Turning Points

1 Electrons

1.1 Discharge tube

A discharge tube has a high voltage applied across it, this voltage ionises the gas. These ions then accelerate towards the cathode, hitting it with enough energy to release free electrons from the surface. These combine with the ions, emitting light.

1.2 Thermionic emission

When a metal is heated free electrons are released from the surface

1.3 Determining the specific charge of an electron

1.3.1 Method 1

Adjust magnetic and electric field so the flow of electrons is horizontal
Combine

$$eV_a = \frac{1}{2}mv^2 \text{ and } Bev = eE$$

To get

$$\frac{e}{m} = \frac{1}{2v_a}\left(\frac{E}{B}\right)^2$$

1.3.2 Method 2

Accelerate electrons in a circle using a magnetic field perpendicular to the direction of motion.
Combine

$$\frac{mv^2}{R} = Bev \text{ and } eV_a = \frac{1}{2}mv^2$$

To get

$$\frac{e}{m} = \frac{2V_a}{(BR)^2}$$

1.4 Milikan's experiment

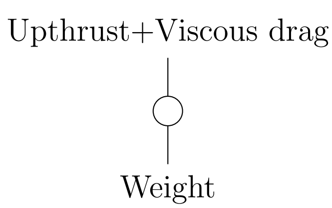


Figure 1: No electric field

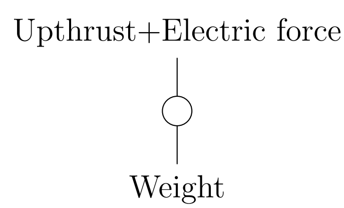


Figure 2: Electric field

1.4.1 With electric field

$$\text{Electric field} = \frac{QV}{d}$$
$$\text{Weight} = mg$$
$$\frac{QV}{d} = mg$$

1.4.2 Without electric field

$$F_D = 6\pi r\eta v$$
$$\text{Weight} = mg$$

Mass=Density×Volume

$$\text{Mass} = \frac{4}{3}\pi r^3\rho$$

$$6\pi r\eta v = \frac{4}{3}\pi r^3\rho g$$
$$r^2 = \frac{9\eta v}{2\rho g}$$

1.4.3 Significance of results

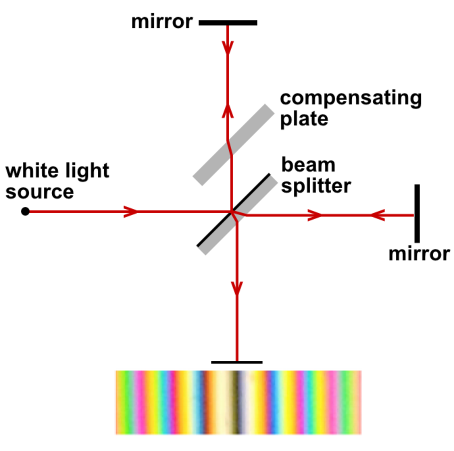
These results were significant because it introduced the idea of quantisation of charge

2 Special relativity

Special relativity is based on two postulates:

- The laws of physics, expressed in equations, have the same form in all inertial frames
- The speed of light in free space is the same for all observers regardless of their state of motion and the speed of the light source

2.1 The Michelson-Morley Experiment



2.2 Relativistic momentum

$$p = mv - \frac{m_0 v}{\sqrt{1-(\frac{v}{c})^2}}$$

2.3 Relativistic kinetic energy

$$\text{Total energy=Rest energy+Relativistic KE}$$

$$E_K = E - E_0$$

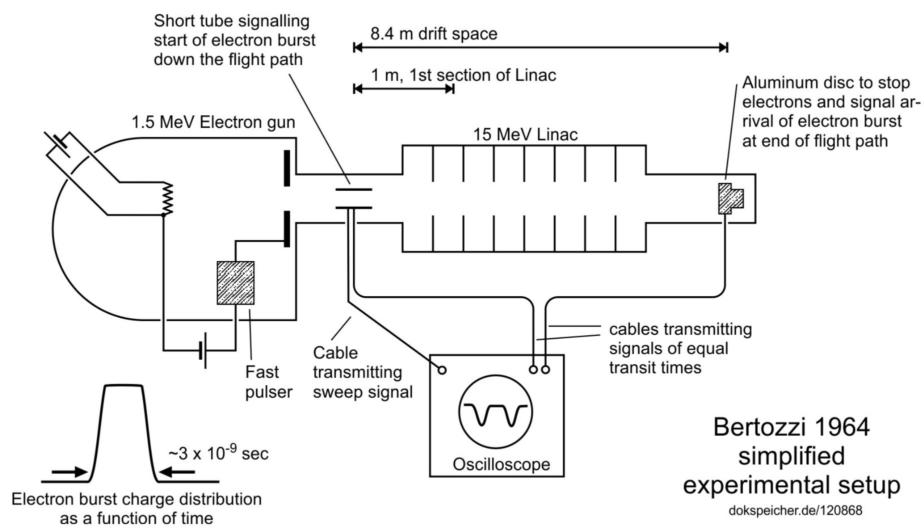
$$E_K = \frac{m_0c^2}{\sqrt{1-(\frac{v}{c})^2}} - m_0c^2$$

$$E_K = m_0c^2\left(\left(1-\left(\frac{v}{c}\right)^2\right)^{-\frac{1}{2}} - 1\right)$$

Apply binomial expansion and approximation to get

$$E_K = \frac{1}{2}m_0v^2$$

2.4 Bertozzi's Experiment



The experiment was set out to determine the variation of the kinetic energy of an electron, based on derived measurements.

Electrons accelerated from rest, through a known P.D.
Gain kinetic energy = eV (Known value)
Calculate speed from $v = \frac{d}{t}$ (d=8.4m)

As the bunch of electrons collided with the plate, the electrons give up their energy and the plate changes its temperature.

Knowing the specific heat capacity and the number of electrons, the energy of one electron can be determined

$$E = \frac{mc\Delta\theta}{n}$$

3 Wave Particle Duality

3.1 Electromagnetic waves

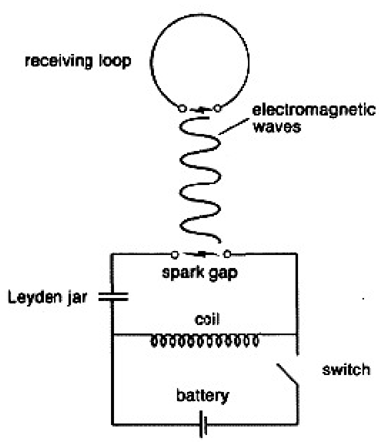
3.1.1 The nature of electromagnetic waves

Electromagnetic waves are formed of perpendicular electric and magnetic fields, each of which sustain the other.

3.1.2 Maxwell's Formula

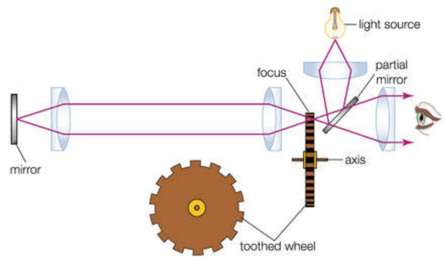
Permeability of free space - Relates the magnetic flux density of a magnetic field to the electric current that creates it
Permittivity of free space - Relaters the electric field strength to the charge that creates it

3.1.3 Hertz and Radio waves



Radio waves were produced when a spark lept between the spark balls across an induction coil
The radio waves induce an EMF across the loop, causing a spark.
By placing a metal sheet in different places Hertz discovered radio waves are reflected by metal and pass straight through insulating materials.
By creating a standing wave and measuring the position of nodes and antinodes, the wavelength could be calculated.
The waves were demonstrated to be polarised when the loop was rotated 90 degrees and no sparks appeared, as the electric field was perpendicular to the loop.

3.1.4 Fizeau's determination of the speed of light and it's implications



This experiment used a fast moving cog wheel which was increased in speed until the reflected light could not be seen. This meant that twice the distance between the wheel and the mirror would be equal to the time for a gap to be replaced by a tooth.
Time for one rotation:

$$T = \frac{1}{f_0}$$

Time for the wheel to move one tooth, where n is the number of teeth

$$t = \frac{T}{2N}$$

Combine the two above equations

$$t = \frac{1}{2f_0N}$$

Apply Speed = $\frac{\text{Distance}}{\text{Time}}$

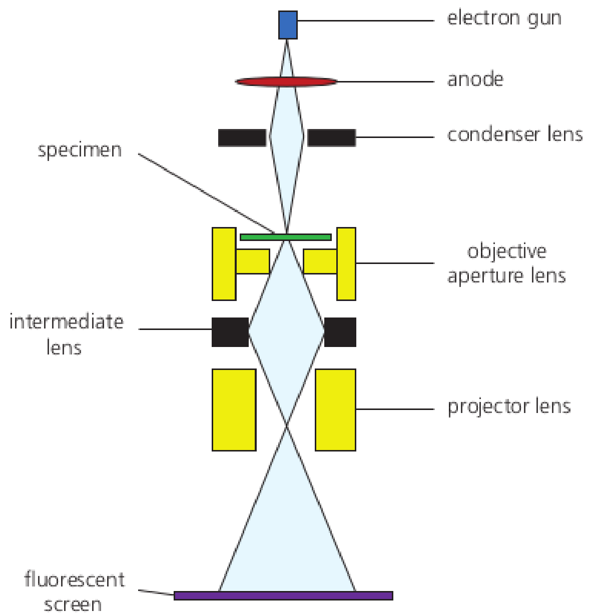
$$c = \frac{2D}{\frac{1}{2f_0N}} = 4Df_0N$$

3.2 Microscopes

To find the voltage required to produce electrons of a given wavelength, rearrange the equation on the formula book

$$\lambda = \frac{h}{\sqrt{2meV}} \Rightarrow V = \frac{h^2}{2me\lambda^2}$$

3.2.1 Transmission electron microscope

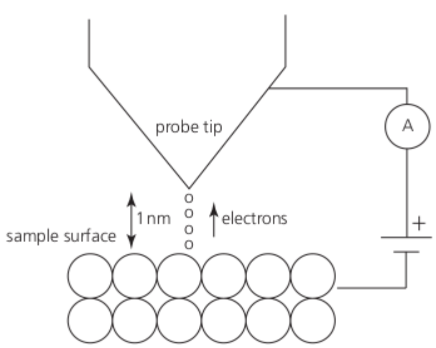


This involves firing a beam of electrons at a high voltage towards an ultra thin specimen.
When an electron wave encounters the specimen it can either:

- Pass straight through the specimen without interacting
- Get absorbed
- Diffract

The image detail can be improved by increasing the anode voltage of the electron gun.
Image detail may reduce when travelling through the specimen as some electrons lose speed.

3.2.2 Scanning Tunnelling Microscope



This has a very fine conducting probe very close to the surface of the sample. Quantum tunnelling means that over the very short distance there is a small probability electrons will cross the gap. A small voltage is maintained between the tip of the probe and the sample to ensure the electrons travel the right way.

An STM can either have the probe at a constant height, and measure the current, or alter the height to keep constant current, and measure the height.

3.3 Newton's CT of light

Definition - Light is made up of tiny particles called corpuscles that always travel in a straight line

3.3.1 Reflection and refraction

Newton believed this theory was true as it can explain both reflection and refraction

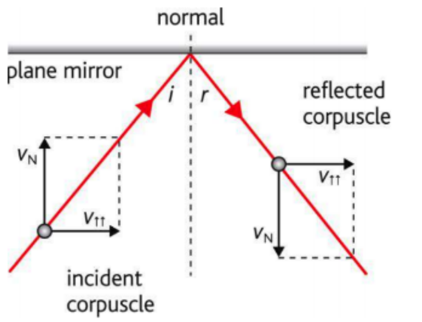


Figure 1 *Reflection of light according to Newton*

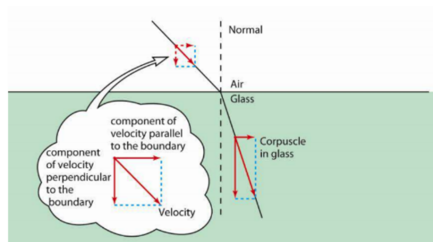


Figure 2 *Refraction of light according to Newton*

Reflection - These corpuscles have perfectly elastic collisions, meaning that the speed before is the speed after. The horizontal velocity doesn't change, the vertical velocity is inverted. Therefore angle of incidence equals angle of reflection.

Refraction - Newton said the corpuscles were attracted into the material, causing them to travel faster, causing the component of the velocity perpendicular to the boundary to increase, causing angle with the normal to reduce. Newton was wrong.

3.3.2 Rival theories

Christiaan Huygens proposed the wave front theory, which is the theory we have been taught to describe refraction and diffraction. This described light travelling slower in a more dense material.

Why Huygens' theory was rejected:

- It was not possible to measure the speed of light at that scale at that time, meaning neither theory could be proved correct or incorrect.
- Newton had a better reputation
- The wave theory only considered longitudinal waves so couldn't explain polarisation.

3.4 The Discovery of photoelectricity

Black body - A theoretical perfect absorber and emitter of radiation
Ultraviolet catastrophe - Where short wavelength radiation is incident on a black body, causing it to emit an infinite amount of power per unit wavelength

3.4.1 The failure of classical wave theory to explain observations on photoelectricity

- Wave theory suggested that given enough time, electrons would gain enough energy from a wave to escape

- There would be a time lag between the light being incident and the emission of an electron
- Any frequency would be able to cause electron emission given enough time

3.4.2 Einstein's Explanation of photoelectricity

Einstein showed electrons must have energy greater than the work function in order to escape a metal. Kinetic energy is the energy difference between the energy of the electron and the work function.

The stopping potential is the potential at which no current flows, and is calculated by:

$$V_s = \frac{E_{K(Max)}}{e}$$

3.5 The significance of Young's double slit experiment

Young's double slit experiment showed interference, disproving Newton's Corpuscular Theory, however Huygen's wave theory was not accepted until Fizeau compared the speed of light in water and air.

3.6 Wave particle duality

By using the equations

$$\frac{1}{2}mv^2 = eV \text{ and } \lambda = \frac{h}{mv}$$

They can be used to get the equation

$$\lambda = \frac{h}{\sqrt{2meV}}$$