

Electromagnetic radiation and quantum phenomena

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Photoelectric effect

Photoelectric effect:

a term for the process of electron emission from the surface of a metal due to light incident on its surface

Photoelectric equation:

$$hf = \phi + E_k$$

ϕ = work function
 h = Planck constant = 6.63×10^{-34} J s
 f = frequency of photons
 E_k = kinetic energy of electron

Terms of the photoelectric effect

- Threshold frequency:** the minimum frequency required to emit electrons from the surface of a metal
- Work function:** a property of materials that indicates the minimum work required to remove an electron from the surface of the metal
- Stopping potential:** the potential needed to stop an electron from leaving the atom
- $E_{k \text{ max}}$:** the maximum possible kinetic energy of the photoelectrons

Photon explanation of threshold frequency

- For electrons to be emitted from the surface of a metal, they must be given enough energy – energy that is equivalent to the value of the work function of the metal.
- This energy is supplied by the photons incident on the metal surface.
- The energy of the photons depends on the frequency of the photons ($E = hf$).
- Therefore, there is a threshold frequency associated with photons that will ensure the photon has sufficient energy to emit an electron.

Wave-particle duality

While light is historically considered a wave, and electrons particles, there are several phenomena in which light acts as particles and electrons act as waves

Demonstration of wave-like and particle-like behaviour

- The process of electron diffraction is evidence of particles displaying wave properties.
- The photoelectric effect is evidence that electromagnetic waves have particle properties.

Collisions of electrons with atoms

Ionisation:

a process of creating ions by an atom either gaining or losing an electron

Excitation:

a process whereby atoms absorb energy, causing an electron to move to higher energy levels without ionisation

De-excitation:

An electron moves from higher energy state to lower energy state and emits a photon in the process.

Excitation

An electron moves from lower energy state to higher energy state by absorbing the energy of a photon.

Ionisation

An electron absorbs a photon with energy greater than the binding energy of the electron, and the electron is emitted from the atom.

Ionisation and excitation in a fluorescent tube

- Fluorescent tubes emit visible light due to the processes of excitation and ionisation:
 - The tube contains mercury vapour. When the mercury atoms collide with electrons, ionisation and excitation occur.
 - Through ionisation and excitation, the mercury atoms emit radiation in the form of ultraviolet photons.
 - The inside of the glass tube is covered in a fluorescent coating, and the atoms that comprise the coating absorb the ultraviolet photons.
 - This causes further excitation.
 - De-excitation then occurs in the atoms of the coating, and visible light photons are emitted.

Line spectra are patterns of discrete lines of light due to emission or absorption that are characteristic to elements. Line spectra from atoms are evidence for transitions between discrete energy levels.

Energy levels and photon emission

Energy levels



$$\text{photon emitted: } hf = E_1 - E_2$$

The energy of the photon ($E = hf$) emitted due to de-excitation or absorbed due to excitation can be determined from the energy difference between the energy levels the electron has transitioned between.

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

Remember: when working with energies on a subatomic level, you will need to be comfortable using the electron volt:

1 eV = amount of energy an electron gains as it is accelerated across a potential of 1 V

De Broglie equation:

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

λ = wavelength
 h = Planck constant = 6.63×10^{-34} J s
 m = mass
 v = velocity

- The equation can be used to determine the wavelength of an electron undergoing electron diffraction.
- As the momentum increases, the wavelength decreases and the amount of diffraction decreases.
- As the momentum decreases, the wavelength increases and the amount of diffraction increases.

Advancements in our understanding

- Quantum mechanics is a relatively new branch of physics, and, therefore, our knowledge of subatomic particles and their properties is continually advancing.
- Research and experiments are continually being carried out at centres such as CERN.
- Adaptions, advancements and improvements on the theory and models already established are evaluated through peer-review by other scientists and validated by the scientific community.

