Module 4 Section 3: Quantum Physics

Photons

He believed that a photon acted as a neutral particle. He said that it would either transfer all or none of its energy when interacting with one other particle (this is called a **one-to-one interaction**). The energy, E, carried by one of these photons had to be:

$$E = hf$$

E = energy of one photon in J

f = frequency of light in Hz

h = Planck's constant = 6.63×10^{-34} Js

So, the higher the frequency of the electromagnetic radiation, the more energy its photons carry. The frequency, wavelength and speed of light are related by the equation:

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

f = frequency in Hz

c = speed of light in a vacuum = 3.00×10^{8} ms^{-1}

λ = wavelength in m

You can substitute this equation into $E = hf$ to give another equation for the energy of one photon:

$$E = hf = \frac{hc}{\lambda}$$

The Electronvolt

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

e = charge of one electron in C

v = speed of the electron in ms^{-1}

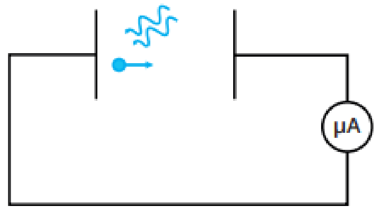
V = potential difference between electrodes in V

m = mass of an electron in kg

1 electronvolt = $e \times V = 1.60 \times 10^{-19}$ C $\times$ 1 JC^{-1}

The Photoelectric Effect

When light with enough energy hits the surface of a metal electrons are released.



Key observations from the experiment include:

- The current produced due to the electrons being released was unaffected by changing the brightness of the light.
- Changing the frequency of the light, changed the current.
- If the frequency of the light was too low, no electrons were released no matter how bright the light was.

This all meant that one packet of light interacted with one electron, proving that light behaved as photons.

The energy of the photons can be calculated using these equations;

$$E = hf = \frac{hc}{\lambda}$$

Equation:

By applying a potential difference to oppose the current in the above circuit, it is possible to measure the p.d. required to just stop the current. This is equivalent to the maximum kinetic energy of the released electrons.

$$E_{k\,max} = e\,V_{stop}$$

This can be used in the equation to calculate the work function, ϕ, of the metal. **The work function is the energy required to just release an electron.**

$$E_{k\,max} = hf - \phi$$

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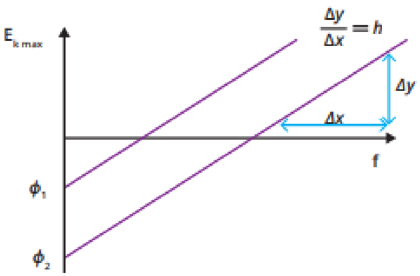
Photoelectric Effect - 2

Comparing the equation $E_{k\,max} = hf - \phi$ to

$$y = mx + c$$

Predicts that a graph of $E_{k\,max}$ against f will be a **straight line with gradient = h and a negative intercept equivalent to ϕ.**

This graph shows the results for two different metals, note that they have the **same gradient** but **different intercepts**.



Wave-particle duality

Electron diffraction:

When **electrons** are accelerated towards graphite crystals, a **diffraction pattern** is produced. This proves that electrons have wave like properties.

This means that waves and particles can behave in similar ways. Louis de Broglie predicted that you could calculate the **momentum of a wave**, or the **wavelength of a particle**, using this equation;

$$p = \frac{h}{\lambda}$$

Planck Constant

$$eV_0 = \frac{hc}{\lambda}$$

e = *charge of one electron in C*

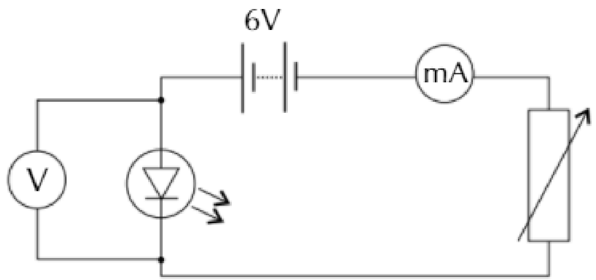
V_0 = *threshold voltage in V*

$\frac{hc}{\lambda}$ = *energy of one photon*

Then rearrange this for the Planck constant to get:

$$h = \frac{eV_0\lambda}{c}$$

To determine the Planck constant from an LED, you will need to set up the circuit shown in Figure 2.



- Start off with the variable resistor set to its maximum resistance, so no current can flow through the circuit.
- Adjust the variable resistor until a current just begins to flow through the circuit (and the LED lights up).
- Record the voltage across the LED. This is the threshold voltage, V_0.
- Record the wavelength of the light emitted by the LED.
- Disconnect the circuit to allow all of the components to cool.
- Repeat the experiment several times and take an average of your result for V_0.
- Then repeat the experiment for a range of LEDs.