**Chapter 29: The Electron**

**Properties of the electron**

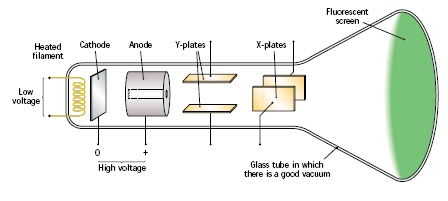
* Orbits the nucleus
* Very small mass
* Negatively charged
* The charge on the electron is the smallest amount of charge found in nature\*.

The man responsible for first measuring this **charge** was **Robert Millikan**.

The term ***electron*** was coined by an Irishman called **George Stoney**.

**Thermionic Emission is the giving off of electrons from the surface of a *hot* metal.**

**The Cathode Ray Tube\***

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**Operation**

1. A current is passed through the heating coil, causing it to heat the cathode which in turn causes electrons to be emitted (by thermionic emission).
2. Because of the high potential difference between the cathode and anode the electrons are accelerated across the tube towards the anode.
3. Electrons which pass through the hole in the middle of the anode continue on until they hit the fluorescent screen.
4. The stream of electrons can be deflected by electric or magnetic fields.

**Uses of the Cathode Ray Tube**

1. **Cathode Ray Oscilloscope (CRO).** This is used today in electronics as a diagnostic tool.
2. It also forms the main component **in televisions and computers**.
3. **The ECG** (electrocardiogram) **is used in medicine** **to display electrical signals in the heart.**

Alternatively **it can be used to display signals produced by the brain, where it is known as an EEG** (electroencephalogram).

**Cathode rays are streams of high-speed electrons**

**Properties of cathode rays**

* They travel in straight lines
* They cause certain substances to fluoresce
* They can be deflected in electric and magnetic fields
* They can produce x-rays when they strike heavy metals

**Energy associated with an electron\***

**An electron’s energy is given by the formula W= QV**

**W = QV**

**The Electronvolt (eV)**

**The electronvolt (eV) is the energy lost or gained by an electron when it accelerates through a potential difference of one volt.**

**1eV =1.6 x 10–19 Joules**

**An electron’s potential energy (W= QV) can be converted to kinetic energy (W = ½ mv2)**

**QV = ½ mv2**

**Electrons in a magnetic field\***

**A beam of electrons moving at right angles to a magnetic field will move in a circular path\*.**

We know that the force on a charge q moving at velocity v in a magnetic field B is given by

**F = Bqv ⇒** (where e = charge on an electron)

**F = Bev**

We also know when something is moving in a circular path at constant speed it experiences a centripetal force F, where

**F = mv2/r**

**mv2/r = Bev**

Now putting these two together we get

Where m is the mass and r is the radius of the circle.

By rearranging this expression we can find the radius of orbit if we know everything else.

*Note for each of the previous three equations v = velocity, not voltage*

**The Photoelectric Effect**

**The Photoelectric Effect is the emission of electrons from a metal due to light of a suitable frequency falling upon it.**



**Demonstration**

**Procedure**:

1. Place a clean piece of zinc on an electroscope.
2. Charge the electroscope negatively.
3. Shine ultraviolet light on the zinc plate.

**Result**:

The leaves fall together

**Observation**:

Shining UV light on the zinc plate frees electrons from the zinc and therefore the electroscope discharges.

**Einstein’s Explanation**

1. Light consists of photons.
2. The photons energy is absorbed by an electron at the surface of a metal.
3. A certain amount (the work function) goes to liberating the electron.
4. The remainder appears as kinetic energy of the liberated electron.
5. Shining visible light has no effect on the apparatus. This is because the packets of energy associated with visible light are too small to liberate electrons.

**A photon is a bundle of electromagnetic radiation.**

**E = hf**

The energy associated with each photon is givenby

h is known as planck’s constant (its values is 6.6 × 10-34 Js) and f is the frequency of the wave.

**Einstein’s photoelectric law**

**Energy of incident photon = work function + kinetic energy of photo-electron.**

**hf = φ + ½mv2**

φ (“phi”) is known as the work function.

It represents the energy required to ‘liberate’ an electron from the surface of a metal.

φ = hf0, where f0 is called the threshold frequency.

The value of the work function is different for different metals.

***A photon checks into a hotel and the porter asks him if he has any luggage.***

***The photon replies: “No, I’m travelling light.”***

**The Photocell**

**Operation**

1. Light of a suitable frequency shines on the cathode.
2. This releases electrons (by the Photoelectric Effect).
3. The electrons are attracted to the anode and from there they flow around the circuit, where they can be detected by a galvanometer.

**Applications of photoelectric sensing devices**

* Burglar alarms
* Automatic doors

**X-Rays**

**X-rays are produced** when high-energy electrons collide with a high density target.



**Operation of the X-ray tube**

1. The low voltage supplies power to a filament which in turn heats the cathode at A.
2. Electrons are emitted from the hot cathode due to Thermionic Emission.
3. They get accelerated across the vacuum due to the very high voltage and smash into the high-density anode (usually tungsten) at B.
4. Most of the kinetic energy gets converted to heat, which must be removed with a coolant.
5. Some inner electrons in the tungsten get bumped up to a high orbital, then quickly fall back down to a lower lever, emitting X-rays in the process.
6. These X-rays are emitted in all directions.
7. Most of these get absorbed by the lead shielding, but some exit through a narrow window, where they are then used for the required purpose.

**Properties of X-Rays:**

* They are Electromagnetic Waves
* They cause ionisation of atoms
* They have high penetration powers

**Uses of X-rays**

* Medicine: To detect broken bones
* Industry: To detect breaks in industrial pipes

Why can X-ray production be considered as the inverse of the Photoelectric Effect?

**Hazards\***

They can cause cancer.

**Extra Credit**

About one hundred years ago, several remarkable and highly-important discoveries were crowded into the short space of ten years: X-rays in 1895, radioactivity the following year, the electron in 1897, quantum theory in 1900, and special relativity in 1905.

Individually, each had enormous significance and collectively they heralded what is now known as ‘modern physics’.

**\*The charge on the electron is the smallest amount of charge found in nature**Physicists still don’t know why an electron has the same charge as a proton!

Later on we will come across particles called quarks, some of which have a charge of 1/3rd that of the electron. But these are not found isolated in nature.

**\*The Cathode Ray Tube**

This phenomenon was noticed before people were familiar with the concept of the electron.

What was known was that if a fluorescent screen was placed on the inside of the tube, fluorescence would occur.

Therefore something seemed to be coming from the cathode.

Because the electrons could not be seen, this ‘something’ was called **cathode rays**, and the apparatus was called a **cathode ray tube**.

Incidentally, the cathode ray tube was first developed by Sir William Crookes, of Crooke’s Radiometer fame (remember what that is?). Crooke was a major player in the world of physics in the late 19th century.

Crooke later lost all respectability among his peers due to his willingness to get involved in physic research (being able to read someone else’s mind and all that). Crookes' final report so outraged the scientific establishment that there was talk of depriving him of his Fellowship of the Royal Society.

**\*The Cathode Ray Tube forms the main component in televisions and computers.**

For this the screen is divided up into little squares called ‘pixels’ (from ‘picture elements’).

The ‘electron-gun’ scans across each row of pixels, starting at the top left hand corner and working down, changing intensity as it travels.

Each pixel stays bright for a fraction of a second, but before it starts to fade the gun has gone back over it and ‘refreshed’ it.

The quality of a television screen is therefore determined by, among other things, the speed at which the gun travels, and the number of pixels on the screen. For example, a 640-by-480 pixel screen is capable of displaying 640 distinct dots on each of 480 lines, or about 300,000 pixels.

For colour televisions there are actually three ‘guns’ involved, each having one of the three primary colours, and the product of their relative intensities determine the colour seen on a given part of the screen.

‘Course by the time you read this the cathode ray tube will probably be obsolete.

**\*Energy associated with an electron**

When an electron gets accelerated across a potential difference, it gains kinetic energy (½ mv2).

But just like an apple falling from a tree which similarly gains kinetic energy, this energy had to come from somewhere.

In the case of the falling apple, the energy it gained came at the expense of (Gravitational) Potential Energy (mgh) which it lost.

In the case of the electron the kinetic energy gained comes at the expense of Electrical Potential Energy, the formula for which is W = QV. Therefore we end up with the expression eV = ½ mv2.

If any of this seems vaguely familiar it’s because we studied it in chapter 20.

In this case Q represents the charge on an electron, for which we use the letter *e*. So we get W = eV.

Now the problems on page 330 are similar to those on page 236, but should still be studied before trying Questions 1, 2, 3, page 333.

**\*The Electron Volt (eV)**

When dealing with energies in our everyday world, we use the joule as the unit of energy (can you remember the definition of the joule? Hint: think of the formula for work).

When working in the world of electrons however, the energies involved are so small that rather than using the joule, another unit is more commonly used. This unit is called the Electron Volt.

**\*A beam of electrons moving at right angles to a magnetic field will move in a circular path.**

A beam of electrons constitutes an electric current but remember that if a current flows in one direction the electrons are actually moving in the opposite direction (and vice versa).

Now if an electron is moving towards the right (meaning *current is to the left*) in a magnetic field where the direction of *flux density is* *into the page*, applying Fleming’s Left Hand Rule tells us that the force on the electron must be downward, and so the electron changes direction.

But because the flux density is constant and is always perpendicular to the direction of the electron, the electron will continually change direction, while moving at the same speed.

The result is that it travels in a circular path.

We’ve come across this concept before, i.e. something which is travelling at constant speed, but changing direction is accelerating.

**\*The photon as a packet of energy;**

In 1905 Einstein published a famous paper that suggested that light could be considered to consist of packets, which he called photons.

Max Planck was the dude who kick-started all this Quantum Theory stuff ten years previously by suggesting that heat energy could be quantised.

Funnily enough, he could never accept Einstein’s findings (which followed on from Planck’s work) that all energy could be considered to consist of discrete packets.

But this was only the beginning of Planck’s misfortune.

To get an idea of how poor a hand he got dealt in life, read Bryson’s account of it in his book *A Short History of Nearly Everything*.

One of the consequences of Einstein’s work was that it was realised that there was a randomness inherent in the laws of physics at the quantum level. Ironically Einstein could never accept this.

His famous phrase was “God does not play dice”.

For what it’s worth, it is a common misconception that work-function is the same as ionisation energy.

Ionisation energy involves bumping electrons out of single standalone atoms (or perhaps molecules) in a gas.

In a metal there is a ‘sea of electrons’ on the surface, and it is one of these electrons which leaves the surface when light of a suitable frequency falls on it.

Because the electron arrangement is different in both cases, the energy involved will be different.

**\*The Photoelectric Effect**

The incident energy is absorbed by an electron at the surface of a metal.

A certain amount (the work function) goes to liberating the electron.

The remainder appears as kinetic energy of the liberated electron.

The strange thing is that if the incident light hasn’t got enough energy to liberate an electron, no amount of time (or increase in intensity) will make a difference.

An increase in intensity simply means that more packets of light are used per second, but if they don’t have sufficient energy, increasing the number will simply have no effect.

However if each photon *has* enough energy to liberalise an atom, increasing the intensity (i.e. the number of photons) will result in more atoms being liberalised, and therefore an increase in current.

Remember that the energy of the incident light is determined by its frequency.

So for example for the metal zinc, visible light is of too low a frequency, and therefore has too little energy, to liberalise electrons form the surface of the zinc.

However Ultra Violet light has a higher frequency and therefore is able to liberalise electrons.

This can be detected as a small current using an ammeter or galvanometer.

This proves that light is like a particle.

It was Einstein who realised this.

**\*Hazards**

X-rays Radiation can cause the ionization of atoms in a persons’ DNA.

This means the atom is now charged, where before it was neutral.

This can affect the function of the DNA.

The DNA can be damaged and then repaired in such a way that the cell continues to divide but with an altered message in the DNA.

This altered message may eventually result in a cell turning into a cancer.

Thus any dose of radiation increases the risk of cancer.

Believe it or not, X-Rays used to be used to help in ascertaining the size and shape of a person’s foot; The customer put his or her foot in the machine for up to 45 seconds, while the salesperson had to use this machine all day.