G482 Revision Notes

Electrons, Waves and Photons

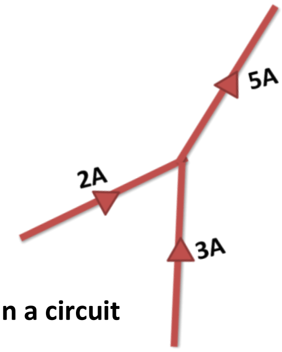
Current:

- Flow of charge per unit time
    - Electrons in metals, ions in electrolyte
- Conventional current – a model used to describe the movement of charge in a circuit (positive to negative)
- Electron flow – the movement of electrons around a circuit (negative to positive)
- One Ampere – one Coulomb per second
- Ammeter – instrument to measure current
    - Connected in series and has negligible resistance to avoid current being affected

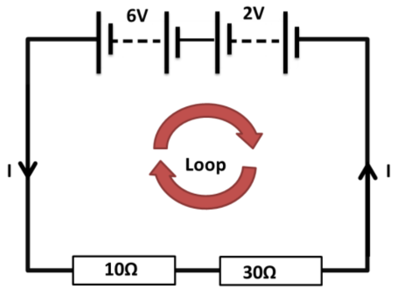
Charge:

- One Coulomb – charge supplied by one Ampere in one second
- Elementary charge = e^{-} = 1.6×10^{-19}

Kirchoff's Laws:



- **First law – the sum of current into a junction is equal to the sum of the current out of that junction**
    - **Conservation of charge**
- **Second law – the sum of e.m.f. is equal to the sum of p.d. around a closed loop in a circuit**
    - **Conservation of energy ($E = IR_1 + IR_2$)**



Mean Drift Velocity:

- Average speed of charged particles along the length of a conductor

Conductors:

- Conductor – material with **high number density** (n) of conduction electrons and therefore low resistance
    - Small drift velocity for high current
- Semiconductor – material with **low number density** (n) of conduction electrons and therefore high resistance
    - Higher drift velocity required for current equal to that of a conductor
- Insulator – material with negligible number density (n) of conduction electrons and therefore very high resistance
    - No charge carriers therefore **n = 0**

- Number densities – if low electrons have more space to move and collide with each other less resulting in higher drift velocities

Potential Difference (p.d.):

- Energy transferred per unit charge, when **electrical energy is converted to another type**
- One Volt = one Joule per Coulomb
- Voltmeter - A device for measuring p.d and e.m.f
  - Measures the difference in electrical potential energy
  - connected in parallel
  - They measure the amount of energy (in joules) per coulomb across a component
- Terminal p.d is the p.d across the external resistance, if there was no internal resistance the terminal p.d would be the same as the e.m.f

Electromotive Force (E.m.f):

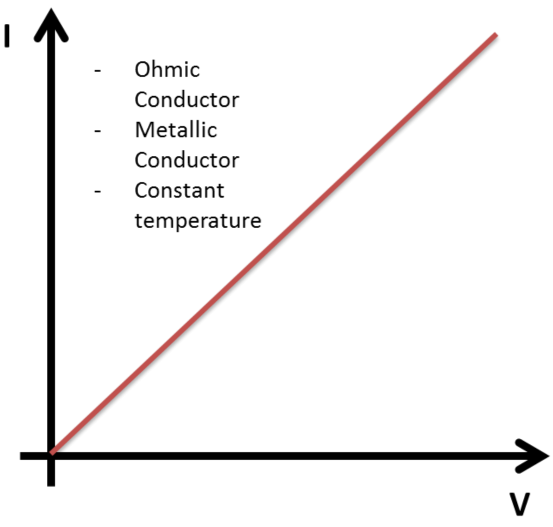
- Energy transferred per unit charge, when **energy is converted from another type into electrical energy**

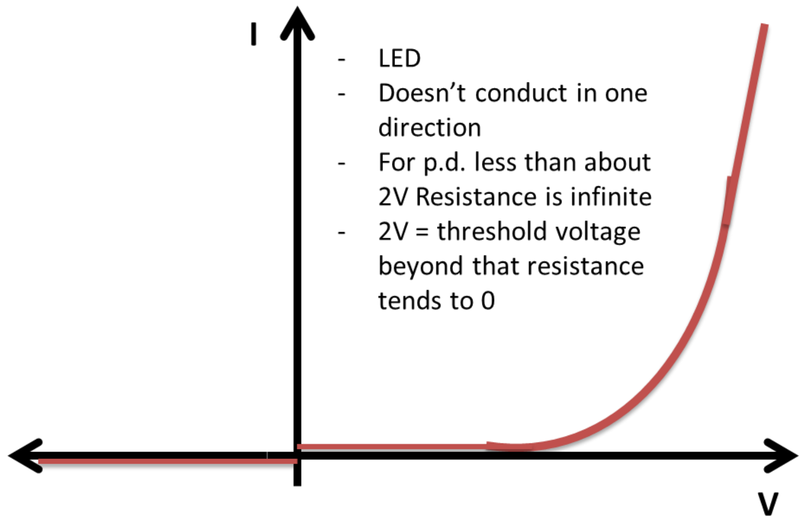
Resistance:

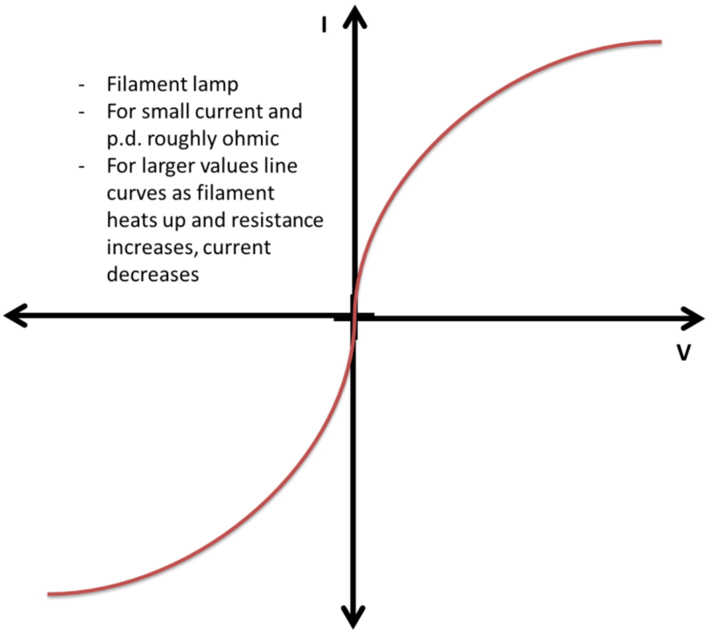
- Property of a component that **regulates** electrical current flowing through it ($R = VI^{-1}$)
- One Ohm = one Volt per Ampere
- **Internal resistance – resistance of an e.m.f. source**
- Effected by temperature and resistivity
  - Low temperatures electrons move freely at higher temperatures they are obstructed by vibrating ions causing collisions
  - As electrons collide they lose energy causing the wire to heat up even more, which further increases the resistance
  - The decrease in mean drift velocity is what causes the increase in resistance

Ohm's Law:

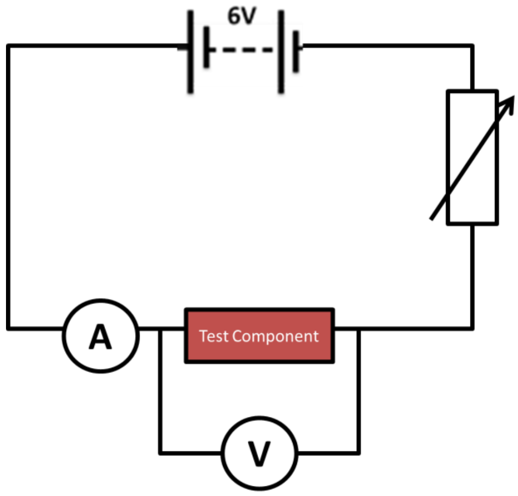
- At constant temperature, the current that flows through a component is directly proportional to the current across it (IαV)







Experiment to determine I/V characteristics:



- Vary current and p.d. using variable resistor
- Record current and p.d. from ammeter and voltmeter
- Plot I/V graph
- Resistance = gradient^{-1}

Light Emitting Diodes (LEDs):

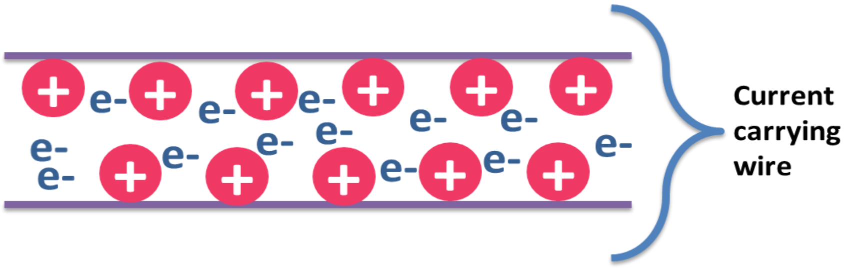
- Only allow current to flow in **one direction** and emit light when a p.d. is applied across it
- Benefits:
  - Turn on **instantly**
  - Emit strong sources of light
  - Very versatile
  - Operate on low p.ds

Resistivity:

- **P = RAL^{-1}** measured in **Ωm**
- Length:
  - Longer wire makes it harder for current to flow
- Area:
  - Wider wire is easier for electrons to pass along
- Material:
  - Impurity atoms disrupt the regular structure of the wire causing more frequent collisions between ions and electrons
- Temperature:
  - Resistivity increases with temperature except for semiconductors where the opposite is true

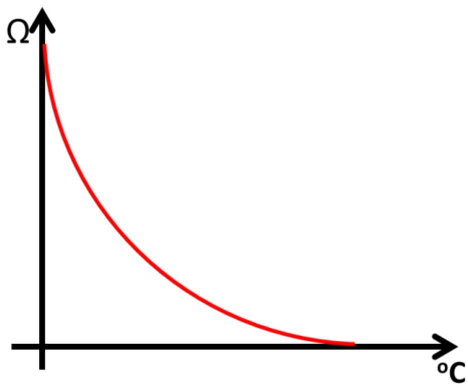
Positive Temperature Coefficient (as is for conductors):

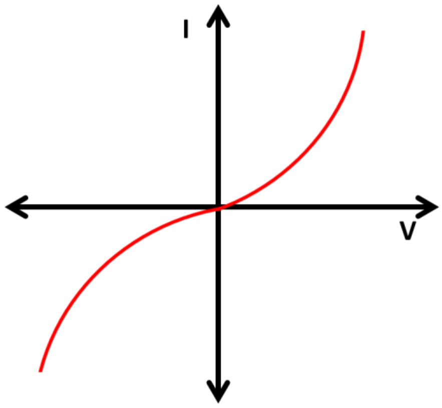
- Heating metal wire makes metal ions vibrate more causing electrons to collide with ions and lose energy, this causes resistance to increase linearly with temperature



Negative Temperature Coefficient (NTC) as is for semiconductors:

- A thermistor has a NTC – when heated electrons in the thermistor gain enough energy to escape the metal lattice
- This increases the number of charge carriers available (increasing n) which causes a fall in resistance
- Light dependent resistors (LDRs) work in the same way except increases light intensity causes electrons to be freed
- I/V for NTC components curves in the opposite direction to that of a filament lamp which has a PTC





Kilowatt Hour:

- The energy transferred by a one kW device in one hour
    - 1kWh = $3.6\text{x}10^6$J
    - For calculations: **Energy transferred (kWh) = power (kW) x time (h)**

Fuses:

- Devices in circuits to protect the wiring from **excessive** currents:
    - High currents cause wires to get hot, damaging them, and could result in fires
    - When a fuse is subjected to higher currents than what they are designed to permit, it will get too hot and **melt**, breaking the circuit and preventing hazardous currents

Series:

- **When components are connected end-to-end**
- Voltage is shared and current is constant around the circuit

Parallel:

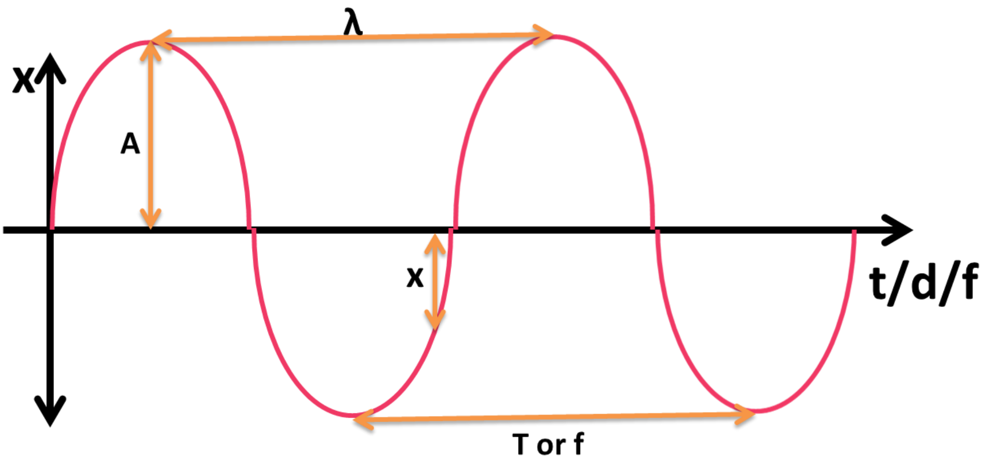
- **When one or more loop is connected to a power supply**
- Current is shared and voltage is constant around the circuit

Data loggers:

- Advantages :
    - If a continuous record of temperature or light intensity is needed, you can connect a data logger to the thermistor or LDR because they produce electrical outputs
    - eliminate the chance of human error in the calculations
    - Can plot accurate graphs straight away
    - Very good at processing collected data

Wave Terminology:

- X = Displacement – distance from given point to equilibrium position
- A = Amplitude – maximum displacement
- λ = Wavelength – smallest distance between a point on a wave to the identical point on the next wave
- T = Time period – time taken for one complete oscillation
- f = Frequency – number of oscillations per second, **$f = T^{-1}$**



Longitudinal wave:

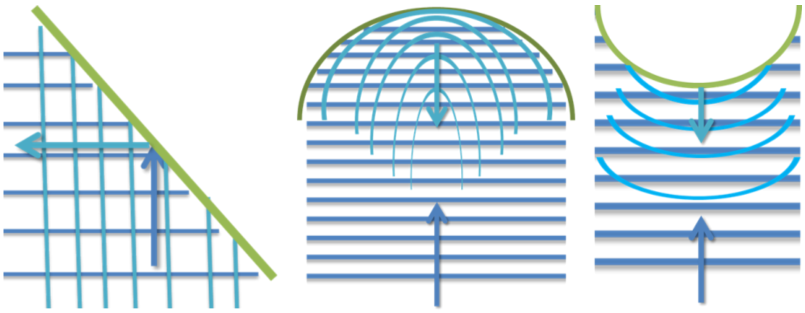
- **The oscillation of particles is parallel to the direction of propagation**

Transverse wave:

- **The oscillation of particles is perpendicular to the direction of propagation**

Reflection:

- **Bouncing back of a wave from a surface**



Phase difference (ϕ):

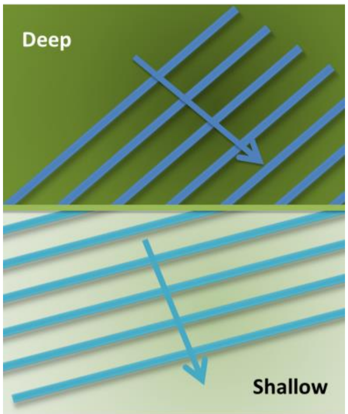
- **The fraction of a cycle between the oscillations of two particles, measured in radians, if two particles have a phase difference of π^c they are in antiphase**

Progressive wave:

- **A wave that transfers energy from one place to another**
- **Wave speed – the speed at which energy is transmitted by a wave $v = f\lambda$**

Refraction:

- **Change in direction of a wave as it crosses an interface between two materials where its speed changes**



Polarised wave:

- **A wave that oscillates in one direction only**

Diffraction:

- **The spreading of a wave when it passes through a gap or past the edge of an object**

Electromagnetic waves:

- Travel at the speed of light in a vacuum **(3×10^8 ms^{-1})**
- All feature an interlocked magnetic and electric oscillation perpendicular to each other
- All are transverse waves
- Only difference is the amount of energy found in their photons (radio have low energy photons, gamma have highest energy photons)

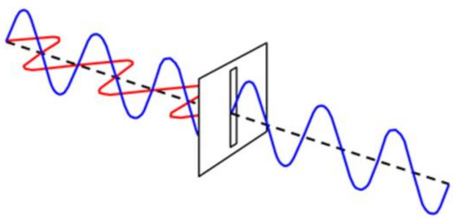
Region	Wavelengths (λ)	Uses	Detection Method
Radio waves	$>10^{6} – 10^{-1}$	Broadcasting radio/TV, radio astronomy, MRI	Resonance of electronic circuits
Microwaves	$10^{-1} – 10^{-3}$	Radar, telecommunications, microwave ovens	Electronic circuits
Infrared	$10^{-3} – 7 \times 10^{-7}$	Night vision goggles/cameras, remote controls, cooking	Heating of skin
Visible	$7 \times 10^{-7} – 4 \times 10^{-7}$	Signalling, photography	Retina of eye
Ultraviolet	$4 \times 10^{-7} – 10^{-8}$	Sterilisation, security marking, sun tanning	Sunburn
X-rays	$10^{-8} – 10^{-13}$	Sterilisation, medical imaging, medical treatment	Photographic film
Gamma rays (ϒ)	$10^{-10} – 10^{-16}$		Geiger Müller tube

Ultraviolet:

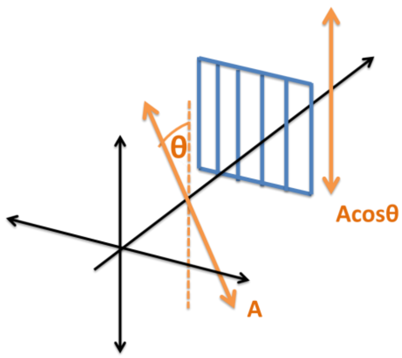
- All can damage the eyes
- UV-A
  - 99% of UV, causes tanning and wrinkles
- UV-B
  - Can cause DNA in skin to become damaged causing skin cancer
- UV-C
  - Absorbed by the ozone layer

Polarisation of waves:

- If a transverse wave is incident on a polariser, oscillations perpendicular to the motion are restricted to 1 plane only (they oscillate at 1 angle)
  - **Light is partially polarised on reflection**



- Polaroid
  - Long chain molecules that absorb energy from the oscillating electric field
- Uses
  - Polaroid sunglasses reduce glare by selecting **one polarisation** of light only so the amount of unpolarised light reaching the eyes is reduced
  - Liquid crystal displays such as calculators produce plane polarised light
  - Stresses in materials are determined by making models from transparent plastic that when viewed through a polaroid shows areas of stress concentration through more concentrated coloured bands
- **Malus' Law**
  - **INTENSITY α AMPLTUDE^2**
  - **$A = A_0\cos\theta$**
  - **$I = I_0\cos^2\theta$**



Superposition of waves:

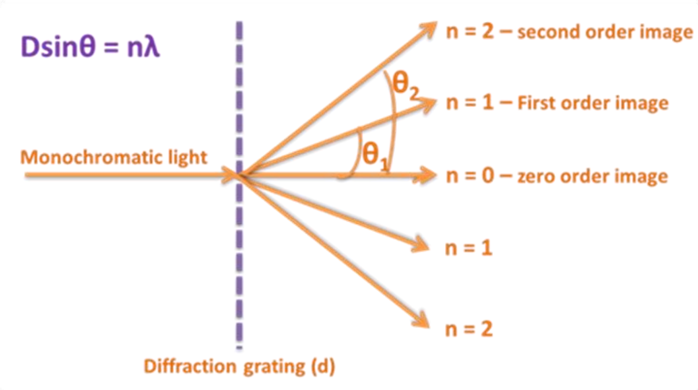
- **Principle – When two or more waves meet at a point the resultant displacement is the sum of the displacements of the individual waves**
- **Interference – the superposition of two or more coherent waves resulting in a new wave being formed**
- **Coherence – two waves with a constant phase relationship**
- **Constructive interference – two waves that superpose to give an increased amplitude**
  - Occurs when path difference is a whole λ value
  - Occurs when phase difference is a whole number multiple of 2π
- **Destructive interference – two wave that superpose and 'cancel out' to give a reduced amplitude**
  - Occurs when path difference is not a whole λ value
  - Occurs when phase difference is not a whole number multiple of 2π
- **Path difference – difference in distances travelled by two wave from coherent sources at a particular point**

Experiment to show two source interference:

- When two loudspeakers are connected to the same signal generator, their signals interact this can be heard as you walk in front of the loudspeakers. You will hear a loud sound where the sound waves **reinforce** one another (constructive), and at other points you will hear quiet sound where waves partially cancel each other out (destructive)

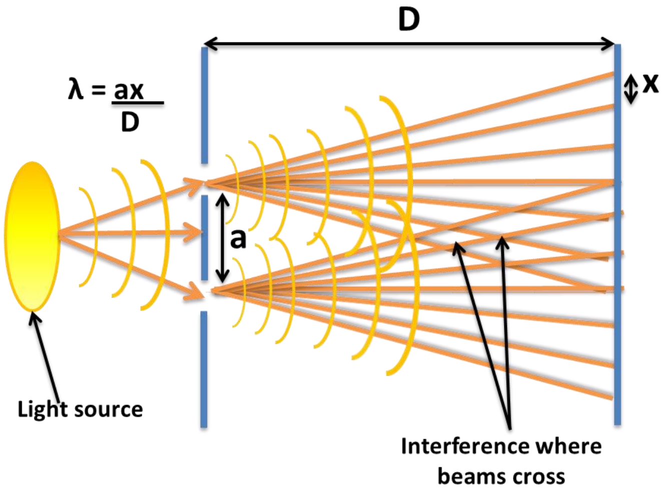
Wave Diffraction patterns:

- Advantages of using multiple slits
    - Maxima are brighter and sharper
    - Inaccuracy is larger with fewer slits for measurements of d (whereas diffraction grating has a set value of d)
    - Maxima are more widely separated with more slits so angle measurement is more accurate
    - If grating has x slits per metre then $\mathbf{d=x^{-1}}$



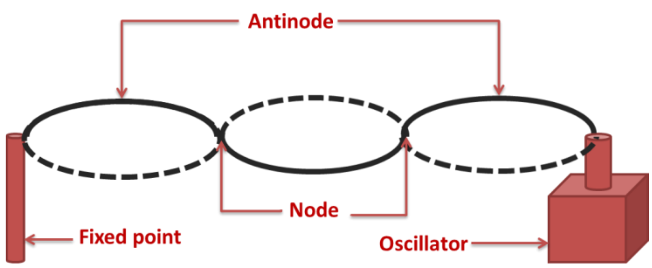
Young's double slit experiment:

- Two sources are **coherent**
- Slits are close so diffraction patterns overlap
- Bright patches on screen
    - Constructive interference (maximum amplitude)
    - **Path difference = whole λ value**
- Dark patches on screen
    - Destructive interference (amplitude = 0)
    - **Path difference ≠ whole λ value, so in antiphase at screen**



Stationary waves:

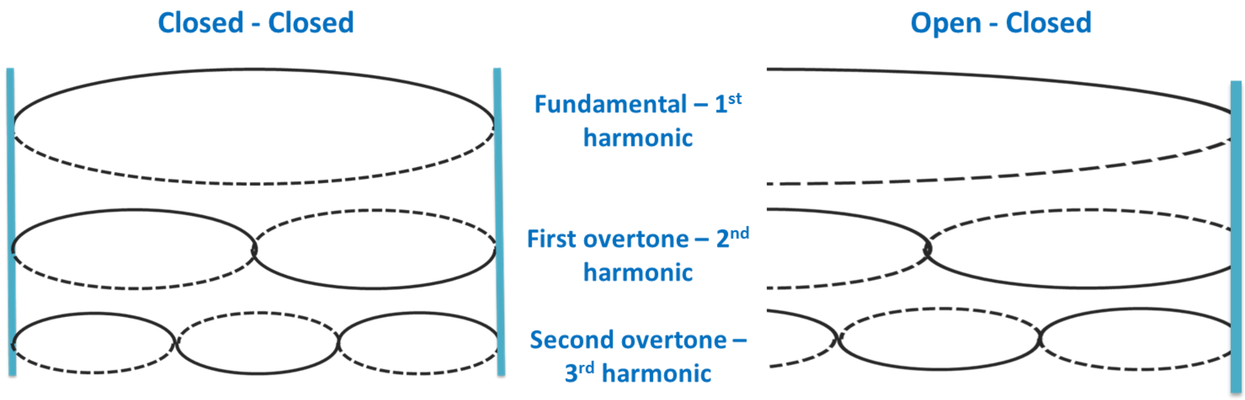
- A wave pattern produced when two progressive waves of the same frequency, travelling in opposite directions **superpose**, and their energy is stored rather than being transferred from one place to another
- Formation
    - Incident wave is reflected at the end of the wire, reflected wave then interacts with the incident wave to produce a resultant wave with nodes and antinodes



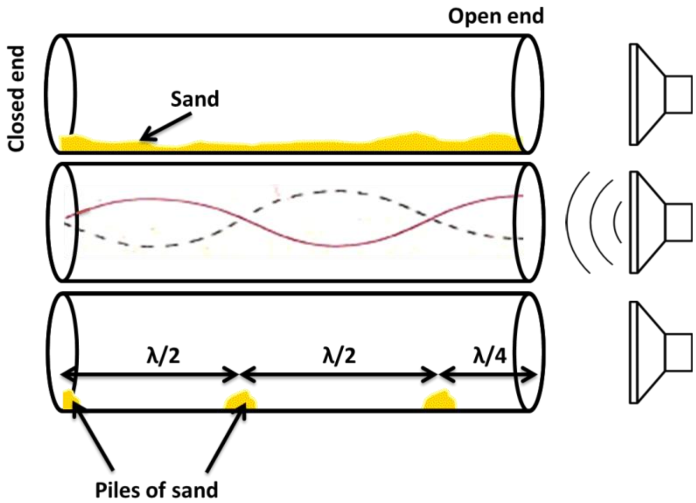
- Contrasting with progressive waves
    - Stationary **store** energy in pockets, progressive **transfer** energy
    - Progressive transfer shape/information, in stationary waves the shape does not move along

- In a progressive wave every point oscillates with the same amplitude and every point oscillates, stationary waves have nodes and antinodes
- In progressive waves all points have a different phase

- Harmonics
    - **Fundamental mode of vibration – lowest frequency stationary wave for a particular system (first harmonic)**
    - **Harmonics – whole number multiples of the fundamental frequency**



Experiment to calculate the speed of sound in air:

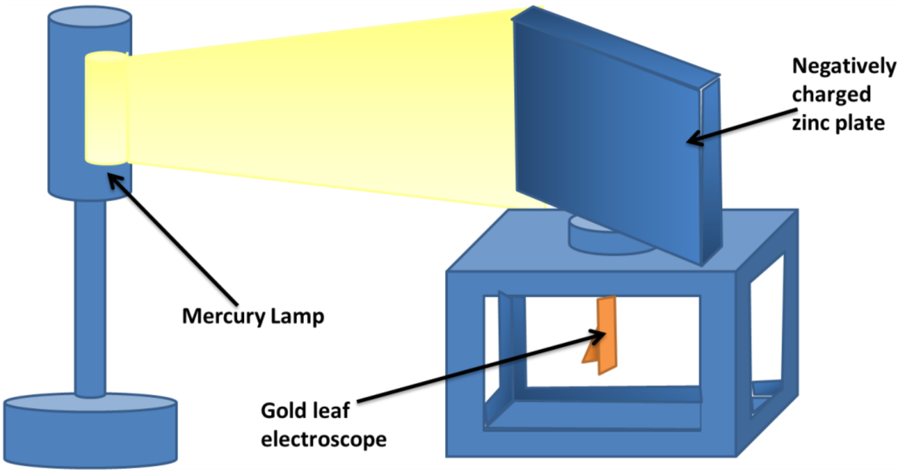


- When loud speaker emits a sound wave it is reflected off the closed end of the tube this reflected wave then interacts with the incident wave to produce a resultant stationary wave with nodes and antinodes
    - Piles of sand then collect at the **nodes** where there is no vibration
    - Distance between piles of sand is **half a wavelength**
    - The frequency of sound is known so the equation $v = f\lambda$ can be used to calculate the speed of sound in air
- A similar experiment can be carried out using microwaves
    - A microwave generator transmits microwaves towards a metal sheet, the microwaves are reflected back from the sheet along their initial path, resulting in a standing, a microwave detector along the stationary wave will register strong signals every **half wavelength** along the wave, from this work out the wavelength, and in turn the speed of the microwave in air

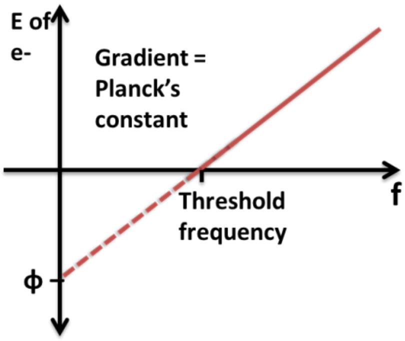
Evidence for the particulate nature of light:

- **Photon – a quantum of energy of electromagnetic radiation**
- **Ground state – the lowest energy state that can be occupied by an electron in an atom**
- Photoelectric effect (photon electron interaction)
    - Photon is absorbed by electron causing electron emission
    - Energy is conserved as $hf = \phi + KE$

- Only photons with energy > ϕ cause electron emission
  - ϕ (work function) is the minimum energy required to release electrons
  - Number of electrons emitted depends upon light intensity, as long as energy is greater than the work function
  - Emission is **instantaneous** and photons transfer all or none of their energy to electrons
- Experimentally
  - Electromagnetic radiation from lamp discharges plate and gold leaf falls
  - A single light photon interacts with a single electron
  - When **photon energy > work function** electron is **instantaneously** removed from the metal surface



  - Energy is conserved, so excess energy is KE in the electron
  - **Lack of electrons** on metal surface causes gold leaf to fall as plate is discharged
- Provides evidence for the particulate nature of light
  - Wave theory would suggest that emission should occur if light is bright enough, however photoelectric effect proves that emission only occurs if the energy is greater than the work function and frequency greater than the threshold frequency
  - Photons must transfer all or none of their energy and it is a **one to one** interaction

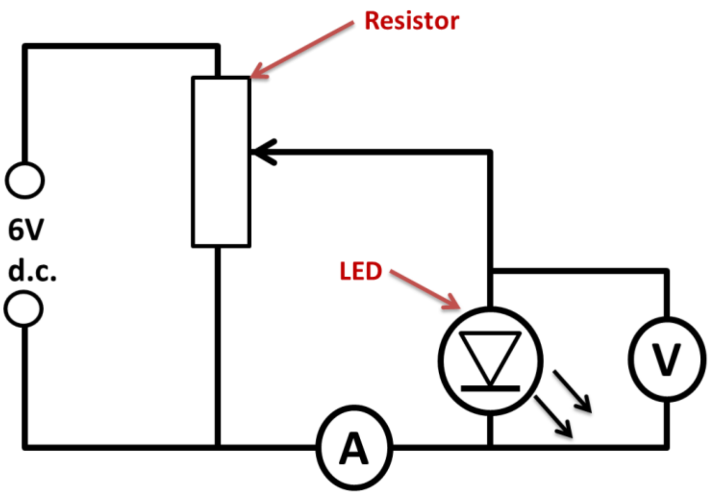


Photocell circuits:

- The **current in a photocell circuit is proportional to the intensity of the incident radiation**, if the intensity of radiation incident on a photocell is doubled, the kinetic energy of the photoelectrons would stay the same
  - But there are twice as many photons in the incident radiation, twice as many electrons are released from the cell, so the current doubles

Experiment to determine Planck's constant:

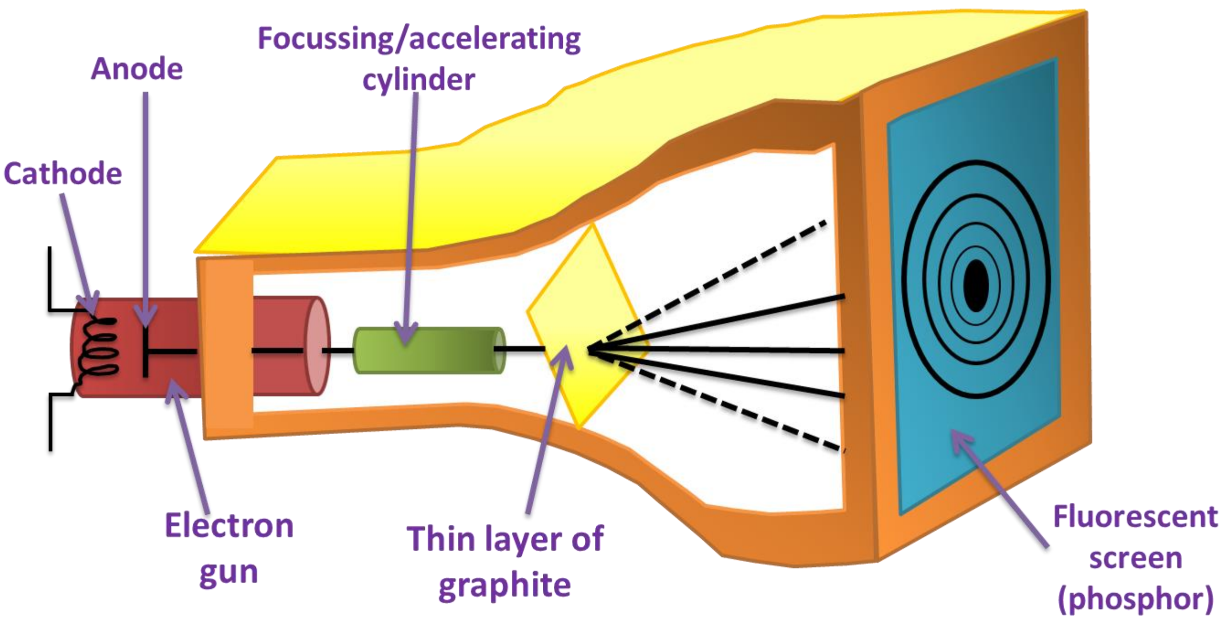
- Increase voltage (using resistor) until LED just begins to glow
  - Insulate LED in opaque tube to make light more visible



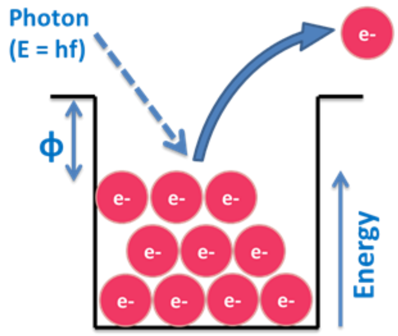
- Measure p.d. when LED glows
- Repeat for different coloured LEDs
- Energy lost by electron is equal to the charge on the electron multiplied by the p.d. across the LED ($E = QV$)
- Calculate frequency using $v = f\lambda$ (λ will be on the LED and $v = 3\times10^8$)
- Plot graph of energy/frequency, the **gradient is equal to Planck's constant (h), y – intercept = ϕ, x – intercept = threshold frequency**
  - $eV = hf$

Electron Diffraction:

- Electron is accelerated from electron gun
- Thin layer of **polycrystalline graphite** is used as diffraction grating
- Electron is diffracted
  - Diffraction is unique to waves so electron is behaving as a wave
  - As graphite is crystalline not all gaps are in the same direction therefore diffraction pattern shows concentric circles
  - The atomic spacing of graphite is roughly equal to the wavelength of electrons
- **De Broglie equation: $\lambda = hm^{-1}v^{-1}$**
  - By increasing the p.d. across the anode/cathode the electron velocity increases
- **Electron volt (eV) – the kinetic energy gained by an electron when it is accelerated through a p.d. of one volt**
  - **JeDi** – Joules to eV divide, eV to Joules multiply (by 1.6×10^{-19})
- Applications of electron diffraction
  - Slow moving electrons with wavelengths close to the order of magnitude of a structure/nuclei can be used to probe properties of atomic structures by using the equation for diffraction gratings



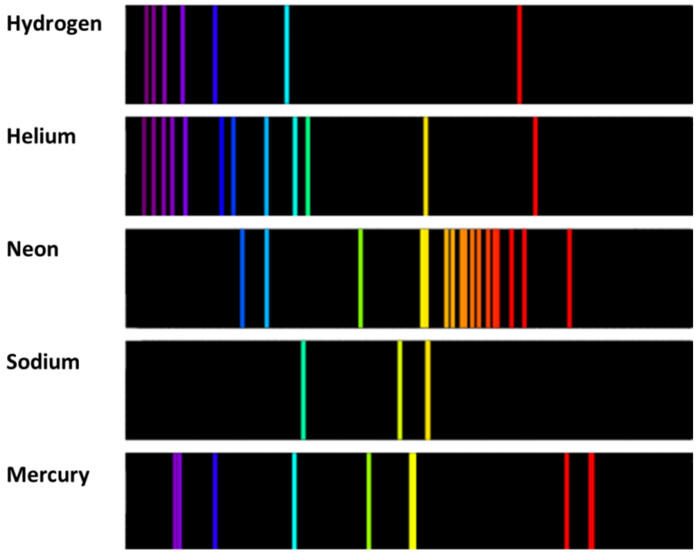
Discrete Energy levels:



- Electrons exist at discrete energy levels
  - The **ground state** is the first energy level
- To move up a level, a certain amount of energy is needed
- This energy can only be received by a certain frequency of light, so a photon of this specific frequency is absorbed for an electron to move up an energy level
- When moving down a level electrons emit a photon
  - This releases energy, such is the equation $\mathbf{hf = E_1 - E_2}$, where E_1 is the energy of the level the electron leaves and E_2 is the energy of the level the electron enters

Emission Spectra:

- A pattern of colours of light, each colour having a specific wavelength
- **Hot gasses** produce line emission spectra
  - When a gas is heated, the electrons move to higher levels
  - When they **drop** down an energy level, they emit photons, producing line emission spectra with a black background with coloured lines
  - Each line corresponds to a particular wavelength of light emitted by the source



Absorption Spectra:

- A dark line of unique wavelength seen in a spectrum of colour
- **Cool gasses** absorb certain wavelengths from the continuous spectrum
  - At low temperatures, electrons are at **ground state**
  - Photons of the correct wavelengths are absorbed by the electrons to **excite** them to a higher energy level
  - These wavelengths are then missing from the continuous spectrum when it comes from the gas
  - The sun does not show a full spectrum as the light emitted by the sun must travel through the cooler outer layers of the sun's atmosphere, so some wavelengths are absorbed

Sodium (Na)