxima is

$$y_{3,\text{ violet}} = \frac{m\lambda_{\text{violet}} D}{d} = \frac{3(400 \times 10^{-9}\text{ m})(4.0\text{ m})}{0.50 \times 10^{-3}\text{ m}} = 0.0096\text{ m} = 9.6\text{ mm}$$

   D. Within the glass, the wavelength is reduced by a factor of $n = 1.5$ from the wavelength in air. Therefore, the difference in path lengths, $d \sin \theta$, must be equal to $m(\lambda/n)$ in order for constructive interference to occur. This implies that the maxima are located at positions given by $y_m = m\lambda D/(nd)$. The distance between adjacent bright fringes is therefore

$$y_{m+1} - y_m = \frac{(m+1)\lambda D}{nd} - \frac{m\lambda D}{nd} = \frac{\lambda D}{nd} = \frac{(500 \times 10^{-9}\text{ m})(4.0\text{ m})}{1.5(0.50 \times 10^{-3}\text{ m})} = 0.0027\text{ m} = 2.7\text{ mm}$$

CHAPTER 10: MODERN PHYSICS REVIEW QUESTIONS

Section I: Multiple Choice

1. **B** Waves will interfere with apertures that are approximately the same size as the wave. The wavelengths of matter from the de Broglie Theory are on the same order as the size of molecule spacing in solids, and therefore these effects are not visible at macroscopic scales.

2. **C** Photoelectrons will be emitted in the photoelectric effect when the energy of a photon of the incident light is greater than the work function of the metal. Thus, decreasing the energy of the photon below the work function of the metal would prevent photoelectrons from being ejected by the metal. The energy of a photon is $E = hf$, so decreasing the frequency of the photon decreases its energy. Since the frequency of light is inversely proportional to the wavelength, decreasing the frequency corresponds to increasing the wavelength, so (C) is correct. The brightness of the light does not correlate with photon energy, which eliminates (A). The stopping potential is something observed from photoelectrons that are ejected, not something that is independently controlled, so (D) can be eliminated.

3. **A** The ground state of an atom is (–1) times its ionization energy, so the ground state would have to be at an energy level of –25 eV. To transition from –16 eV to –25 eV, a photon with an energy of 9 eV would have to be produced in order for energy to be conserved. To find the wavelength of the photon, $E = hf = h(c/\lambda) = hc/\lambda$, so $\lambda = hc/E$. From the equation sheet, $hc = 1240 \text{ nm} \cdot \text{eV}$ and $\lambda = \dfrac{1240 \text{ nm} \cdot \text{eV}}{9 \text{ eV}} = 138 \text{ nm}$.

4. **D** The gap between the ground-state and the first excited state is

$$-10 \text{ eV} - (-40 \text{ eV}) = 30 \text{ eV}$$

Therefore, the electron must absorb the energy of a 30 eV photon (at least) in order to move even to the first excited state. Since the incident photons have only 15 eV of energy, the electron will be unaffected.

5. **D** When a charged particle goes into a magnetic field, it will be deflected, but an uncharged particle will not be deflected. Particles with opposite signs will deflect in opposite directions. An alpha particle is charged and a neutron is not, so (D) is the correct answer.

6. **D** If the atom begins in the $n = 3$ state, it could lose energy by making any of the following transitions: $3 \rightarrow 2$, $3 \rightarrow 1$, or $3 \rightarrow 2 \rightarrow 1$. The $3 \rightarrow 2$ transition would result in the emission of $-5 \text{ eV} - (-8 \text{ eV}) = 3 \text{ eV}$; the $3 \rightarrow 1$ transition would emit a $-5 \text{ eV} - (-12 \text{ eV}) = 7 \text{ eV}$ photon; and the $2 \rightarrow 1$ transition would result in the emission of $-8 \text{ eV} - (-12 \text{ eV}) = 4 \text{ eV}$. Therefore, if the atom is initially in the $n = 3$ state, it could emit photons of energy 3 eV, 4 eV, or 7 eV.

7. **C** To emit a photon, an energy level transition must go to a lower energy level (a transition to a higher level requires absorbing a photon), so (A) and (B) are incorrect. A long wavelength corresponds to a small energy photon, so (D) is also incorrect, and (C) is the correct answer.

8. **D** At the time that Louis de Broglie made his hypothesis, it was known that light, which often behaves like a wave, also has particle-like behavior. The de Broglie Hypothesis is that while electrons (and other matter) most often demonstrate particle-like behaviors, they would also demonstrate wave-like behaviors. Diffraction is a phenomenon associated with wave interference, so de Broglie's Hypothesis can be summarized as electrons will diffract in certain circumstances.

9. **B** The binding energy is given by $E_B = (\Delta m)c^2$, so (A) is true. The binding energy, which is the energy associated with the mass defect, is typically measured in MeV, while typical electronic transitions are measured in eV, so (C) is also true. Mass defect is also typically 4 orders of magnitude smaller than the mass of the involved nucleons, so (D) is true. Choice (B) is false because the binding energy is always positive, so that the mass of the bound nucleons plus the binding energy equals the mass of the constituent nucleons.

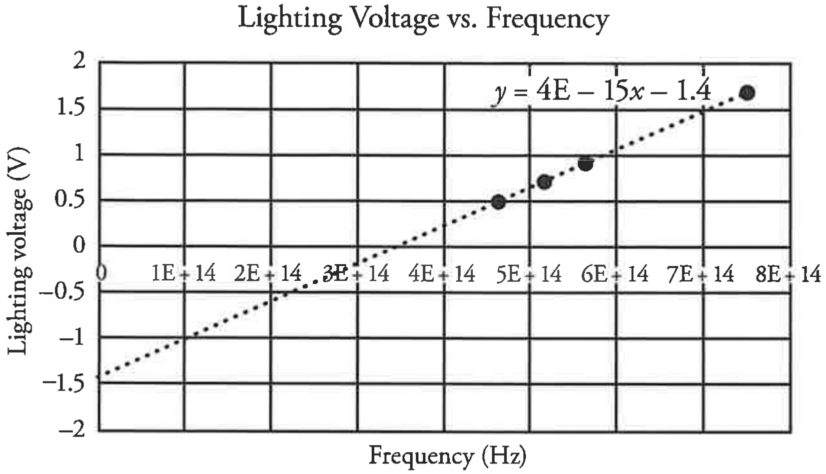
10. **B** In order to balance the mass number (the superscripts), you must have $2 + 63 = 64 + A$, so $A = 1$. In order to balance the charge (the subscripts), you need $1 + 29 = 30 + Z$, so $Z = 0$. A particle with a mass number of 1 and no charge is a neutron, ${}_{0}^{1}\text{n}$.

11. **A** The alpha decay process produces an alpha particle ${}_{2}^{4}\text{He}$ and a daughter nucleus. The daughter nucleus must have a mass number 4 below the original isotope and a charge number 2 below the original isotope, resulting in ${}_{76}^{171}\text{Os}$. The beta(+) decay process produces a positive beta particle ${}_{1}^{0}e$ and a daughter nucleus. The daughter nucleus must have a mass number equal to the original isotope and a charge number 1 below the original isotope, resulting in ${}_{77}^{175}\text{Ir}$.

Section II: Free Response

1. A. The work function is the amount of energy that must be supplied before a photoelectron is released. For any amount of energy supplied by the power supply below the work function of the material that the LED light is made of, there will be no production of photoelectrons. Therefore, the work function of the material must be greater than 0.1 eV since there were no photoelectrons emitted at the voltage of 1 V.

B.



The slope of the graph is $4 \times 10^{-15}\text{V} \cdot \text{s}$ and the y-intercept is –1.4 V. The slope has the value of Planck's constant, and the intercept is the work function of the material the LED lights are made of.

C. i. To change the intercept, the work function would have to be different, so a supply of LEDs made from a different material would have to be obtained.

ii. It would not be possible to change the slope, as the slope determined from this experiment is Planck's constant.