Workshop Tutorials for Physics

Solutions to QR1: **Photons**

A. Qualitative Questions:

1. Light as a wave and particle.

	Wave Model	Particle Model
Brightness	square of wave amplitude	number of photons (flux density)
Colour	frequency or wavelength	energy of photons

2. The photoelectric effect.

a. If the intensity of illumination was doubled the maximum kinetic energy would not change as each electron is ejected by a single photon. Increasing intensity changes the number of photons, not their energy, hence the same energy per photoelectron is still available. However the photocurrent, which depends on the number of photons, would increase.

b. If the length of time of exposure to light was doubled the electron kinetic energy would not change. See **a** for explanation.

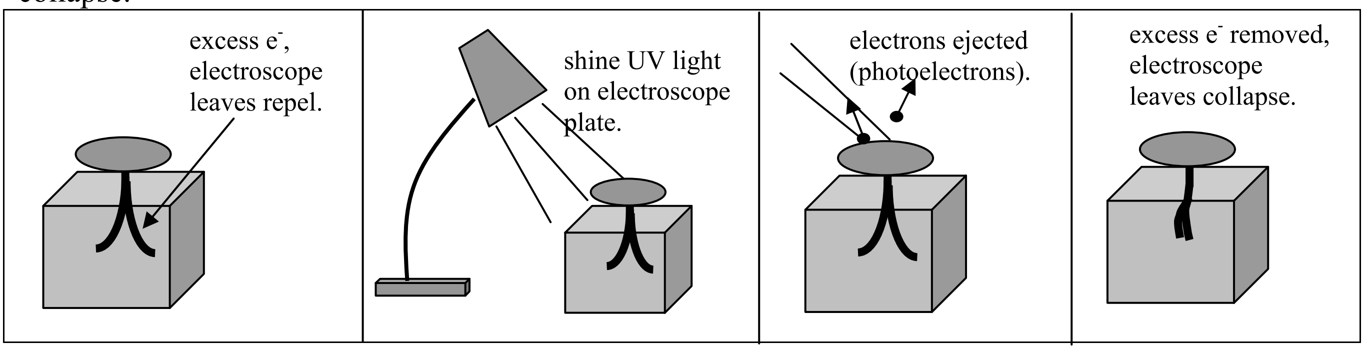
c. If the frequency of the light was doubled then the energy of each photon, $E = hf$, would also be doubled, hence the energy of the ejected electrons would also increase. $K_{max} = hf - \Phi$, if $f \rightarrow 2f$ then the $K_{max} \rightarrow 2hf - \Phi$. (Note that it more than doubles because the work function doesn't change.)

d. If the material of the surface was changed the work function would be different, hence the amount of energy from the photon which becomes kinetic energy would also change. If Φ increases, K decreases and vice versa.

B. Activity Questions:

1. Photoelectric effect

The UV light removes electrons from the negatively charged electroscope, which allows the leaves to collapse.



The Photoelectric Effect is one of the first topics studied in quantum mechanics to introduce experimental evidence of the particle nature of light. This experiment clearly shows the inadequacy of the wave model. The photoelectric effect is dependent on frequency. The wave model predicts that the ejection of electrons will occur at any frequency, given enough intensity. This is not observed. The particle model, which requires that light be absorbed by the electrons in discrete quanta, each with energy hf, accounts for the cut-off frequency. The electron requires at least as much energy as the work function, Φ, to be ejected from the material, hence the lowest frequency which will allow an electron to be ejected is $f_{cut\text{-}off} = \Phi/h$.

2. Wave and particle nature of light 1- interference pattern

This demonstrates the wave nature of light. A particle could only pass through one slit or the other. However, a wave can pass through both slits simultaneously and interfere with itself.

3. Wave and particle nature of light 2- emission spectra

If you accept that the spectral lines result from transitions of electrons from one energy level to another, then the excess energy of an electron when it jumps down from one energy level to another is released as a photon. These lines have discrete colours (frequencies) and correspond to photons of different energies.

C. Quantitative Questions:

1. The photoelectric effect and the photoelectric equation.

a. $hf = \Phi + K_{\text{max}}$

The energy provided by the photon is conserved in the collision, with some being used to overcome the attraction between the electron and the target material, allowing it to escape the material, (the work function) and the remainder being carried off by the electron as kinetic energy. Hence this equation is a statement of conservation of energy.

b. There will be a range of kinetic energies, from zero to K_{max}, as many of the electrons lose some of the energy they have gained from the photon before being ejected, so their kinetic energy is

$K = K_{max} - E_{lost}. = hf - \Phi - E_{lost}.$

These energy losses are usually considered to be due to collisions within the material.

c. using $hf = \Phi + K_{\text{max}}$,

$K_{max} = hf - \Phi$

$= h\,(c/\lambda) - \Phi$

$= 6.63 \times 10^{-34}$ J.s $(3.00 \times 10^{8}$ m.s$^{-1}/200 \times 10^{-9}$ m$) - 4.20$ eV $\times 1.60 \times 10^{-19}$ J.eV^{-1}

$=3.23 \times 10^{-19}$ J or $2.02 \times$ eV

d. $K_{min} = 0$ J. An electron may lose any amount of energy up to $(hf - \Phi)$ and still be ejected. If an electron loses more than this it will not be ejected and the energy will be dissipated as thermal energy (heat) in the material.

e. The stopping potential will be $V_{\text{stop}} = K_{max} / e = 3.23 \times 10^{-19}$ J / 1.60×10^{-19} C = 2.02 V

f. The cut-off wavelength for aluminium is when $hf = \Phi$,

so $\lambda = hc / \Phi$

$= 6.63 \times 10^{-34}$ J.s $\times 3.00 \times 10^{8}$ m.s^{-1} / 4.20 eV $\times 1.60 \times 10^{-19}$ J.eV^{-1}

= 295 nm.

2. A caesium surface is illuminated with 600 nm light from a laser.

a. The energy of the photons emitted from this laser is

$E = hf = hc/\lambda = 6.63 \times 10^{-34}$ J.s $\times 3.00 \times 10^{8}$ m.s^{-1} / 600×10^{-9} m $= 3.31 \times 10^{-19}$ J or 2.07 eV.

b. The laser has a power of 2.00 mW, which is 2.00×10^{-3} J per second. The number of photons emitted per second is therefore 2.00×10^{-3} J.s^{-1} / 3.31×10^{-19} J per photon = 6.03×10^{15} photons.s^{-1}

Photosensitive surfaces are not always efficient. Suppose the fractional efficiency of a Cs surface is 1.00×10^{-16} (one in every 1.00×10^{16} photons ejects an electron).

c. We will get 1.00×10^{-16} electrons per photon, and we have 6.03×10^{15} photons.s^{-1}, so the number of electrons ejected per second is 1.00×10^{-16} electrons per photon $\times 6.03 \times 10^{15}$ photons.s^{-1} = 0.603 electrons per second.

d. If every photoelectron takes place in charge flow, then we have 0.603 electrons per second, which is 0.603 electrons.s^{-1} $\times 1.60 \times 10^{-19}$ C. electron^{-1} = 9.6×10^{-20} C.s^{-1} or 9.6×10^{-20} A.

e. A photoelectron is just an electron which has been ejected from its orbital by a photon, it's exactly the same as any other electron, a photocurrent is a current due to photoelectrons and is the same as the flow of any other electrons.