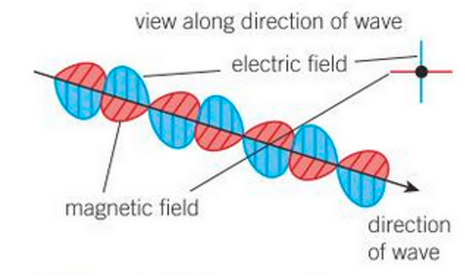
Photons and the Photoelectric Effect

21 January 2020 10:32

Doubtless you know all about electromagnetic waves. It is really helpful to have these figures (or at least some of them) at your fingertips. For some reason I remember the wavelength of the first laser I used - 660nm - it was red.

Type	radio	microwave	infrared	visible	ultraviolet	X-rays	gamma rays
Wavelength range	>0.1 m	0.1 m to 1 mm	1 mm to 700 nm	700 nm to 400 nm	400 nm to 1 nm	10 nm to 0.001 nm	<1 nm

The classic diagram of an e/m wave is something like this:



You can see magnetic and electric fields at 90 degrees and in phase. What is really odd is that normally we talk about waves needing a medium to propagate through - ie air for sound, water for ... Well, water waves. E/M waves are able to go through the vacuum of space - ie there appears to be no medium.

E/m waves are emitted as short bursts or packets of energy, often in random directions (not always though eg laser).

Energy of a photon depends on its frequency and Plank's constant: $E = hf$

If you have n photons passing a point in 1 second, then you can work out the power of the e/m by doing

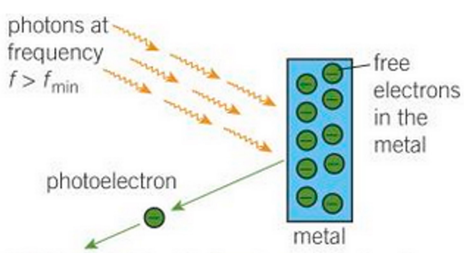
$$E = \mathrm{n}hf$$

The Photoelectric Effect

As you know there are conduction electrons in metals. When e/m is 'shone' onto a metal it can emit electrons from its surface. However, what was more interesting was that you had to have e/m above a certain frequency. This frequency depended on the metal, as well as other factors. Some important points:

- If you lowered the frequency even a tiny bit below this frequency then NO electrons were emitted. If you increased the frequency then electrons carried on being emitted. This is the threshold frequency and the effect became known as the 'Photoelectric Effect'.
- The number of photons emitted in a second depends on the intensity of the e/m radiation. If you go below the threshold frequency it doesn't matter how intense you make the radiation - no electrons are emitted.
- Electrons are emitted instantly - at the time this was a surprise. As long as you are at or above the threshold frequency then the electrons are emitted straight away - there is no 'buliding up' of energy...

All this was evidence that light is not behaving as a wave. If you have a wave then energy is arriving constantly as the wave travels - you'd therefore expect that the energy of the conduction electrons would build up steadily until 'ping' they are emitted. Not so!



Einstein in 1905 put forward the idea that the e/m radiation consisted of particles. He said:

- The conduction electons absorb single photons of energy = hf
- An electron can leave the surface if it has absorbed energy greater than the work function, ϕ. So ϕ is the minimum energy

needed by an electron to escape the metal

- If the photon that is absorbed has more energy than ϕ then the rest becomes kinetic energy.

$$E_{Kmax} = hf - \phi \Rightarrow hf = E_{Kmax} + \phi$$

And for emission to take place $$f_{min} = \frac{\phi}{h}$$

If you make the metal positive then you can attract the emitted electrons back. You can therefore stop the emission (effectively). The voltage needed to do this is called the stopping potential V_s

This reduces the maximum kinetic energy to zero, and so we know that the energy would have been eV_s (e being the charge on the electron)

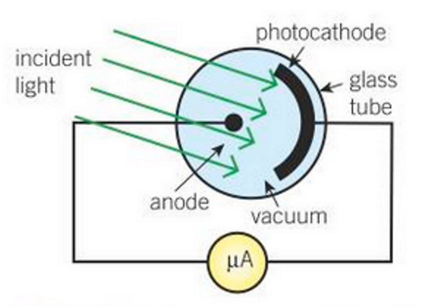
A chap called Millikan did some experiments measuring the max KE of various metals. His results seemed to fit well with Einstein's formulas - the concept of photons was becoming accepted.

Conduction Electrons in a metal

These move about at random (unless there is a current) and their average E_k depends on the temperature of the metal. The work function ϕ is of the order of 10-19J, which is some 20 times bigger than the Ek of the conduction electrons.

When a conduction electron absorbs and photon it gains the photon's energy as Ek. If the energy is less than ϕ then the electron can't leave the surface, but has a higher Ek - so it whizzes around having collisions and losing that Ek.

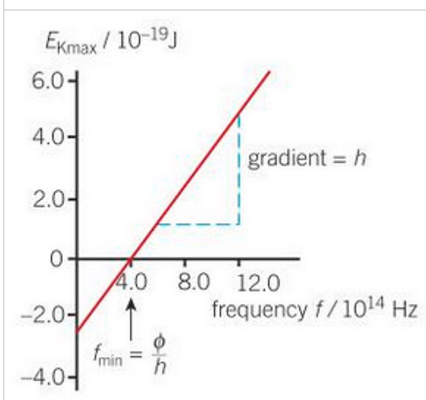
Vacuum Photocell



Electrons are emitted at the photocathode by the photoelectric effect. These are then attracted to the anode (why??? - other diagrams on the search engine of your choice show a small cell to create a potential...)

The current is proportional to the intensity of the light. More photons (at the same frequency) means more e^- emitted and more current

Intensity of the light does not effect the max Ek. The energy gained by the e- is always down to one absorption.



If you vary the frequency and measure the Ek max you get this graph

Since $E_{Kmax} = hf - \phi$ & remembering $y = mx + c$ we can see the gradient = h & y intercept = $-\phi$ → we can also see the threshold freq.