Electromagnetic radiation and quantum phenomena

The photoelectric effect

- If we shine light with high enough frequency on metals, photoelectrons are released.
  - No photoelectrons emitted if the incident frequency < threshold frequency, f_T
  - Rate of electron emission ∝ intensity
- The photoelectric effect could not be explained by wave theory as this states:
  - For a certain frequency, energy ∝ intensity
  - Energy would spread evenly across the wavefront
  - Each free electron would gain some energy
  - Gradually each free electron would gain enough to leave

No explanation for E_k depending only on f, or for the existence of Phy_T could only be explained by the theory of "packets" (i.e.photons).

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

For e^- release, $hf \geq \phi$ (work function) so $f_T = \frac{\phi}{h}$

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

Stopping potential gives max E_k: $e \times V_s = E_{k\,max}$

Energy levels

- e^- can move down an energy level by photoemission
- $e \times V = E_k$ carried by an electron accelerated through a 1V potential difference
- Energy gained by electron = accelerating potential difference
- Energy carried by each photon is equal to the difference in energy between the two levels (E2 = lower energy level):

$$\Delta E = E_2 - E_1 = hf$$

- In **excitation** electrons move up energy levels if they absorb a photon with sufficient energy to cover the difference.
- If electrons emit photons, they can move down energy levels - de-excitation. Energy of the photon emitted = $hf = E_1 - E_2$ (E_2 lower level)
- If an electron is removed from an atom it is **ionised** - energy of each level in the atom is equal to the energy required to ionise from that level.
- Ground state = "ionisation energy"

Line spectra are evidence for the transitions between discrete energy levels in atoms. If we look at a tube of glowing gas through a prism we see a spectrum of discrete lines, rather than continuous colours. The pattern of wavelengths is unique to each element. The wavelength is linked to the energy of the photons released when electrons de-excite.

The fluorescent tube

1. An initial high voltage is applied across mercury vapour. This **accelerates** free electrons, which **ionise** some of the mercury atoms, producing **more** free electrons
2. Free electrons collide with electrons in other mercury atoms, **exciting** them to higher levels.
3. When the excited electrons **return to ground states** they emit **UV photons**.
4. **Phosphor** coating on the tube **absorbs** these particles, **exciting** its electrons.
5. The excited phosphorous electrons **de-excite in steps**, emitting lower energy visible photons.

Wave-particle duality

- Interference and diffraction show light as a wave, but the photoelectric effect shows it as a particle.
- Electron diffraction shows the wave nature of electrons
  - Diffraction patterns showed when accelerated electrons in vacuo interact with the spaces in graphite crystal
  - Following wave theory, the spread of the lines increased if wavelength increased. Slower electrons = wider spacing.

$$\textbf{de Broglie } \lambda = \frac{h}{mv}$$

- A vacuum photocell is a glass tube containing two metal plates - a photocathode and photoanode, when light of frequency ≥ f_T of the metal is incident on the photocathode, electrons are emitted from the cathode and are attracted to the anode. A microammeter can measure the photoelectric current, which is proportional to the number of electrons per second that transfer from the cathode to the anode.