

3.1 Photo- electricity 2

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Einstein's quantum explanation of the photoelectric effect

- Einstein used Planck's quantum theory of radiation, (see Revision Card AS12), to explain photoelectric emission. He assumed that a beam of light was not a continuous stream of waves but a spray of wave packets which he named **photons**.

[Photons are not particles but pure energy. Quantum mechanics describes them using a phasor, which is a complex number but which we can think of as a rotating vector, rather like the hand of a stopwatch. The frequency at which the phasor rotates is the frequency of the radiation and the length or amplitude of the phasor is related to the intensity of the radiation. In fact, the intensity is proportional to the amplitude squared].

The energy of a photon is proportional to its frequency (f):

$$\text{photon energy} = hf = \frac{hc}{\lambda}$$

where h is Planck's constant (6.63×10^{-34} Js) and λ is the wavelength of the radiation.

- Einstein explained that each photon is absorbed by only one electron. That electron therefore gains hf joules of energy. (You cannot have half a photon, so the electron gains all or nothing).

- If hf is greater than the minimum energy needed to escape from the metal surface, (known as the **work function** of the metal, ϕ), the electron will be emitted.

- Applying the law of conservation of energy, he came up with an equation for the maximum kinetic energy with which an electron could fly out:

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

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- If a photon has just enough energy to release an electron from the metal surface, so that the electron emerges with no kinetic energy, then

$$0 = hf_{min} - \phi$$

So

$$hf_{min} = \phi$$

f_{min} is known as the threshold frequency for the metal.

Conduction Electrons in Metals

- The free electrons, or conduction electrons, in a metal require in the region of 10^{-19} J of kinetic energy to escape from the metal surface. In normal circumstances, they do have some kinetic energy because of the metal's temperature. This gives them their random motion but, at room temperature, this is only about 10^{-21} J, which is far too little to escape.
- When photons above the threshold energy are absorbed by conduction electrons, the electrons' kinetic energy increases and they can escape. If photons of below the threshold energy land on the metal, they are absorbed by the conduction electrons but the electrons lose the energy again by repeated collisions with other electrons and with the ions of the metal lattice.
- Different metals have different work functions. The more reactive the metal, the lower its work function will be.
- Zinc, for example, has $\phi = 6.88 \times 10^{-19} \text{ J}$ and therefore needs photons with energies at least as high as ultraviolet to release its electrons.
- Caesium, on the other hand, has $\phi = 3.36 \times 10^{-19} \text{ J}$ so photons of all the visible frequencies from violet down to red are able to release electrons from a caesium surface.

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