Problem Set 12.2: The photoelectric effect

1. The photoelectric effect supported the particle model of light in two significant ways. Firstly, the fact there was a threshold frequency which determined whether or not a photoelectron current would flow supported the idea that each quantum of light contains a certain amount of energy; dependant on the frequency of that light. Secondly, the effect of increasing the intensity of the light on the photoelectron current when the light source is above the threshold frequency also supports the idea that the number of photons is related to the intensity.

2. $E = \frac{hc}{\lambda}$
$h = \frac{E\lambda}{c}$
$h = \frac{4.00\times10^{-7}\times1.40\times10^{-19}}{3\times10^{8}}$
$h = 1.87\times10^{-34}\text{J.s}$

$h = \frac{3.00\times10^{-7}\times3.06\times10^{-19}}{3\times10^{8}}$
$h = 3.06\times10^{-34}\text{J.s}$

3. $E_K = hf - W$
$E_K = 6.63\times10^{-34}\times6.7\times10^{14} - 2.14\times1.60\times10^{-19}$
$E_K = 1.02\times10^{-19}\ \text{J}$

4. a) The minimum energy required of a photon incident on the metal surface to liberate an electron.

b) $E = \frac{hc}{\lambda}$
$\lambda = \frac{hc}{E}$
$\lambda = \frac{6.63\times10^{-34}\times3\times10^{8}}{4.08\times1.60\times10^{-19}}$
$\lambda = 3.04\times10^{-7}\text{m}$

c) $E_K = hf - W$
$E_K = 6.63\times10^{-34}\times2.3\times10^{15} - 4.08\times1.60\times10^{-19}$
$E_K = 9.32\times10^{-19}\ \text{J}$

5. a) No effect

b) No effect

c) No effect

d) Different metals have different work functions, which mean there are differences in the minimum frequency of light that will cause photoelectrons to be emitted from the metal (the threshold frequency).

e) According to $= \frac{c}{f}$, the wavelength and frequency are inversely proportional. Increasing the wavelength will cause a decrease in the frequency of the light. If this drops below the threshold frequency, no photoelectrons will be emitted.

f) If the frequency is above the threshold frequency, a higher intensity will increase the photoelectron current. If the frequency is below the threshold frequency, no current will flow, and changing the intensity will not change this.

g) If the surface of the metal is covered (and the material is opaque) light will not be able to strike the surface of the metal. If this is the case, the photoelectric effect will not be seen.

6. a) $E_{photon} = \frac{hc}{\lambda}$

$E_{photon} = \frac{6.63\times10^{-34}\times3\times10^{8}}{325\times10^{-9}}$

$E_{photon} = 6.12\times10^{-19}\text{J}$

$E_{photon} = 3.83\text{ eV}$

$E_K = E_{photon} - W$

$E_K = 3.83 - 5.01$

No solution as the incident energy is below the work function.

b) No effect. The stopping potential is related to the maximum kinetic energy of the electrons that are liberated. Doubling the intensity changes the amount of photoelectrons which are liberated, but not the energy of those electrons (this is related to increasing the frequency of the light). Therefore, there is no effect on the stopping potential.

7. a) At the threshold frequency, electrons are free but have no kinetic energy.

$E_K = hf - W$

$0 = hf - W$

$W = 1.25\times10^{14}\times6.63\times10^{-34}$

$W = 8.29\times10^{-20}\text{J}$

$W = 5.18\times10^{-1}\text{eV}$

b) $\lambda = \frac{c}{f}$

$\lambda = \frac{3.00\times10^{8}}{6.95\times10^{14}}$

$\lambda = 4.31\times10^{-7}\text{m}$

c) $E = hf$

$E = 6.63\times10^{-34}\times6.95\times10^{14}$

$E = 4.61\times10^{-19}\text{J}$

$E = 2.88\text{ eV}$

d) $E_K = hf - W$

$E_K = 2.88 - 5.18\times10^{-1}$

$E_K = 2.36\text{ eV}$

e) $E_K = 2.36\text{eV} = 3.78\times10^{-19}\text{J}$

$E_K = \frac{1}{2}mv^2$

$3.78\times10^{-19} = \frac{1}{2}(9.11\times10^{-31})v^2$

$v = 9.11\times10^5\text{m.s}^{-1}$

8. a) $E_{photon} = \frac{hc}{\lambda}$

$E_{photon} = \frac{6.63\times10^{-34}\times3\times10^{8}}{287\times10^{-9}}$

$E_{photon} = 6.93\times10^{-19}\text{J}$

$E_{photon} = 4.33\text{ eV}$

$E_{K\,MAX} = 3.68\text{ eV}$

$E_K = E_{photon} - W$

$3.68 = 4.33 - W$

$W = 6.51\times10^{-1}\text{eV}$

b) $E_{K\,MAX} = 3.68\text{ eV} = 5.89\times10^{-19}\text{J}$

$E_{K\,MAX} = \frac{1}{2}mv^2$

$5.89\times10^{-19} = \frac{1}{2}(9.11\times10^{-31})v^2$

$v = 1.14\times10^6\text{m.s}^{-1}$

9. a) In order for photoelectrons to be emitted from the surface the photons must have a minimum energy to dislodge them. As E=hf, this corresponds to photons of a minimum frequency. This is different for each material, however. 465nm light must correspond to a frequency which is higher than the threshold frequency in sodium, but not in platinum.

b) The current will increase in sodium as a higher intensity will mean more photons are produced, meaning more electrons will be liberated. As the light is below the threshold frequency for platinum, platinum's current will remain at zero.

c) $\lambda \propto \frac{1}{f}$: increasing wavelength greatly greatly deceases frequency. Sodium will most likely stop producing electrons as a great decrease to frequency would put it below the threshold frequency, and platinum's current will remain at zero.

d) $\lambda \propto \frac{1}{f}$: decreasing wavelength greatly increases frequency. Sodium will continue producing electrons at the same rate, and platinum is likely to produce a photoelectron current as a great increase to its frequency will most likely bring it above the threshold frequency.

e) Current will decrease in sodium, as a small reverse voltage will stop electrons with lower kinetic energy from moving.

10. a) $f = \frac{c}{\lambda}$

$f = \frac{3.00\times10^{8}}{3.55\times10^{-7}}$

$f = 8.45\times10^{14}$ Hz

b) $E = hf$

$E = 6.63\times10^{-34}\times8.45\times10^{14}$

$E = 5.60\times10^{-19}$J

c) $E_K = E_{photon} - W$

$E_K = 5.60\times10^{-19} - 2.64\times10^{-19}$

$E_K = 2.96\times10^{-19}$J

d) $W = \frac{hc}{\lambda}$

$2.64\times10^{-19} = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{\lambda}$

$\lambda = 7.53\times10^{-7}$ m

11. There is no energy change, but there will be a decrease in the number of photoelectrons (a decrease in the current). The light source does not change in frequency so the energy of the photons is constant throughout the entire process. The smoke, however, would cause photon to deflect from their path towards the photocell. This means less photons would interact with the electrons on the surface of the photocell, causing less photoelectrons to be emitted. This means the current would decrease.

12. bi) $f_0 = 9.00\times10^{14}$ Hz (x-intercept of graph)

ii) $h = 6.36\times10^{-34}$J.s (gradient of graph)

iii) $W = 5.71\times10^{-19}$J (y-intercept of graph)