3 Quantum Phenomena

3.1 The Photoelectric Effect

Conduction electrons move about freely inside the metal. It was found that sparks produced by a **spark detector** when ultraviolet radiation was directed at the spark gap.

Further investigation showed that electrons are emitted from the surface of a metal when electromagnetic radiation above a certain frequency was direct at the metal. This is known as the **photoelectric effect**.

- Photoelectric emission of electron from a metal surface does not take place if the frequency of the incident electromagnetic radiation is below a certain value known as the **threshold frequency**.
- The number of electron emitted per second is proportional to the intensity of the incident radiation, provided the frequency is greater than the threshold frequency.
- Photoelectric emissions **occur without delay** as soon as the incident radiation is directed at the surface. Provided the frequency exceeds the threshold frequency, and reguardless of the intensity.

Observations from the photoelectric effect could not be explained using the **wave theory** of light.

- The **existence of a threshold frequency** - each conduction electron at the surface of a metal should gain some energy from the incoming waves.
- Why photoelectric emission **occurs without delay**.

The Photon Model of Light

The photon theory of light was put forward to explain the photoelectric effect.

- Light is composed of **wavepackets** or photons.
- Each photon has energy $E = hf = hc/\lambda$.

To explain the photoelectric effect

- When light is incident on a metal surface, an electron at the surface **absorbs a single photon** from the incident light and therefore gains energy equals to hf - the energy of a photon.
- An electron can leave the metal surface if the energy gained from a single photon exceeds the **work function** ϕ of the metal.
  - The **work function** is the minimum energy needed by an electron to escape from the metal surface.
  - Excess energy gained by the photoelectron becomes its kinetic energy.

The maximum kinetic energy is given by

$$E_{\mathrm{Kmax}} = hf - \phi$$

Emissions can take place provided $E_{\text{Kmax}} > 0$, so the threshold frequency of the metal is

$$f_{\text{min}} = \frac{\phi}{h}$$

Stopping Potential

Electrons that escape from the metal plate can be **attracted back** by giving the plate a sufficient positive charge.

- The minimum potential needed to stop photoelectric emission is called the **stopping potential** V_s.
- At this potential, the maximum kinetic energy of the emitted electron is reduced to zero because each electron must do extra work $e \times V_s$ to leave the surface.

Conclusive experimental evidence of the photon theory was obtained by

- Measuring the stopping potential for a range of metals.
- Using light of different frequencies.

The results fitting the photoelectric equation very closely.

3.2 More about Photoelectricity

The energy of each vibrating atom is **quantised** - only certain levels of the energy are allowed, and energy could only be in multiples of a basic amount, or **quantum**.

- If a conduction electron absorbs a photon but does not leave the metal, it **collides repeatedly** with other electrons and positive ions, quickly loses its extra kinetic energy.

The Vacuum Photocell

A vacuum photocell is a glass tube that contains

- A metal plate, referred to as the **photocathode**.
- A smaller metal electrode, referred to as the **anode**.

When light of a frequency greater than the threshold frequency for the metal is directed at the photocathode, electrons are emitted from the cathode and are attracted to the anode. A microammeter can be used to measure the **photoelectric current** proportional to the number of electrons per second that transfer from the cathode to the anode.

- The number of **photoelectrons** transferred per second is given by $n = I/e$.
- The photoelectric current is **proportional to the intensity** of the light incident on the cathode - each electron must have absorbed one photon to escape from the metal surface.
  - **Light intensity** is a measure of energy per second carried by the incident light.
  - Which is proportional to the number of photons per second incident on the cathode.

- The intensity of the incident light does not affect the **maximum kinetic energy** of a photoelectron.
  - No matter how intense the incident light is, the energy gained by a photoelectron is due to the absorption of one photon only.
- The **maximum kinetic energy** of the photoelectrons emitted for a given frequency of light can be measured using a photocell.
- A graph of E_{Kmax} against f
  - The gradient is h
  - The x-intercept is the **threshold frequency**.
  - The y-intercept is the **work function**.

3.3 Collisions of Electrons with Atoms

An **ion** is a charged atom - the number of electrons in an ions is not equal to the number of protons.

An ion if formed from an **uncharged atom** by adding and removing electrons from the atom. Any process of creating ions is called **ionisation**

- Alpha, beta and gamma radiation create ions when they pass through substances and **collide with atoms** of the substance.
- Electrons passing through a fluorescent tube create ions when they **collide with atoms** of the vapour in the tube.

The **electron volt** is a unit of energy equal to the work done when an electron is moved through a pd of 1V.

Excitation by Collision

Gas atoms can absorb energy from colliding electrons without being ionised, this process is known as **excitation**. It happens at **certain energies**, which are characteristics of the atom.

- If a colliding electron loses all its kinetic energy when it causes excitation, the current due to the flow of electrons through the gas is **reduced**.
- If a colliding electron does not have enough kinetic energy to cause excitation, it is **deflected by the atom** with no overall loss of kinetic energy.

The energy values at which an atom absorbs energy are known as its **excitation energies**.

The excitations energies of atoms in a gas-filled tube can be determined by

1. Increasing the potential difference between the filament and the anode, and
2. Measure the pd when the anode current falls.

When excitation occurs, the colliding electron makes an atomic electron move from an inner shell to an outer shell. Energy is needed to move the atomic electron away from the nucleus.

The excitation energy is <u>always less than the ionisation energy</u> of the atom, because the atomic electron is not removed completely from the atom when excitation occurs.