5. (a) $\sum F = F_e - F_g = 0$

$qE = mg$

$q\dfrac{V}{L} = mg$

$$\boxed{q = \frac{mgL}{V}}$$

(b) The charge on the plastic sphere has to be some multiple of the charge of an electron (1.6 x 10^{-19} C). Since the voltage needed to maintain a net force of zero on the sphere is inversely proportional to the charge on the sphere, the voltage difference needed between two spheres (whose difference in the number of electrons on each is one) will be the greatest when one has one extra (or less) electron and the other has two. For example, solving the equation above for voltage as a function of charge yields $V = \dfrac{mgL}{q}$, where m, g, and L are all constants. The difference in voltage between two spheres (where one sphere has one more or less electron than the other) is greatest when the number of electrons goes from 1 to 2, rather than 2 to 3, or 3 to 4, etc. as shown on the graph because $\frac{1}{1} - \frac{1}{2} = \frac{1}{2}$ is greater than $\frac{1}{2} - \frac{1}{3} = \frac{1}{6}$ which in turn is greater than $\frac{1}{3} - \frac{1}{4} = \frac{1}{12}$, etc. So the gaps between voltages in the graph will get progressively larger as the number of extra electrons on the sphere decreases.

(c) $q = \dfrac{mgL}{V}$ so $m = \dfrac{qV}{gL}$. Substituting data from the graph into this equation yields

$$m = \frac{\left(1.6 \text{ x } 10^{-19}\ \text{C}\right)\left(3000\ \text{V}\right)}{\left(9.8\ \text{m/s}^2\right)\left(0.050\ \text{m}\right)}$$

$$\boxed{m = 9.8 \text{ x } 10^{-16}\ \text{kg}}$$

(d)

i. It will begin to move in a circular motion because the force from the magnetic field on the moving charge will be perpendicular to its motion, or towards the center of a circle.

ii. Using the right-hand rule, if it were positively charged it would move in a counter-clockwise circular motion, and if it were negatively charged it would move in a clockwise circle.

(e) $W_{net} = \Delta KE$

$F_B d\cos\theta = \frac{1}{2}mv_{final}^2 - \frac{1}{2}mv_{initial}^2$

$qvBL\cos 180 = 0 - \frac{1}{2}mv^2$

$$\boxed{B = \frac{mv}{2qL}}$$

7. (a) $c = \lambda f$

$3.0 \text{ x } 10^{8}\ \text{m/s} = \left(400 \text{ x } 10^{-9}\ \text{m}\right) f$

$\boxed{f = 7.5 \text{ x } 10^{14}\ \text{Hz}}$

(b) $hf = KE_{\text{max}} + \phi$

$\left(6.63 \text{ x } 10^{-34}\ \text{J}\cdot\text{s}\right)\left(7.5 \text{ x } 10^{14}\ \text{Hz}\right) = 1.1 \text{ x } 10^{-19}\ \text{J} + \phi$

$\boxed{\phi = 3.87 \text{ x } 10^{-19}\ \text{J}}$

(c) $qV_0 = KE_{\text{max}}$

$\left(1.6 \text{ x } 10^{-19}\ \text{C}\right)V_0 = 1.1 \text{ x } 10^{-19}\ \text{J}$

$\boxed{V_0 = 0.69\ \text{V}}$

(d) $KE_{\text{max}} = \frac{1}{2}mv^2$

$1.1 \text{ x } 10^{-19}\ \text{J} = \frac{1}{2}\left(9.11 \text{ x } 10^{-31}\ \text{kg}\right)v^2$

$v = 4.9 \text{ x } 10^{5}\ \text{m/s}$

$p = mv$

$p = \left(9.11 \text{ x } 10^{-31}\ \text{kg}\right)\left(4.9 \text{ x } 10^{5}\ \text{m/s}\right)$

$\boxed{p = 4.5 \text{ x } 10^{-25}\ \text{kg}\cdot\text{m/s}}$

7. (a) $\lambda = \frac{h}{p}$

$$0.85 \text{ x } 10^{-9} \text{ m} = \frac{6.63 \text{ x } 10^{-34} \text{ J} \cdot \text{s}}{\left(9.11 \text{ x } 10^{-31} \text{ kg}\right) v}$$

$$v = 8.56 \text{ x } 10^{5} \text{ m/s}$$

$$KE = \tfrac{1}{2} m v^2 = \tfrac{1}{2}\left(9.11 \text{ x } 10^{-31} \text{ kg}\right)\left(8.56 \text{ x } 10^{5} \text{ m/s}\right)^2$$

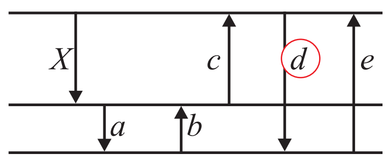
$$\boxed{KE = 3.37 \text{ x } 10^{-19} \text{ J} = 2.09 \text{ eV}}$$

(b) $h\frac{c}{\lambda} = KE + W_0$

$$6.63 \text{ x } 10^{-34} \text{ J} \cdot \text{s} \frac{3 \text{ x } 10^{8} \text{ m/s}}{250 \text{ x } 10^{-9} \text{ m}} = 3.37 \text{ x } 10^{-19} \text{ J} + W_0$$

$$\boxed{W_0 = 4.59 \text{ x } 10^{-19} \text{ J} = 2.87 \text{ eV}}$$

(c)



In order for an atom to emit a photon of light, it must drop to a lower energy level, so the arrow indicating the trasition should be pointing down. Also, frequency is inversely proportional to wavelength ($c = \lambda f$), so a photon with a smaller wavelength has a higher frequency. Therefore, the photon with a 250 nm wavelength has a higher frequency than the photon with a wavelength of 400 nm. Finally, the energy of a photon is directly proportional to its frequency ($E = hf$), so the transition of the photon with a 250 nm wavelength should have a longer arrow representing its transition than the photon with a wavelength of 400 nm. Therfore choice *d* is the correct possible electron transition that would produce a photon with a 250 nm wavelength.

7. (a) $p = \frac{h}{\lambda} = \frac{6.63 \text{ x } 10^{-34} \text{ J}\cdot\text{s}}{0.038 \text{ x } 10^{-9} \text{ m}}$

$\boxed{p = 1.74 \text{ x } 10^{-23} \text{ kg}\cdot\text{m/s}}$

(b) $p = mv$

$1.74 \text{ x } 10^{-23} \text{ kg}\cdot\text{m/s} = \left(9.11 \text{ x } 10^{-31} \text{ kg}\right)v$

$v = 1.91 \text{ x } 10^{7} \text{ m/s}$

$KE = \frac{1}{2}mv^2 = \frac{1}{2}\left(9.11 \text{ x } 10^{-31} \text{ kg}\right)\left(1.91 \text{ x } 10^{7} \text{ m/s}\right)^2$

$\boxed{KE = 1.66 \text{ x } 10^{-16} \text{ J}}$

(c) $\Delta PE = \Delta KE$

$qV = KE - 0$

$\left(1.6 \text{ x } 10^{-19} \text{ C}\right)V = 1.66 \text{ x } 10^{-16} \text{ J}$

$\boxed{V = 1040 \text{ V}}$

(d) $hf = KE + W_o$

$\left(6.63 \text{ x } 10^{-34} \text{ Js}\right)f = 0 \text{ J} + \left(4.5 \text{ eV}\right)\left(1.6 \text{ x } 10^{-19} \text{ J/eV}\right)$

$\boxed{f = 1.09 \text{ x } 10^{15} \text{ Hz}}$

7. (a) $E = mc^2 = \dfrac{\left(9.11 \text{ x } 10^{-31} \text{ kg}\right)\left(3.00 \text{ x } 10^{8} \text{ m/s}\right)^2}{1.6 \text{ x } 10^{-19} \text{ J/eV}}$

$$\boxed{E = 5.12 \text{ x } 10^{5} \text{ eV}}$$

(b) The total energy before the annihilation will be double the rest energy of the positron since an electron has the same mass, therefore, the same energy. This will also be the total energy of the two photons with each photon having the same energy. Thus, each photon will have the same energy as the rest energy of the positron before the annihilation.

$$\boxed{E = 5.12 \text{ x } 10^{5} \text{ eV}}$$

(c) $E = hf = h\dfrac{c}{\lambda}$

$$\left(5.12 \text{ x } 10^{5} \text{ eV}\right)\left(1.6 \text{ x } 10^{-19} \text{ J/eV}\right) = \left(6.63 \text{ x } 10^{-34} \text{ J}\cdot\text{s}\right)\frac{3.00 \text{ x } 10^{8} \text{ m/s}}{\lambda}$$

$$\boxed{\lambda = 2.43 \text{ x } 10^{-12} \text{ m} = 2.43 \text{ x } 10^{-3} \text{ nm}}$$

(d) $p = \dfrac{h}{\lambda} = \dfrac{6.63 \text{ x } 10^{-34} \text{ J}\cdot\text{s}}{2.43 \text{ x } 10^{-12} \text{ m}}$

$$\boxed{p = 2.73 \text{ x } 10^{-22} \text{ kg}\cdot\text{m/s}}$$

(e) 0-The two photons will have equal and opposite momenta which will add to zero.

6. (a) $E = h\nu = h\dfrac{c}{\lambda} = \left(6.63 \text{ x } 10^{-34}\ \text{J}\cdot\text{s}\right)\dfrac{\left(3.00 \text{ x } 10^{8}\ \text{m/s}\right)}{\left(1.50 \text{ x } 10^{-8}\ \text{m}\right)}$

$\boxed{E = 1.33 \text{ x } 10^{-17}\ \text{J}}$

(b) $E = \frac{1}{2}mv^2$

$1.33 \text{ x } 10^{-17}\ \text{J} = \frac{1}{2}\left(9.11 \text{ x } 10^{-31}\ \text{kg}\right)v^2$

$v = 5.40 \text{ x } 10^{6}$ m/s

$\lambda = \dfrac{h}{p} = \dfrac{h}{mv} = \dfrac{6.63 \text{ x } 10^{-34}\ \text{J}\cdot\text{s}}{\left(9.11 \text{ x } 10^{-31}\ \text{kg}\right)\left(5.40 \text{ x } 10^{6}\ \text{km/s}\right)}$

$\boxed{\lambda = 1.35 \text{ x } 10^{-10}\ \text{kg}\cdot\text{m/s}}$

(c) Send a beam of electrons at a very thin crystal sample and onto a fluorescent screen. The nuclei of the crystal act as barriers to the electrons and the space between the nuclei act as slits. The beam of electrons will display a pattern on the screen similar to a diffraction and interference pattern produced when a wave (such as light) passes through a multiple slit apparatus.

7. (a) $\Delta E = h\nu = h\dfrac{c}{\lambda}$

$E_2 - E_4 = h\dfrac{c}{\lambda}$

$$(-13.6\text{ eV})(1.60 \times 10^{-19}\text{ J/eV}) - E_4 = (6.63 \times 10^{-34}\text{ J}\cdot\text{s})\frac{3.00 \times 10^{8}\text{ m/s}}{(121.9\text{ nm})(10^{-9}\text{ m/nm})}$$

$$E_4 = -5.44 \times 10^{-19}\text{ J} = \frac{5.44 \times 10^{-19}\text{ J}}{1.60 \times 10^{-19}\text{ J/eV}}$$

OR: $E_n = \dfrac{-54.4\text{ eV}}{n^2}$, so $E_4 = \dfrac{-54.4\text{ eV}}{4^2}$

$E_4 = -3.40$ eV

$\boxed{E_4 = -3.40\text{ eV}}$

(b) $p = \dfrac{h}{\lambda} = \dfrac{6.63 \times 10^{-34}\text{ J}\cdot\text{s}}{(121.9\text{ nm})(10^{-9}\text{ m/nm})}$

$\boxed{p = 5.44 \times 10^{-27}\text{ kg}\cdot\text{m/s}}$

(c) $E_{photon} = KE_{max} + W_o$

$h\nu = KE_{max} + W_o$

$h\dfrac{c}{\lambda} = KE_{max} + W_o$

$$(6.63 \times 10^{-34}\text{ J}\cdot\text{s})\frac{3.00 \times 10^{8}\text{ m/s}}{(121.9\text{ nm})(10^{-9}\text{ m/nm})} = KE_{max} + (4.7\text{ eV})(1.6 \times 10^{-19}\text{ J/eV})$$

$\boxed{KE_{max} = 8.80 \times 10^{-19}\text{ J} = 5.5\text{ eV}}$

(d) $qV_o = KE_{max}$

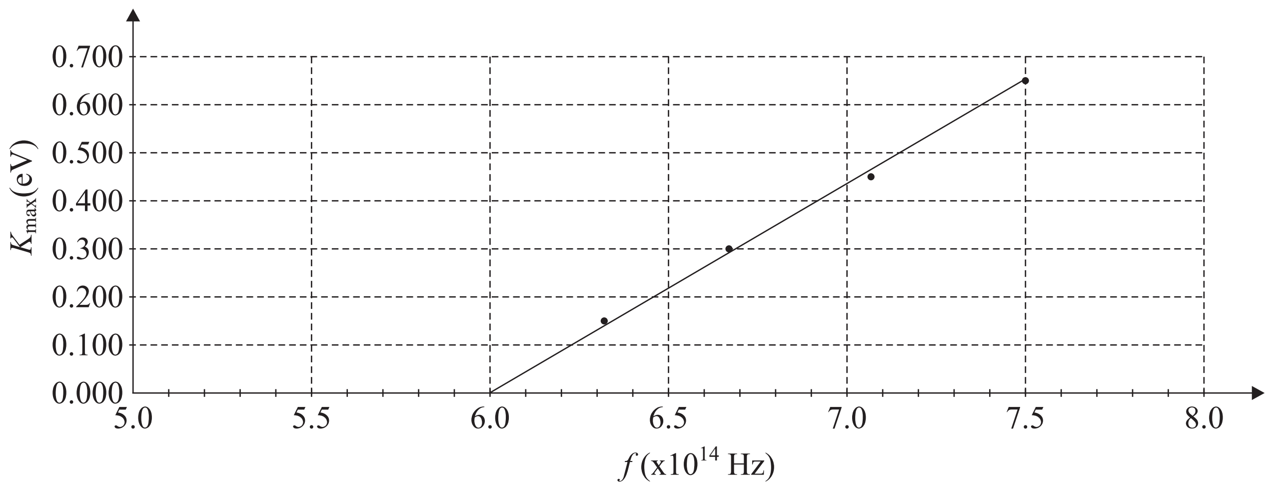
$(1.6 \times 10^{-19}\text{ C})V_o = 8.80 \times 10^{-19}\text{ J}$

$\boxed{V_o = 5.5\text{ V}}$

6. (a)

	M_1	M_2
Ammeter		**X**
Voltmeter	**X**	

(b)



(c) $m = \dfrac{\Delta KE_{max}}{\Delta f} = \dfrac{(0.65\text{ eV} - 0.15\text{ eV})}{(7.50 \times 10^{14}\text{ Hz} - 6.32 \times 10^{14}\text{ Hz})} = \boxed{4.24 \times 10^{-15}\text{ eV}\cdot\text{s} = h}$

$h = (4.24 \times 10^{-15}\text{ eV}\cdot\text{s})(1.60 \times 10^{-19}\text{ J/eV})$

$\boxed{h = 6.78 \times 10^{-34}\text{ J}\cdot\text{s}}$

(d) The x-intercept would be a larger value but the slope would be the same. A larger work function would require more energy to liberate the electron. The x-intercept is the point where the most loosely held electrons (surface electrons) have been liberated but have no KE. As the frequency, and, thus, the energy ($E = hf$), of the photon is increased beyond this liberation point, the energy is converted to KE of the liberated electron. Once the electron is liberated, the relation between the KE_{max} and the frequency is the same so a similar slope should be produced. The following mathematical argument also makes this point:

$E_{photon} = KE_{max} + W_0$, where E_{photon} is the energy of a photon ($E = hf$) and W_0 is the work function of the metal.

$hf = KE_{max} + W_0$

7. (a) $KE = \frac{1}{2}mv^2$ $\qquad$ $E_2 + KE_{min} = E_2' \Rightarrow 20.61\text{ eV} + KE_{min} = 20.66\text{ eV}$

$(0.05\text{ eV})(1.6 \times 10^{-19}\text{ J/eV}) = \frac{1}{2}(4)(1.66 \times 10^{-27}\text{ kg/u})v^2$ $\qquad$ $KE_{min} = 0.05\text{ eV}$

$$\boxed{v = 1.6 \times 10^3\text{ m/s}}$$

(b) $$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}\text{ J}\cdot\text{s}}{(4\text{ u})(1.66 \times 10^{-27}\text{ kg/u})(1.6 \times 10^3\text{ m/s})}$$

$$\boxed{\lambda = 6.2 \times 10^{-11}\text{ m} = 0.62\text{ Å}}$$

(c) $$\Delta E = h\frac{c}{\lambda}$$ $\qquad$ $\Delta E = E_2' - E_1' = 20.66\text{ eV} - 18.70\text{ eV} = 1.96\text{ eV}$

$$(1.96\text{ eV})(1.6 \times 10^{-19}\text{ J/eV}) = (6.63 \times 10^{-34}\text{ J}\cdot\text{s})\frac{(3.0 \times 10^8\text{ m/s})}{\lambda}$$

$$\boxed{\lambda = 6.34 \times 10^{-7}\text{ m} = 634\text{ nm}}$$

(d) $$P = \frac{E_{pulse}}{t}$$

$E_{pulse} = Pt = (0.50\text{ W})(20 \times 10\text{-}3\text{ s}) = 0.01\text{ J}$

$$E_{photon} = h\frac{c}{\lambda} = (6.63 \times 10^{-34}\text{ Js})\frac{3.00 \times 10^8\text{ m/s}}{6.34 \times 10^{-7}\text{ m}} = 3.14 \times 10^{-19}\text{ J}$$

$$\#\text{ photons} = \frac{\text{total energy of pulse}}{\text{energy of one photon}} = \frac{0.01\text{ J}}{(3.14 \times 10^{-19}\text{ J/photon})}$$

$$\boxed{\#\text{ photons} = 3.18 \times 10^{16}\text{ photons}}$$

7. (a) $E = \frac{hc}{\lambda} = \frac{(6.63 \text{ x } 10^{-34} \text{ J} \bullet \text{s})(3.00 \text{ x } 10^{8} \text{ m/s})}{2.0 \text{ x } 10^{-11} \text{ m}}$

$$\boxed{E = 9.9 \text{ x } 10^{-15} \text{ J}}$$

(b) $p = \frac{h}{\lambda} = \frac{6.63 \text{ x } 10^{-34} \text{ J}}{2.0 \text{ x } 10^{-11} \text{ m}} p = \frac{h}{\lambda} = \frac{6.63 \text{ x } 10^{-34} \text{ J} \bullet \text{s}}{2.0 \text{ x } 10^{-11} \text{ m}}$

$$\boxed{p = 3.3 \text{ x } 10^{-23} \text{ kg} \bullet \text{m/s}}$$

(c) __**x**__ Increased ______ Decreased

The energy of the photon will be decreased as some of the energy is transferred to the electron. Since the relationship between the energy of a photon and its wavelength is $E = \frac{hc}{\lambda}$ (an inverse relationship), the wavlength of the photon will increase.

(d) The change in wavelength of the photon is given by

$\Delta\lambda = \frac{2h}{m_e c} = \frac{2 \cdot (6.63 \text{ x } 10^{-34} \text{ J} \cdot \text{s})}{(9.11 \text{ x } 10^{-31} \text{ kg})(3.00 \text{ x } 10^{8} \text{ m/s})} = 4.9 \text{ x } 10^{-12} \text{ m}$. Therefore, the new wavelength will be $\lambda_{new} = \lambda + \Delta\lambda = 2.0 \text{ x } 10^{-11} \text{ m} + 4.9 \text{ x } 10^{-12} \text{ m} = 2.5 \text{ x } 10^{-11} \text{ m}$. The momentum of the new photon can be found by $p = \frac{h}{\lambda_{new}} = \frac{6.63 \text{ x } 10^{-34} \text{ J} \cdot \text{s}}{2.5 \text{ x } 10^{-11} \text{ m}} = 2.7 \text{ x } 10^{-23} \text{ kg} \cdot \text{m/s}$. This momentum is now in the negative direction. So, the momentum of the electron can be determined by momentum conservation as follows:

$$p_{photon} + p_{electron} = p'_{photon} + p'_{electron}$$

$$3.3 \text{ x } 10^{-23} \text{ kg} \bullet \text{m/s} + 0 = (-2.7 \text{ x } 10^{-23} \text{ kg} \bullet \text{m/s}) + p'_{electron}$$

$$\boxed{p'_{electron} = 6.0 \text{ x } 10^{-23} \text{ kg} \bullet \text{m/s}}$$

5. (a) i. $Ke_{max} = qV_0 = (1.6 \times 10^{-19}\ C)(4.5\ V)$

$Ke_{max} = 7.2 \times 10^{-19}\ J$

ii. $Ke_{max} = ½m(v_{max})^2$

$7.2 \times 10^{-19}\ J = ½(9.11 \times 10^{-31}\ kg)(v_{max})^2$

$v_{max} = 1.26 \times 10^6\ m/s$

(b) $hf = Ke_{max} + W_0$

$$h\frac{c}{\lambda} = Ke_{max} + W_0$$

$$(6.63 \times 10^{-34}\ Js)\frac{3x10^8\ m/s}{\lambda} = 7.2 \times 10^{-19}\ J + (2.3\ eV)(1.6 \times 10^{-19}\ J/eV)$$

$\lambda = 1.83 \times 10^{-7}\ m = 183\ nm$

(c) $hf = W_0$

$(6.63 \times 10^{-34}\ Js)f = (2.3\ eV)(1.6 \times 10^{-19}\ J/eV)$

$f = 5.55 \times 10^{14}\ hz$