Eduqas Physics A Level

Newtonian Physics

Basic Physics (1.1)

SI Units
The SI quantities are as follows:

Quantity		**Unit**	
Name	**Symbol**	**Name**	**Abbreviation**
Mass	m	Kilogram	kg
Length	l	Metre	m
Time	t	Second	s
Electric Current	I	Ampere	A
Temperature	T	Kelvin	K
Amount of Substance	N	Mole	mol
Luminous Intensity	L	Candela	cd

Vectors vs Scalars

- Vector quantity has **magnitude** and **direction.**
- Scalar quantity has **just magnitude.**
- **Vectors**
    - Displacement
    - Velocity
    - Acceleration
    - Force
    - Momentum
    - Electric Field Strength
    - Magnetic Flux Density
    - Gravitational Field Strength
- **Scalars**
    - Density
    - Mass
    - Volume
    - Area
    - Distance
    - Length
    - Speed
    - Work
    - Energy
    - Power
    - Time
    - Resistance
    - Temperature

- PD
- Charge
- Capacitance
- Pressure
- Perpendicular components of a vector (of magnitude A) at angle x to the plane can be found by **Asin(x)** and **Acos(x)**

Density

$$\text{Density }(\rho) = \frac{\text{Mass (m)}}{\text{Volume (V)}}$$

Turning Effect

- Turning effect of a force about a point depends on the direction of the force, magnitude of the force and distance of the force from the point (pivot)
- When in equilibrium, there is no resultant moment about any point – for every point:
    - *Equilibrium Conditions are no resultant moments and no resultant forces*
    - $\sum \text{Clockwise Moments} = \sum \text{Anticlockwise Moments}$
- $\text{Moments} = \text{Force} \times \text{Perpendicular Distance from Pivot}$

Centre of Gravity

- The C of G is the point about which we can consider all of the weight of a body to act. For a uniform gravitational field, the Centre of Gravity will act on any plane of symmetry, therefore we can sometimes use this to find the C of G.
- For a standing object, the lower the Centre of Gravity, the more stable the object is as while the Centre of Gravity is above the base of the object, the object itself is stable. Once the Centre of Gravity is not above the object, it will tip.

Kinematics (1.2)

- $\text{Speed} = \frac{\text{Distance}}{\text{Time}}$
- $\text{Mean Speed} = \frac{\text{Distamce Travelled}}{\text{Time Taken}}$
- $\text{Mean Velocity} = \frac{\text{Displacement}}{\text{Time Taken}}$
- $\text{Acceleration} = \frac{\Delta V}{\Delta T}$
- SUVAT
    - $S = ut + ½ at^2$
    - $S = vt – ½ at^2$
    - $V = u + at$
    - $V^2 = u^2 + 2as$
    - $S = ½(u+v)t$

Dynamics (1.3)

- **NEWTON'S LAWS**
    - A BODY'S VELOCITY WILL BE CONSTANT UNTIL A FORCE ACTS ON IT.
    - THE RATE OF CHANGE OF MOMENTUM OF A BODY IS DIRECTLY PROPORTIONAL TO THE RESULTANT FORCE.
    - WHEN A FORCE IS APPLIED, THERE WILL BE ANOTHER FORCE, **IDENTICAL IN TYPE, OPPOSITE IN DIRECTION AND IDENTICAL IN MAGNITUDE** ACTING
- **Momentum**
    - P = mv

- Mass is a scalar quantity, which is a measure of the body's inertia.
- **CONSERVED**
    - **The vector sum of the momenta of the bodies in a system is constant provided there is no resultant force from outside the system.**
- COLLISIONS
    - INELASTIC
        - Just momentum is conserved.
    - ELASTIC
        - Momentum and Kinetic Energy is conserved.
- Ft = Change in P (IMPULSE)

- **Forces between materials in Contact**
    - NORMAL FORCE
        - If an object rests against a surface, the surface exerts a force on the object
        - Because the molecules in the two bodies are placed in close contact – the electrons in the outer shells repel one another.
    - FRICTION
        - **Static Friction**
            - $F \leq \mu N$
            - Force acts to stop the two surfaces sliding over each other – it opposes relative motion
        - **Limiting Friction**
            - $F = \mu N$
            - Friction is just enough to prevent motion
        - **Dynamic Friction**
            - Friction is less than the force acting in the direction of motion.
            - *Arises from temporary bonds which form as molecules in the surface move past each other*
                - Bonds stretch and break – the stored energy in the bonds is converted to vibrational energy of the molecules.
    - AIR RESISTANCE
        - Example of **viscous drag**
        - It opposes relative motion between the object and the fluid.
        - Molecules of the fluid bounce off a moving object moves slightly faster than they hit it – momentum increase in the fluid. Therefore force on the fluid in the direction of motion. **BY NIII** the fluid exerts an equal and opposite force on the body.
        - $F_d = \frac{1}{2}\rho v^2 c_d A$
        - Rho is the density of the fluid
        - Cd is the drag coefficient.
        - The force increases with the increase in the surface area, velocity and the density of the fluid.
- **NII**
    - Equivalent to F = ma
- Gravitational Force
    - Weight = Force x Gravitational Field Strength
    - W = mg

Energy Concepts (1.4)

- **WORK DONE**
  - Work Done = Force x DistanceMovedInTheDirectionOfTheForce
  - *Work = Force x ComponentOfDisplacementInTheDirectionOfTheForce*
  - W = Fx
  - **Work is done when a force moves its point of application**
  - Energy is the ability to do work.
- **Kinetic Energy**
  - *THE ENERGY POSSESSED BY A BODY BY VIRTUE OF ITS SPEED*
  - KE = ½mv^2
- **Gravitational Potential Energy**
  - GPE = ½ mgΔh
- **Elastic Potential Energy**
  - K is the spring constant
  - EPE = ½ kx^2
- **POWER**
  - $\text{Power} = \frac{\text{Energy Transfer}}{\text{Time}}$
  - $\text{E} = \text{Pt}$
  - P = Fv
    - P = Fd/t
    - P = Fv
    - FORCE IN THE DIRECTION OF THE VELOCITY
- Dissipative Forces
  - Friction and Drag causes energy to be lost from the system
  - Can be calculated by work done = force of friction x distance over which the force is applied.
  - Look up for more details on friction (the spec is rather vague in terms of how much one needs to know about it)
- **Efficiency**
  - $\text{Efficiency (in \%)} = \frac{\text{Useful Energy Transfer}}{\text{Total Energy Input}} \times 100$
  - $\eta = \frac{\text{Useful Energy Transfer}}{\text{Total Energy Input}} \times 100$

Circular Motion (1.5)

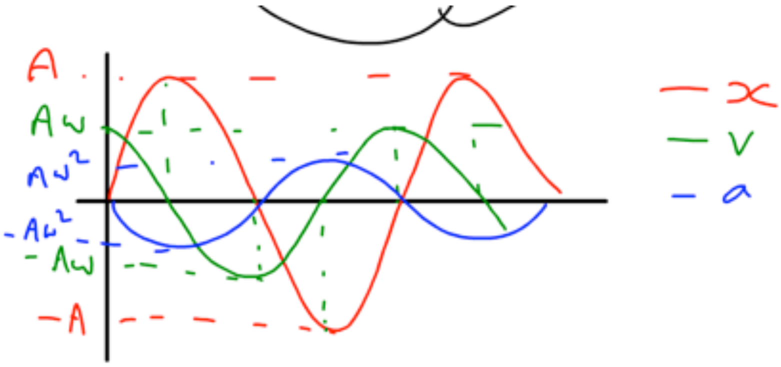
- **Definitions:**
  - **Circular Motion:** Motion at a constant speed but a varying velocity – with the motion occurring around a circle.
  - **Period:** The time to complete one revolution about some axis
  - **Frequency:** The number of revolutions per unit time.
  - **Angular Displacement:** The angle (mostly in radians) turned through.
  - **Angular Velocity:** The rate of change of angular displacement – rad/s
  - **Angular Acceleration:** The rate of change of angular velocity
- **Trivials**
  - $\text{T} = \frac{1}{\text{f}}$

- $w = \frac{d\theta}{dt}$; $w(\text{average}) = \frac{\Delta\theta}{\Delta t}$
- $w = 2\pi f$ (when the object is going around a circle)
- FOR UNIFORM CIRCULAR MOTION: α (ANGULAR ACCELERATION) $= \frac{a}{r}$

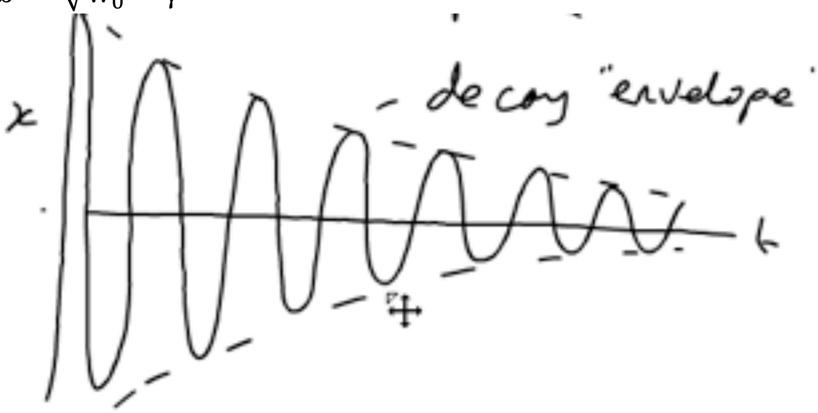
- **Other stuff**
  - T (period of rotation) = $2\pi/\omega$
  - V (tangential speed) = $r\omega$
  - $\text{Centripetal Acceleration} = \frac{v^2}{r} = \omega^2 r$
  - $\text{Centripetal Force} = \frac{mv^2}{r} = m\omega^2 r$
    - Centripetal force is the force acting towards the centre of the rotation – for example for the earth, the force is the gravitational attraction of the sun on the earth.
    - It acts at right angles to the velocity so it has no component parallel to motion – leaves the tangential velocity unchanged.

Vibrations (1.6)

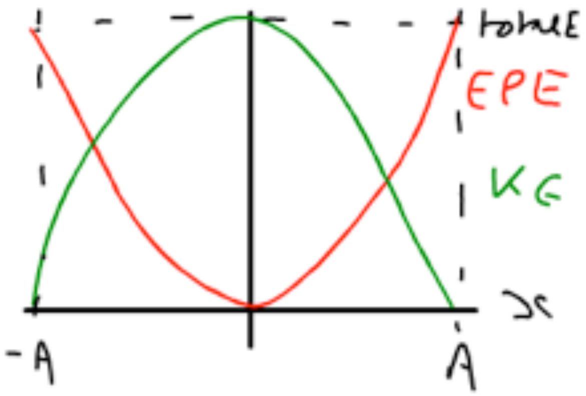
- **A BODY PERFORMS SHM IF IT'S ACCELERATION IS PROPORTIONAL TO ITS DISPLACEMENT FROM A FIXED POINT, BUT IN THE OPPOSITE DIRECTION**
  - $a = -\omega^2 x$ is the defining feature of SHM
  - FOR A SPRING
    - $\omega = \sqrt{\frac{k}{m}}$
    - $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ $\{\omega = 2\pi f\}$
  - FOR A PENDULUM
    - $\omega = \sqrt{\frac{g}{L}}$
    - $f = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$
  - Conditions for SHM
    - FREQUENCY IS INDEPENDENT OF AMPLITUDE (ISOCHRONOUS)
    - Energy in the system will remain constant
  - Purposes
    - Artificial Gravity
    - Calculating g
  - $x = \text{Amplitude} \times \sin(\omega t + \Sigma)$
  - OR
  - $x = A\sin(\omega t) + B\cos(\omega t)$
  - {A is related to the initial velocity while B is the initial displacement}
  - $v = A\omega\cos(\omega t + \Sigma)$
  - $a = -A\omega\sin(\omega t + \Sigma)$

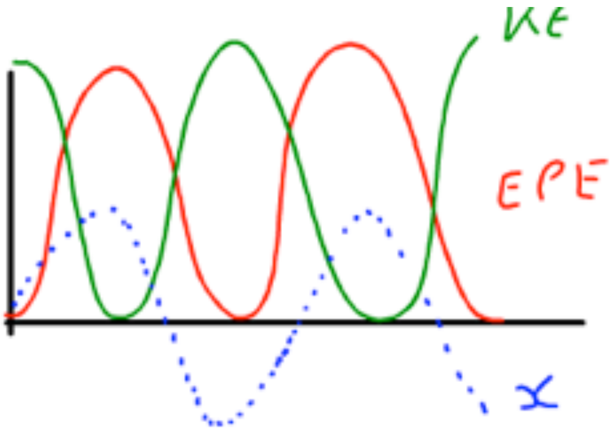


- DAMPING
  - Damping is a force which removes force from an oscillator, resulting in the amplitude decaying exponentially.
  - $x = Ae^{-\gamma t}\sin(\omega t)$
    - $\omega = \sqrt{w_0 - \gamma^2}$



  - **Underdamped – Still oscillates but amplitude reduces to zero over time. {** $\gamma < \omega$**}**
  - **Critical Damping – Quickly returns to equilibrium without further oscillation {** $\gamma = \omega$**}**
  - **Overdamped – Time taken to return to equilibrium is greater than that of critical damping as damping is too large. {** $\gamma > \omega$**}**
  - USES
    - To reduce the speed of the oscillations on things which may have to oscillate
      - Door closures, car suspensions, Millennium Bridge
    - Critical Damping
      - Bike ensures that it doesn't oscillate after going over a pothole.
      - If damping it too heavy, jolts are transmitted strongly from the wheels to the rest of the bike.
- **ENERGY IN SHM**
  - All oscillators store multiple forms of energy and interchange between them.
  - **SPRING**
    - EPE and KE
    - ½ kx^2 + ½ mv^2
    - = ½ kA^2 = ½ $m(A\omega)^2$

- 

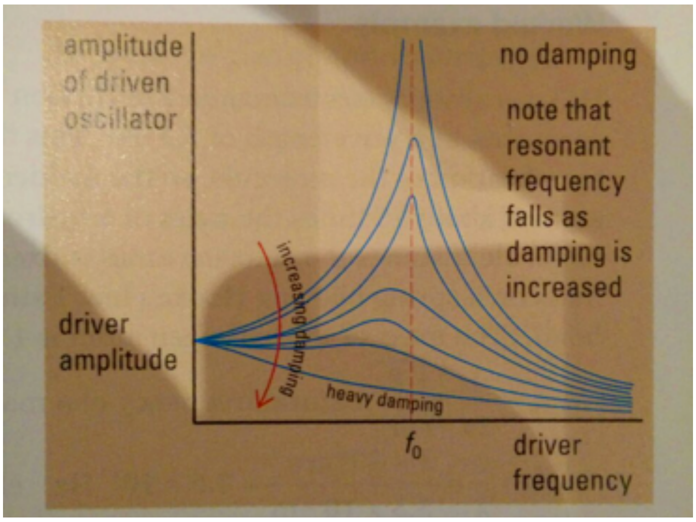
- 

  - **FORCED OSCILLATIONS**
    - Systems are driven by a sinusoidal external force
    - Driven oscillator responds at the driving frequency (not its natural frequency) with a phase and amplitude which vary with the driving frequency.

Transient solution — Steady-state solution

$$x(t) = A_h e^{-\gamma t} \sin(\omega' t + \varphi_h) + A\cos(\omega t - \varphi)$$

Determined by initial position and velocity — Determined by driving force

- 

- The effects of damping are shown in the graph above, with the graph also showing how the nearer to the resonant frequency that the driver frequency is, the greater the amplitude is:
  - $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ for a spring
  - $f = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$ for a pendulum
  - **Resonance**
    - Useful
      - Radio tuning circuits
      - **Ears**
        - The membrane in the ear has varying stiffness' so that different parts of it respond to different parts of the sound.
      - Playground swings
      - Microwaves – tuned to resonate with water molecules
    - Not useful
      - 'buzzing' of speaker cases
      - **Washing Machines**
        - Any assymettry in the position of various items in the washing load will lead to periodic driving forces of a significant amplitude.
        - This is because of the fast rotation of the drum of the washing machine.
        - This could lead to components inside the washing machine to resonate at this frequency.
      - **EYES**
        - Eyeball has a natural frequency of 18 Hz – caused helicopter accidents in which the pilots have missed seeing things because of vibrations from the helicopter engine and rotors.
      - Bridges
        - Tacoma Narrow Bridge which resonated with the wind.

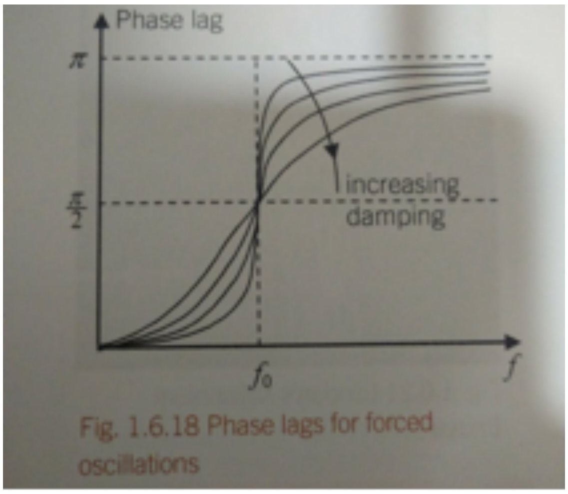
        - Soldiers walking on a bridge at frequency resonated with bridge which could cause it to collapse.
        - Millenium Bridge
- As the driver frequency is reduced, the driven oscillator (since the driving is very slow) becomes in phase with the driver.
- As the driver frequency increases, the driven becomes more out of phase with the driver, with the resonant frequency occurring when the two are around 90 degrees out of phase.
- When the driving frequency is much higher than the natural frequency, the two are 180 degrees out of phase.
- 

Fig. 1.6.18 Phase lags for forced oscillations
- **Damping**
    - As damping increases, the peak is shifted left, with the maximum amplitude being slightly lower than the resonant frequency of the driven oscillator.
        - The peak also broadens
        - The entire curve (all amplitudes) are reduced due to the damping.

Kinetic Theory (1.7)

Ideal Gas Laws

- Boyle's and Charles' Law
    - $\frac{\mathrm{pV}}{\mathrm{T}} = \text{constant}$
    - $\mathrm{pV} = \mathrm{nRT}$
        - R = molar gas constant
        - T = temperature in Kelvin
        - n = volume of gas in moles
        - p = pressure
        - V = volume
- **Dalton's Law:** The pressure of mixtures of gases is equal to the sum of the pressures of the individual gas components.
- **The law of multiple proportions:** 1 unit of nitrogen combines with 2 units of oxygen to give 3 units of nitrogen dioxide.
- **Brownian Motion:** The random motion of smoke particles in a gas.
- **Graham's Law:** The rate of diffusion of a gas is inversely proportional to the square root of the molecular mass

Atomic Properties

- If a beam of positive ions is accelerated and injected at right angles into a magnetic field, they follow a circular path, as they experience a force at right angles to the direction of motion – the principle of a mass spectrometer.

$$r^2 = \frac{2mV}{B^2q}$$

- Where m = ionic mass, q = charge, B = magnetic flux density, V = voltage, r = radius of the path moved by the ion.

Expressing amounts of substances

- **Mole** is an amount of a substance which contains as many basic entities (atoms, molecules) as 12g (exactly) of pure Carbon-12.
- **Avagadro's Constant –** The number of basic entities in a mole (has a value of 6.022 x 10^{23} mole^{-1})
- $\text{Mole} = \frac{\text{Mass}}{\text{Mr}}$

IDEAL GAS EQUATION

- $pV = nRT$
- **pV = NkT, where k is the Boltzmann Constant**
- **ASSUMPTIONS**
    - Assumes the gas is an ideal gas
    - Molecules are spheres
    - Gases are made of random motion
    - Pressure is due to collisions between the molecules and the walls of the container
    - All collisions are perfectly elastic
    - No intermolecular forces between the molecules
    - Volume taken up by the molecules is entirely negligible relative to the volume of the container.
    - Temperature of the gas is proportional to the average kinetic energy of the molecules.

Pressure and Molecular Motion

- SEE BOOK FOR DERIVATION
- RMS speed =$\sqrt{\overline{c^2}}$
- $pV = \frac{1}{3}Nm\overline{c^2}$
- $\text{Kinetic Energy } (E_K) = \frac{1}{2}m{c_{rms}}^2$
    - $\text{Therefore, Total KE} = \frac{1}{2}Nm{c_{rms}}^2$
    - $KE = \frac{3}{2}nRT = \frac{3}{2}kt$
        - Where R = molar gas constant
        - And k = Boltzmann Constant

Thermal Physics (1.8)

Definitions

- **Thermodynamic System** is the collection of particles within a volume of space which has a specific boundary – ie a surface which limits its extent.
- **Isolated System** is a system which does not allow energy or matter to enter or leave
- **Closed System** is a system which does not allow matter to enter or leave
- **Heat Engine** is a system which converts thermal energy into mechanical work

- **Heat, Q,** is the spontaneous flow of energy in response to a difference in temperature. It flows from a high temperature to a low temperature. They are in **thermal equilibrium** if there is no flow of heat between them.
- **Zeroeth Law:** Two systems which separately in thermal equilibrium with a third system will be in thermal equilibrium with each other,

Internal Engine

- THE INTERNAL ENERGY OF A SYSTEM IS THE SUM OF THE POTENTIAL AND KINETIC ENERGIES OF ITS PARTICLES.
- Potential Energy comprises of:
  - Intermolecular Forces
  - Chemical Bonds
  - Excited Energy States in atoms
  - Nuclear energy states
- $\mathrm{U} = \frac{3}{2}\mathrm{nRT} = \frac{3}{2}\mathrm{pV}$ **(FOR AN IDEAL GAS – therefore energy is solely kinetic)**

WORK DONE

- $\text{Work Done} = \mathrm{p}\Delta\mathrm{V}\ (\text{as long as the pressure remains constant})$
- **DERIVATION**
  - Work Done = Fx (force on a piston)
  - F = Ap
  - W = Apx
  - Ax = V
  - => W = pV – if p is constant
  - OR
  - $\int_{V1}^{V2} \mathrm{pVdv}$ **i.e.** Wd = area under p-V graph

First Law of Thermodynamics

- The First Law of Thermodynamics states that when net heat, Q, flows into a system which does net work, W, on its surroundings, the internal energy, U, changes according to the relationship.
- $\Delta\mathrm{U} = \mathrm{Q} - \mathrm{W}$
  - **Q = heat input**
  - **W = work output**
- **For a solid or liquid, W is generally negligible, therefore:**
  - $\Delta\theta = \mathrm{Q}$

Specific Heat Capacity

- $\mathrm{Q} = \mathrm{mc}\Delta\theta$
  - Q = heat input
  - m = mass of the object
  - c = specific heat capacity
  - Theta = temperature

Electricity and the Universe

Conduction of Electricity (2.1)

DEFINITIONS

- **Conservation of Charge** state that the net charge in a system remains constant, provided charges cannot enter or leave.

- **Current** is the rate of flow of charge passing per unit time through a cross-sections of a conductor. It is measured in the Ampere.

How to detect

- **Galvanometer**
    - Galvanometer deflects initially when a power supply is connected across the galvanometer.
- Also, when a metal plate (capacitor) is connected across the power supply and a glass charged ball is placed between the two plates, it is attracted to one side and repelled from the other.

Drift Velocity

- **FOR DERIVATION, SEE BOOK!**
- **For metals,** the mechanism of conduction is the drift of free electrons.
    - $I = nAve$
        - I = current
        - N = number of free electrons per unit volume
        - V = drift velocity
        - E = electron charge

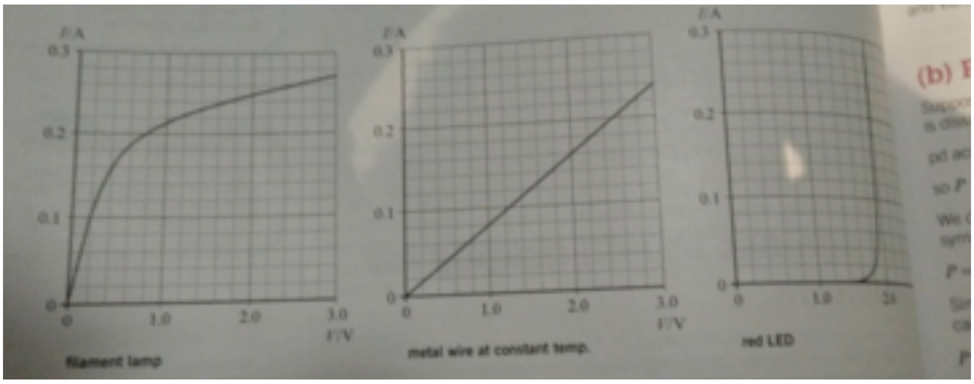
Rules

- Kirchoff's Voltage Law – Sum of voltage around a closed loop = sum of emf.
- Kirchoff's Current Law – Sum of current into a node = sum of current out of node.

Resistance (2.2)

Definitions

- **Potential Difference** between two points is the work done, that is the loss of electrical potential energy per unit charge passing between the two points.
    - $V = \frac{E}{Q}$
- **Work Done = PE lost per unit charge x change in charge**
    - Wd = V x It
- **Power = Wd per unit time**
    - **P = VI**
        - $P = I^2R = \frac{V^2}{R}$
- **Ohm's Law:**
    - The current through a conductor is proportional to the pd, V, across it.
    - This applies to metals at constant temperature (ohmic resistors)
- **Resistance:**
    - Defined by:
    - $R = \frac{\text{Pd across conductor}}{\text{current through resistor}} = \frac{V}{I}$
- Conductance
    - Defined by
    - $G = \frac{(\text{current through conductor})}{\text{pd across conductor}} = \frac{I}{V}$
- **VI Graphs**
-

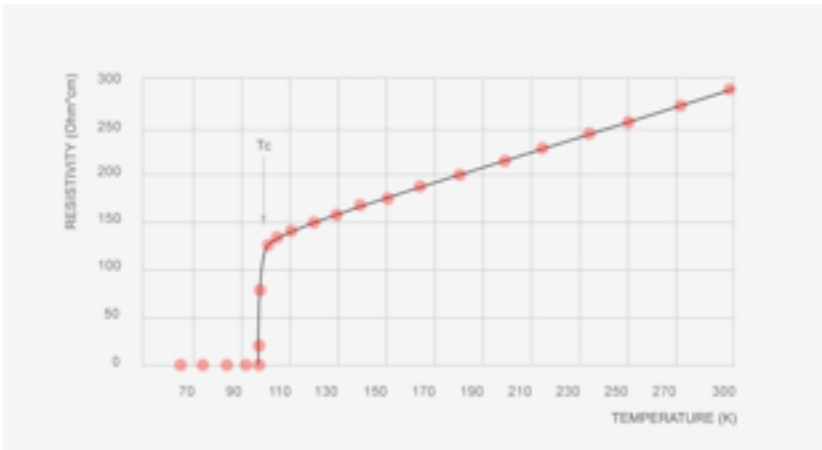
- 

- **How does resistance arise?**
    - In metals, charge flows due to the drift of free electrons.
    - The resistance arises when the electrons collide with themselves and ions.
    - As the temperature rises, the vibrational velocity of the ions increases and therefore the time between the collisions between ions and electrons reduces.
        - Therefore the drift velocity reduces.
        - By $I = nAve$, I reduces. Therefore, by R = V / I, R increases.
    - **For filament bulbs**
        - **As the pd increases** the amount of Joule heating increases as the number and intensity of collisions increases. Therefore, the resistance increases.
    - **RESISTANCE VARIES LINEARLY AS THE TEMPERATURE INCREASES**
        - **Mostly due to the change in resistivity, since there is close to no changes in A or L.**

RESISTIVITY

- $R = \frac{\rho L}{A}$ OR $G = \frac{\sigma L}{A}$
- Where ρ is the resistivity, a constant that depends only on the properties of the wire.

Superconductivity

- A **Superconductor** is a material that below a certain temperature, the superconducting transition temperature, loses all its electrical resistance.
- 

- Most metals show superconductivity properties below a certain temperature, but this temperature if often very low, very close to absolute zero.

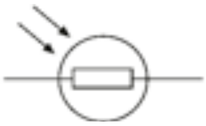
- **There are, however,** some materials which notably have transition temperatures above the boiling point of nitrogen.
    - **They can therefore be used for:**
        - **Electrical power transmission cables.**
        - **MRI**
        - **MagLev Vehicles**

DC Circuits (2.3)

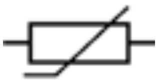
Kirchoff's Laws

- 1) The sum of currents coming into a node = sum of the currents coming out of the node.
- 2) The sum of EMFs = sum of PDs.

Quick things to remember

- Resistance of a voltmeter is so high that the current through it is negligible.
- Resistance of an ammeter is so low that the pd across it is negligible.
- **For a series circuit**
    - $R_T = R_1 + R_2 + \cdots + R_n$
- **For a parallel circuit**
    - $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$
- **Potential Divider**
    - $\text{Vout} = \text{Vin} \times \frac{R_{bottom}}{R_{top} + R_{bottom}}$
    - This can be replicated using a **RHEOSTAT** where the length of coil on either side of the potential divider can be changed to control the voltage coming out of the system
- **Thermistors and LDRs**
    - 

- LDR

- 

- THERMISTOR

- As the temperature goes up, the resistance of the thermistor goes down (NTC)
    - Made of a semiconductor where the number of mobile charge carriers increase as the temperature goes up, therefore meaning the resistance goes down.
- As the light intensity increases, the resistance of the LDR goes down.
    - Inherent property of certain semiconductors such as Cadmium Sulfide.

Power Supplies

- **EMF:** The electromotive force of a cell or battery is the energy that changes category from chemical to electrical potential per unit charge passing through the cell.
- **PD across cell**
    - $V = E - Ir$

        - Where E is the EMF of the cell and r is the internal resistance of the cell.
    - **Power**
        - $P = \frac{E^2R}{(R+r)^2}$

Capacitance (2.4)

A capacitor consists of two conductors separated by an insulator or dielectric.

- Mostly parallel plate capacitors – plates of constant thickness separated by an insulator, generally a vacuum or air.
- Can also use a dielectric – thin film of oxide on one of the plates. It means that the capacitor must be connected the right way around in the circuit so that the plate is at a positive potential relative to the other plate. Otherwise the film would be destroyed.
- Capacitor is charged by the build up of charge on the plates, as free electrons move to one of the plates. This charging stops when the potential difference across the capacitor is equal to the EMF of the battery being used to charge the capacitor.
- $C = \frac{Q}{V}$
- $C = \frac{\varepsilon_0 A}{d}$
    - Where epsilon nought is the permittivity of free space = 8.85 x 10^{-12}
- When there is a dielectric
    - $C = \frac{\varepsilon_0 \varepsilon_r A}{d}$ where ε_r is the relative permittivity.
- The electric field within a parallel plate capacitor is uniform and therefore the equation
    - $E = \frac{V}{d}$
- can be used for the capacitor, the potential across it and the distance between the points in order to find the electric field strength.

Combining capacitors

- **In parallel**
    - $C_T = C_1 + C_2 + \cdots + C_n$
- **In series**
    - $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}$

Energy of a capacitor

- U = VQ
- Since both V and Q are changing as the capacitor is being charged, the energy of the capacitor is the area under the charging circuit = ½ VQ = ½ CV^2 = ½ Q^2 / C

Charging and discharging a capacitor through a resistor

- **DISCHARGING**
    - $IR = \frac{Q}{C}$
    - $I = -\frac{\Delta Q}{\Delta T}$
    - $-\frac{\Delta Q}{\Delta T} = \frac{Q}{RC}$
    - $Q = Q_0 e^{-\frac{t}{RC}}$
        - **RC is the time constant**
            - **THE TIME TAKEN FOR THE CHARGE TO FALL TO 1/e OF THE ORIGINAL CHARGE**

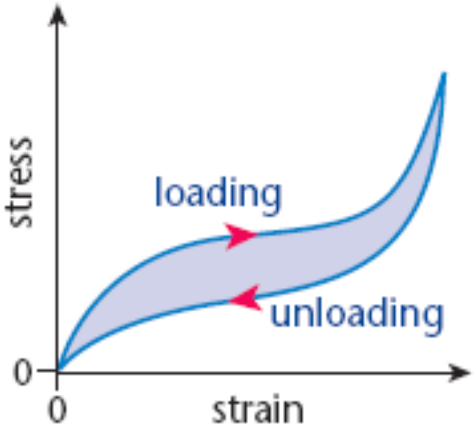
    - **Can be substitute for I or V**
- **CHARGING**
  - $Q = Q_0\left(1 - e^{-\frac{t}{RC}}\right)$
    - **Time taken for it to reach 1 – 1/e of final charge**

Solids under stress (1.5)

- If equal and opposite are applied to the opposite ends of an object, its particles will be forced into new equilibrium positions with respect to one another
- Made of ***COMPRESSIVE, TENSILE & SHEAR*** forces.
- These objects are said to be under stress – the forces shown are those applied externally to the object; by NIII, the object exerts equal and opposite forces on the external object.
- **GASES** cannot be put under tension because the molecules are not bound together.
- **LIQUIDS** cannot withstand a shear because they have no rigidity to their shape.
- **HOOKE'S LAW**
  - When an object is subject to a tensile force, it stretches., for most objects, the degree of the stretch is directly proportional to the tension.
  - F = kx
  - K is the spring constant.
  - If an object is subject to too much stress, it will fracture, but before that happens, the tension-extension graph ceases to be linear – entering a plastic region {elastic limit}
  - THE STIFFNESS OF THE OBJECT IS RELATED TO THE SPRING CONSTANT FOR THE SPRING.
    - Gradient of a force-extension graph.
  - **Work done is the area under the graph – for elastic materials = EPE**
    - **½ Fx if Hooke's Law is obeyed**
- **Stress, Strain and E**
  - Stress (s) = Force / Cross-Sectional Area
  - Strain (e) = Change in Length / Total Length
  - $\sigma = E\,(\text{Young's Modulus})\varepsilon$
  - $E = \frac{Fl}{A\Delta l}$

Material	E / GPa
Steel	210
Glass	50-90
Diamond	1220
Aluminium	69
Rubber (small strain)	0.1

- General values of E tend to be in the scale of GPa – Gigapascals.
- **Strain Energy per Unit Volume = ½ se**
  - **W = ½ FDl**
  - **W/V = ½ FDl / Al**
  - **W/V = ½ se**



-
- **RUBBER**
  - In non hookian materials – the unloading curve is below the loading curve
  - Phenomenon is known as hysteresis – the work done on the rubber in extension is the area under the loading curve
  - The work done by the rubber in contracting is the area under the unloading curve.
  - Therefore, the area between the curves represents the mechanical energy loss in the cycle.
- **Ductile Materials (CRYSTALLINE)**
  - **Structure**
    - Many metals can be drawn out into wires – they are ductile
      - DUCTILE MATERIALS ARE MALLEABLE, ESPECIALLY WHEN THEY'RE HOT
    - Metals are **crystalline** – made of a lattice structure – containing positive ions and a sea of delocalised e- electrons.
    - *Gas turbine blades have been developed consisting of a superalloy of nickel. Most metal samples, are **polycrystalline.***
    - WHEN MOVING FROM MOLTEN STATE, CRYSTALLISATION OCCURS AT MULTIPLE POINTS SIMULTANEOUSLY – HENCE FORMATION OF IRREGULARITIES.
      - Irregularities are random.
    - In ductile metals, there are a number of irregularities within the lattice. An **edge dislocation** is where an additional ½ - plane of ions is present
      - **Point defect –** lattice ion is missing or a 'foreign atom' or just an additional ion is present
  - **Stress-Strain Graph**

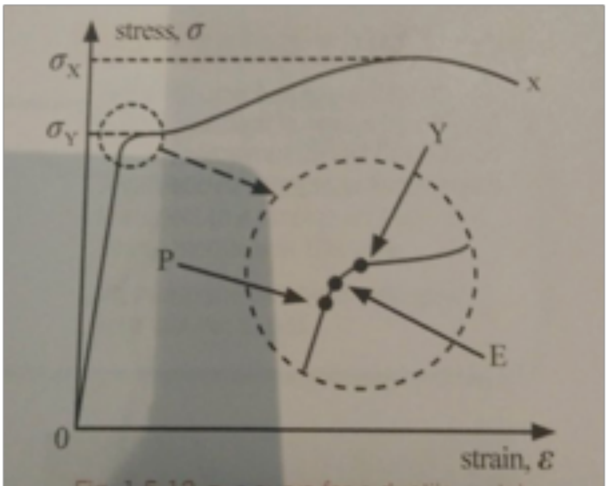
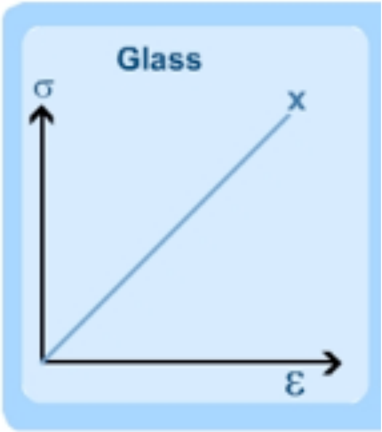


Fig. 1.5.12 σ–ε curve for a ductile metal

-
- Limit of proportionality – P is the point at which the portion is no longer linear.
    - Gradient of this section is the Young's Modulus.
- Elastic limit is point past which the strains are elastic, before that, they are plastic.
- Y is the area at which the material shows a large increase in strain for little or no increase in stress.
- Max stress is the breaking stress or ultimate tensile strength.
- The sample experiences **necking** at the maximum strains – just prior to the breakage of it.
    - Be careful about the difference between the Engineering Stress and the True Stress
    - At this point – the **ENGINEERING STRESS DROPS – but TRUE STRAIN CONTINUES TO RISE**
        - Because the Surface area reduces – as the the object comes close to breaking.
- **Structure and Properties**
    - When under low tension:
        - The separation between the ions is increased - elastic deformation - since upon the reduction of the stress – the materials ions will return to the position of the old ions.
    - Past elastic limit:
        - Irreversible rearrangement of particles – **due to edge dislocations**
        - Under the influence of the forces, the placement of the force can break bonds between the bonds and reform them. – with the individual ions themselves moving very minimal amounts.
        - What happens depends on other factors:
            - EDGE LOCATIONS CAN GET ENTANGLED
            - SIZE OF GRAINS
            - PRESENCE OF POINT DISLOCATIONS
    - How to strengthen the material
        - Introduce foreign atoms

- Introduce barriers to dislocation movement (create dislocation entanglement)
- Heating or quenching regimes can make the metal more or less ductile.

- **Stress and Strain in Brittle Materials**
- 

    - COMPLETELY HOOKIAN
        - Non-crystalline structure - AMORHOUSE
        - Eg. Silicon Dioxide
            - Has an amorphous structure – often covalently bonded.
            - Structures form when the SiO_2 cools down to quickly for the molecules to form the crystalline state.
        - Brittle because there is no ability for the movement of dislocations, since these don't exist.
    - **Brittle Fracture**
        - Brittle materials are weak in tension
            - Breaking Stress is low
            - Because of absence of plastic deformation – simply breaks at what would be the elastic limit.
        - **DUE TO CRACK PROPOGATION**
            - Forces are transmitted around the crack – therefore the stress is much magnified.
            - Therefore, the material will break at near the crack – therefore increasing the size of the crack and therefore allowing the crack to propagate – at the speed of sound.
- **POLYMERS**
    - Substance made of molecules consisting of long chains of identical sections called repeat units – identical sections are called **monomers.**
        - **Monomers are:** molecules with a double bond which is broken open to form the repeat unit of a polymer.
    - **RUBBER**
        - **Polymerised Isoprene – $CH_2{=}C(CH_3)CH{=}CH_2$**
        - The double bonds are broken in polymerization.
        - Molecule can rotate around each of the single C-C bonds – so the shape of rubber molecules is randomly tangled.
            - Under tension, it responds by straightening out.

- Hence, the low forces required – since the bonds are not being stretched, simply rotations.
- HOWEVER, the **cross-linkages** between the molecules limits the total extension possible.
- Upon removal of the tension, the bonds rerotate – and the rubber contracts.
- SOME ENERGY IS CONVERTED BY INTERMOLECULAR COLLISIONS INTO RANDOM KINETIC ENERGY OF THE MOLECULES, SO NOT AS MUCH WORK IS DONE IN CONTRACTING, LEADING TO THE HYSTERESIS EFFECT.

- **CHARACTERISTICS OF RUBBER**
  - Rubber is stiff for low extensions – becomes less stiff before finally more stiff.
  - Unloading curve is lower than loading curve – hysteresis.
  - Particularly large strains.
  - Stress values are low – MPa
  - Volume is pretty much constant throughout the stress-strain curve.

Electrostatic and gravitational fields of force (2.6)

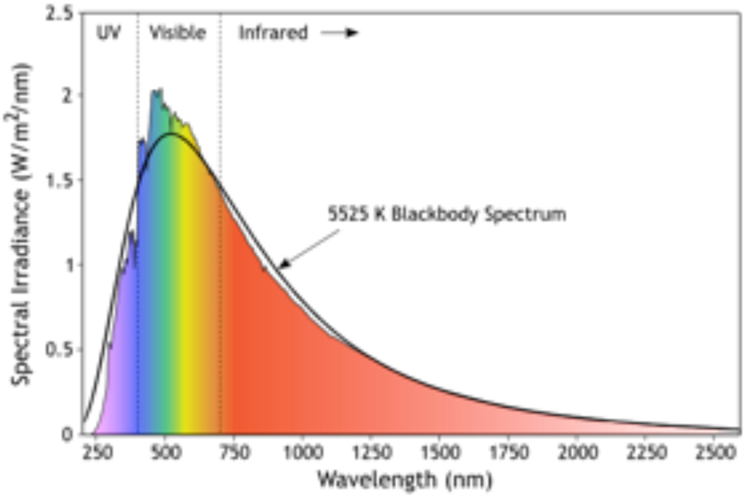
- **ELECTROSTATIC DEFINITIONS:**
- **Coulomb's Law**
  - The force between point charges, q and Q, in a vacuum and separated by distance r is given by:
  - $F = \frac{qQ}{4\pi\varepsilon_0 r^2}$
  - Where e0 is the permittivity of free space.
- **The magnitude of the electric field strength at distance r from a point charge Q, or from the CENTRE OF A SPHERICALLY SYMMETRIC CHARGE DISTRIBUTION OF TOTAL CHARGE Q is:**
  - $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ because $E = \frac{F}{q}$
  - The direction of the field is radially outwards if Q is positive and radially inwards if it is negative.
  - **Electric Field Strength is the force per unit charge on a small positive test charge placed at the point.**
- **The Potential Energy** of a test charge, q, at a point P in an electric field is the work done by the field on q, as q goes from P to infinity.
  - $PE = \frac{Qq}{4\pi\varepsilon_0 r}$
- **The Potential** is the work done by the field per unit charge on a test charge as it moves from a point to infinity.
  - $V = \frac{Q}{4\pi\varepsilon_0 r}$
  - $PE = q\Delta V$
  - $E = \frac{V}{r}$
- **FIELD LINES AND EQUIPOTENTIALS**
  - Field lines show the direction of the electric field at a point.
    - "Electric field line is a line whose direction at each point along it is the direction of the electric field at that point"

    - Point charges have radially outside lines (so strength reduces as you get further away) pointing towards or away from the charge depending on whether the charge is positive or negative.
  - Equipotential surfaces are surfaces that connect points at the same potential to one another.
    - "Equipotential surfaces are imaginary surfaces on which all points are at the same potential"
    - For a point charge, these are spheres.
    - The surfaces are closer together when the field is stronger.
- **GRAVITATIONAL DEFINITIONS**
- **Newton's Law of Gravitation**
  - $\mathrm{F} = \frac{\mathrm{GmM}}{\mathrm{r}^2}$ where G is the Gravitational Constant
- **Gravitational Field Strength** is defined as the force per unit mass on a test mass at a distance r away.
- **For the definitions for PE, V etc look at the table!!**
- **Main difference is that with the gravitational force, the force is ONLY ATTRACTIVE, as opposed to for the electrostatic fields where the force could be repulsive.**

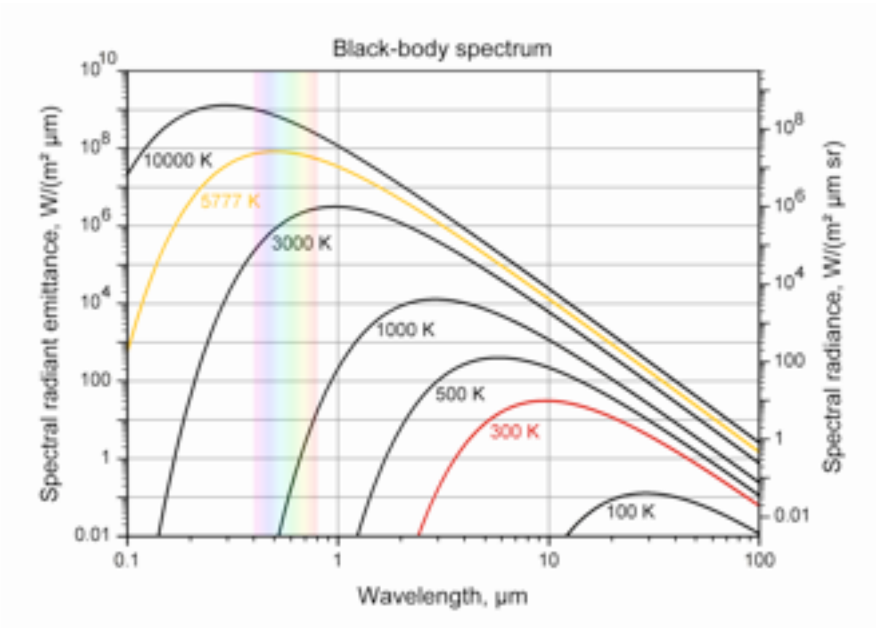
ELECTRIC FIELDS	GRAVITATIONAL FIELDS
Electric field strength, E, is the force per unit charge on a small positive test charge placed at the point	Gravitational field strength, g, is the force per unit mass on a small test mass placed at the point
Inverse square law for the force between two electric charges in the form $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$ (Coulomb's law)	Inverse square law for the force between two masses in the form $F = G\frac{M_1M_2}{r^2}$ (Newton's law of gravitation)
F can be attractive or repulsive	F is attractive only
$E = \frac{1}{4\pi\varepsilon_o}\frac{Q}{r^2}$ for the field strength due to a point charge in free space or air	$g = \frac{GM}{r^2}$ for the field strength due to a point mass
Potential at a point due to a point charge in terms of the work done in bringing a unit positive charge from infinity to that point	Potential at a point due to a point mass in terms of the work done in bringing a unit mass from infinity to that point
$V_E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$ and $PE = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r}$	$V_g = -\frac{GM}{r}$ and $PE = -\frac{GM_1M_2}{r}$
Change in potential energy of a point charge moving in any electric field $= q\Delta V_E$	Change in potential energy of a point mass moving in any gravitational field $= m\Delta V_g$
Field strength at a point is given by E = - slope of the $V_E - r$ graph at that point	Field strength at a point is given by g = - slope of the $V_g - r$ graph at that point
Note that $\frac{1}{4\pi\varepsilon_0} \approx 9 \times 10^9\, \mathrm{F^{-1}m}$ is an acceptable approximation	

Using radiation to investigate stars (1.6)

Black Body Radiation



- **Spectrum of the Sun consists of two parts:**
    - **CONTINUOUS SPECTRUM – consists of all wavelengths within a range**
    - **LINE SPECTRUM – consists of a series of f a series of individual wavelengths**
    - **Dark lines are the Fraunhofer lines**
    - **BLACKBODY SPECTRUM -** Dark line show that the sun acts very similar to a black body – but there are a few subtle differences.
- A black body is defined as one that absorbs all radiation which is incedent upon it. It also emits more radiation at any wavelength than a non-black body in the continuous spectrum.



- Looking at cavity radiation – the specific peak emission of radiation varies depending on the temperature of the object.
    - Used by looking at the radiation from a furnace hole – at different temperatures.
- Hence, red light visible from about 1000K – though much more at higher temperatures.
    - **Wien Displacement Law**
        - $\lambda_{\mathrm{max}} = \frac{\mathrm{W}}{\mathrm{T}}$ {W is the Wien Constant and T is temperature in Kelvin}
        - Wien Constant is 2.898×10^{-3} m K (metres Kelvin)

- **Stefan-Boltzmann Law**
    - Total power of the radiation emitted by a black body, per unit area is directly proportional to T^4
    - $P = AsT^4$
        - A is the Surface Area
        - Sigma is the Stefan Constant – 5.67×10^{-8} W m^{-2} K^{-4}
- **The intensity of radiation decreases as the inverse square of the distance – star 10 times as far away would appear as 0.01 as bright.**
- **Measuring the distance to a star**
    - Since the angle to stars change with the changes in the earths orbit, therefore we can calculate the distance to the star – as long as we know the radius of the earths orbit.
        - $\tan x = r/d$
        - if x is measured in rad, then since the angle is normally very low – tan $x \approx x$
        - $x = r/d$
        - $d = r/$
    - To measure larger distances, where the precision of theta is very minimal – given the very low changes in angles, astronomers make use of objects of known brightness's - using the inverse square law to find the distance.
        - *CEPEHEID VARIABLE STARS – nearby galaxies*
        - *TYPE 1A SUPERNOVAE – more distant galaxies*
- **FRAUNHOFER LINES**
    - **Absorption Spectrum**
        - The variation in intensity of radiation with wavelength due to absorption by a material.
    - As light from a black body reaches us, the radiation must pass through gases, which is made of a number of elements. Each of these elements has a specific absorption spectra, which defines what wavelengths of light the gas absorbs. There is also a corresponding emission spectra, which shows the emissions of the gases.
    - Therefore, looking at the fraunhofer lines which are observed, we can specifically see what elements there are in the gas, by seeing which changes are present and which are not.
    - **We can also estimate the temperature by looking at which of the lines of each element are present.**
        - EG. Mg has two main absorption lines – 470nm and 518nm.
        - On the sun's spectra, there is a dip for 518nm but none at 470nm.
        - Therefore the temperature was too high for light to be absorbed at the lower wavelength.
        - At a high temperature, entirely 518nm, at a low temperature, 470nm.
        - Basically, the particles of the gas must be at the correct energy state.
- **Multiwavelength Astronomy**
    - Some non-thermal processes result in the emission of radiation, including 21cm HI and synchrotron radiation, giving us information about the hydrogen clouds and the magnetic field.

- By looking at the same areas in different spectra can each give us pieces of information.
- For example, looking at the visible spectrum can tell us that some parts of galaxies are low mass, and generally yellowish.
- UV can tell us that some parts are warmer. IR can tell us where parts are heating up dust. X-Ray only shows the very hot areas.
- 21cm can show us the presence of Hydrogen Clouds – telling us where processes creating hydrogen took place.

Orbits and the wider universe (2.8)

Kepler's Laws

- **Kepler's 1st Law**
  - The orbit of a planet is an ellipse with the star at one focus.
  - **K2**
    - The line joining the planet to the star sweeps out equal areas in equal periods of time
  - **K3**
    - The square of the period, T, of the orbit is proportional to the cube of the semi-major axis, a, of the orbit.
      - $\frac{GmM}{r^2} = \frac{mv^2}{r}$, $v = \frac{2\pi r}{T}$, $\frac{GM}{r^2} = \frac{4\pi^2 r}{T^2}$, $T^2 = \frac{4\pi^2}{GM} r^3$

Definitions

- **TNO (Trans-Neptunian Object)**
  - A TNO is a minor planet which orbits the star with an average distance (semi-major axis) greater than that of Neptune.
  - **Perihelion (Periastron, Perigee, Perinigricon)**
    - Point of closest approach of a planet to the star
  - **Aphelion (Apastron, Apogee, Aponigricon)**
    - Most distant point from the star
  - **Radial Velocity**
    - Component of the velocity of an object relative to an observer on the earth, in the direction from the earth to the object.
  - **Exoplanet**
    - Planet which orbits a star other than the Sun.
  - **Brown Dwarf**
    - Stellar-type object with too low a mass for hydrogen fusion.

Energy of an Orbiting Body

- E = KE + PE
- $E = \frac{1}{2}mv^2 - \frac{GMm}{r}$
- $E = -\frac{\frac{1}{2}GMm}{r}$ (when the orbit is an ellipse, $r = a$) where a is the semi-major axis.
- Kepler's Laws actually suggest that the orbits are conic sections, not necessarily ellipses.
  - When E < 0, the orbit is elliptical
  - When E = 0, the orbit is parabolic
  - When E > 0, the orbit is hyperbolic

DARK MATTER (EVIDENCE) (spec notes that it could have some relation to the Higgs Boson, despite no such evidence and few theories to this effect…)

- $v^2 = \frac{GM}{r} => v = \sqrt{\frac{GM}{r}}$
- However, looking at rotation curves, this is clearly not true as the orbital speed tails of in reality as opposed to following a $\sqrt{\frac{1}{r}}$ as we expect.
- Therefore we predict that there is a lot more mass that we have not yet observed which would make up for the higher than expected velocities.
- Also, **GRAVITATIONAL LENSING**
    - Gravitational Lensing predicts that light should be bent by massive objects, forming observable circular halos around objects, as the light is bent more than we would otherwise expect given the mass of objects between the light emitter and the earth.
- Also, **Cosmic Microwave Background Radiation**
    - The CMBR retain the imprints of density fluctuations in the early universe. Baryonic matter and non-baryonic matter have different effects. Therefore, we predict that 85% of the mass is non-baryonic.

Other important things

- **Doppler Effect**
    - Doppler Effect is the observed change in frequency of waves depending on the relative velocity of the observer and the emitter of the waves.
    - For full derivation of this, see the textbook.
    - During an orbit, the change in wavelength goes from the greatest negative to the greater positive, depending on the placement of the velocity and its direction.
    - $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ **or** $\frac{\Delta f}{f} = -\frac{v}{c}$
- **Bodies in mutual orbit**
    - CENTRE OF MASS
        - $m_1r_1 = m_2r_2$
        - $r_1 = \frac{m_2}{m_1+m_2}d$
        - $r_2 = \frac{m_1}{m_1+m_2}d$
    - ORBITS OF BINARY OBJECTS
        - $T = 2\pi\sqrt{\frac{d^3}{G(m_1+m_2)}}$
- **The Transit Method**
    - If the observer is in the plane of the orbit of the companion, the starlight will dim periodically as the planet passes in front of the stellar disk.
    - Using this fact, we can find planets looking at the light from various areas in the sky.
    - We've found 1000 planets using this.
    - In addition to the Doppler measurement, which deliver the mass of the planet, the mean density and therefore the nature of the planet can be investigated.
- **The Expansion of the Universe**
    - **HUBBLE'S LAW**
        - Hubble's Law states that the recession velocity of deep-space objects is proportional to their proper distance

- The recession velocity of a deep space object is the Hubble shift interpretation of their red shift.
- The proper distance of a deep-space object is the distance from us to the current position of the object.
- **Astronomers have discovered that all objects outside our local cluster of galaxies have a spectrum which is red-shifted.**
- $v = H_0 d$ **where** H_0 **is the Hubble Constant and d is the Proper Distance.**
- The Hubble Constant is hard to determine, as for objects beyond a certain distance it is hard to find the distance of objects by parallax.
    - One method is using the apparent brightness of **standard candles**
        - OBJECTS OF KNOWN LUMINOSITY, SUCH AS A SPECIFIC SUPERNOVA. THEREFORE, USING THE INVERSE SQUARE LAW, WE CAN FIND THE LUMINOSITY.

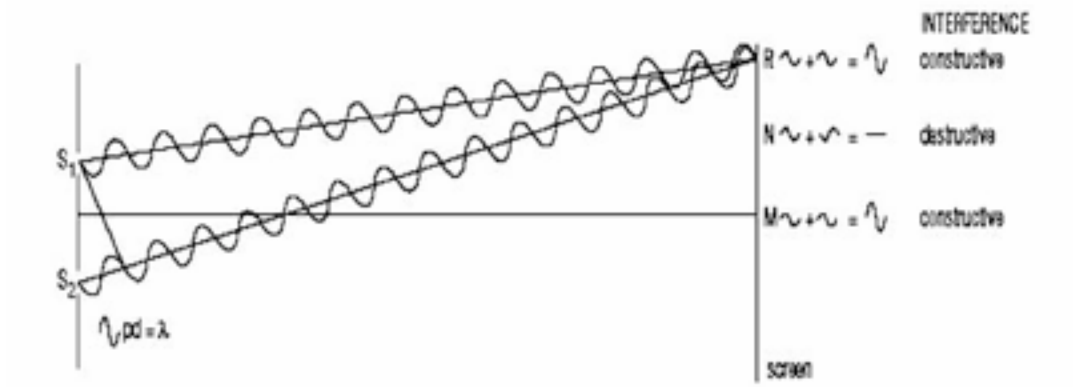
- **Critical Density**
    - According to General Theory of Relativity, the universe should be flat. Therefore, assuming the universe is a shell, and there is mass within the radius of the shell.
    - $\text{Mass of shell} = 4\pi r^2 \rho \Lambda r$
    - $\text{Mass within the shell} = \frac{4}{3}\pi r^3 \rho$ where ρ = mean density of the universe
    - $\text{Recession Speed} = H_0 r$
    - $E = KE + PE$
    - $= 2\pi r^4 \rho {H_0}^2 \Delta r - \frac{16}{3} G \pi^2 r^4 \rho^2 \Delta r$
    - If the universe was flat, E = 0
    - Therefore:
        - $\text{Critical Density } (\rho) = \frac{3{H_0}^2}{8\pi G}$
        - Current measurements of baryonic matter shows that its density much less than this – therefore even more evidence for the existence of dark matter.
- **Hubble Time**
    - $\text{Hubble Time } (T_H) = \frac{1}{H^0}$
    - This is actually rather close to the actual value that we currently expect.

Light, Nuclei and AC Theory

The Nature of Waves (2.4)

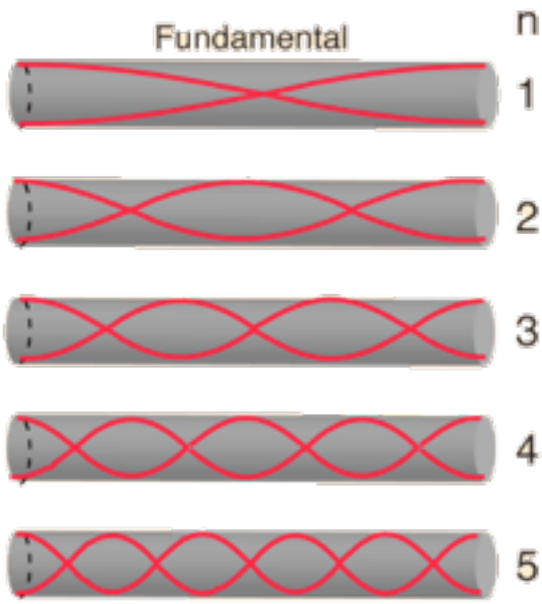
- A wave is an oscillation accompanied by the transfer of energy through a medium.
    - **PROGRESSIVE WAVE –** a disturbance, or sequence of disturbances, travelling through a medium, taking energy with it, but not taking the particles of the medium with it,
    - **Transverse Wave:** The particles of the medium of the medium are displaced at right angles to the direction of propagation
        - EM waves, secondary waves (SHEAR waves)
            - **Similarities**
                -

            - **Differences**
                - Can travel without a medium – travel through a vacuum.
                - Instead of particles oscillating as an EM wave travels, it is the Electric Field Strength and the Magnetic Field Strength that oscillate at each point.
                - They vibrate perpendicular to each other.
        - POLARISED OR UNPOLARISED
            - Polarised is where the vibrations are on one plane,
            - Unpolarised is when the vibrations are on multiple different planes simulataneously.
    - **Longitudinal Wave:** The particles of the medium are displaced parallel to the direction of wave travel.
        - Water waves, sound waves, seismic waves.
- **Definitions**
    - **Cycle:** Smallest portion of an oscillation, starting at any point, which repeats exactly.
    - **Amplitude:** Maximum value of the displacement.
    - **Period:** Time for one cycle of oscillation
    - **Frequency:** The number of cycles per unit time.
    - **Phase:** Oscillations of the same frequency are in phase If they are the same point in their cycles at the same time.
    - **Wavelength:** Distance between consecutive particles that are oscillating in phase.
    - **Wavefront:** Surface at all points on which the oscillations are in phase.
    - **Coherent Light**
        - **Nearly monochromatic:** continuous stream of oscillations of a single frequency
        - Has wavefronts extending across it's widths as if it came from a point source.
        - **CONSTANT PHASE RELATIONSHIP BETWEEN THEIR OSCILLATIONS**
- $V = f\lambda$
- **Polarisation**
    - A = A0cos(x)
    - I is proportional to A^2
    - Therefore:
        - $I = I_{=} \times \cos(x)$
- **Diffraction**
    - Spreading of waves around obstacles in their way.
    - When the slit's width is equal to, or less than, the wavelength, the diffracted wavefronts at some distance from the slit are more or less semi-circular
- **Principle of Superposition**
    - The resultant displacement at each point is the vector sum of the displacements that each wave passing through the point would produce by itself.
    - Maxima combine with constructive interference to increase in intensity – when two waves are in phase.
    - Otherwise, we get destructive interference, when the resultant vector is closer to 0.
    - **For constructive interference, the path difference is a multiple of the wavelength.**

- 

- Where x is the angle from the middle of S1 and S2 to R:
  - Path difference = a sin x
  - a sin(x) = nλ for constructive interference.
- **YOUNG's FRINGES EXPERIMENT**
  - Two parallel slits – close together – get a patteron of light and dark fringer – shows that light is wave like.
  - $\lambda = \frac{a\gamma}{D}$
  - This relies upon y and a being much less than D (the distance from the slits to the screen is much larger than the distance between the slits and the distance between the maxima on the screen)
  - This is because it relies on the small angle approximation.
  - **Incoming light must be in phase – cannot be produced from an LED or multiple light sources.**
- **Diffraction Grating**
  - $n\lambda = d\sin(\theta)$
  - The **diffraction grating constant** (D) is the number of lines or slits per metre.
  - D = 1/d

- **STATIONARY WAVES**
  - In a stationery wave all points between a pair of neighbouring nodes oscillate in phase; points either side of a node oscillate in antiphase.
    - IN A PROGRESSIVE WAVE, THERE IS A GRADUAL CHANGE OF PHASE ALONG THE WAVE.
  - In a stationary wave, the amplitude of vibration varies smoothly from zero, at the nodes, to a maximum, at the antinodes.
    - In a progressive wave, all points oscillate with the same amplitude.
  - NODES are ½ wavelength from each other.
  - **FORMATION OF STATIONERY WAVES:**
    - Energy is put into forming progressive waves, such as by plucking a string.
    - Progressive waves are produced, which each travel in opposite directions along the string.
    - The waves reflect each end.
    - Waves die out until the waves which are left which have a node at each end – string is a multiple of ½ lamda.
  - **HARMONICS**
    - 1^{st} Harmonic is ½ lamda
    - 2^{nd} Harmonic is lamda
    - 3^{rd} is 3/2 lamda
    - etc
    - **IN AIR COLUMNS**

- 

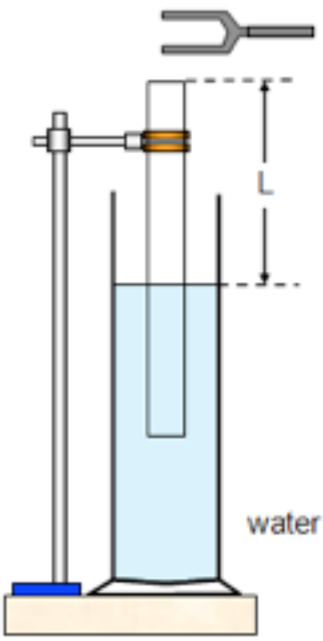
    - There is an antinode (area of low pressure) just where the air is moved from above the tube.
    - Fundamentals for air column (open for both sides) are shown – therefore there is an anti-node on both sides.
    - *This method can be used to find the speed of sound in air using a water column:*
    - 

Figure 5

- **Spectrometer**
    - Instead of simply using a diffraction grating allows the person to get a very high angular resolution.
    - Non-coherent light can also be used.
    - The spectral lines are very narrow as the collimator is effective at producing narrow slits.
    - It isolates light from the outside.

Wave Properties (2.5)

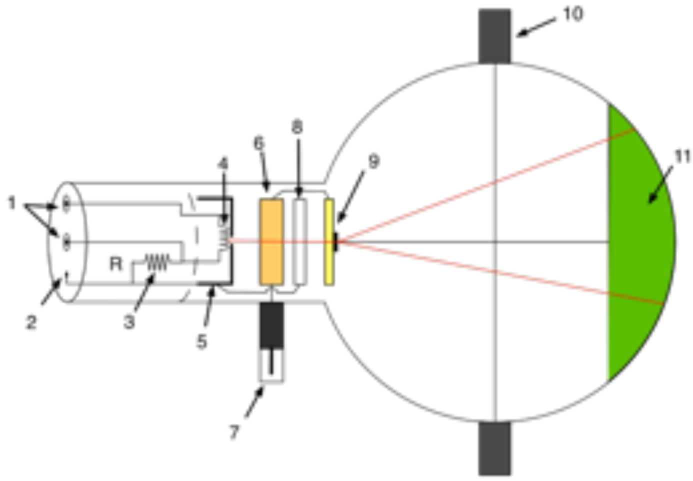
Refraction of Light (2.6)

- Waves exhibit a change of direction if they move from one material into another in which the speed or propagation is different (unless the direction of propagation is at right angles to the boundary).
  - *Seismic wave speeds depend upon stiffness and density of rocks.*
  - *The speed of radio waves through the ionosphere (upper atmosphere) is affected by the free-electron concentration.*
- $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$ – where n1 and n2 are the refractive indexes of the two materials (from which the light is passing from and to).
  - $n = \frac{c}{v}$ $(c \text{ is the speed of light in a vacuum and } v \text{ is the speed of light in the material})$
  - The higher the optical density of the material, the higher the refractive index of the product.
- **Total Internal Reflection**
  - Sub in 90 degrees for θ_2; $n1 \sin(\theta) = n2$
    - $\sin(c) = \frac{n2}{n1}; c = sin^{-1}\left(\frac{n2}{n1}\right)$
  - **USES OF TIR**
    - Totally Reflecting Prisms
      - Binoculars, Microscopes and Prisms
      - Lack of the multiple reflections which are present in mirrors – which would make the image much worse. For prisms, the little reflection that would occur would simply send the light back to the area from which the light came, and therefore would not affect the final image at all.
    - Mirages
      - The surface of a road or sand desert absorbs radiation from the Sun and heats up.
      - Forms a temperature gradient – as the road heats up the air directly above the road.
      - Refractive index decreases as a light ray approaches the surface, hence, the critical angle reduces. From the view of the person – at a very high angle – relative to the road – they see the glimmering view of the sky in the place of the road (specifically down – below the surface)
    - **Optical Fibres**
      - Used for data transmission (LAN and longer distance)
      - Used also in remote imaging systems – endoscopy.
      - **Structure**
        - SINGLE GLASS THREAD – contains a core containing the light signal and the cladding, which keeps the light signal in the core.
        - Around this, there is a coating – of about 0.25mm
        - Cable consists of lots of these fibres.
      - Relies upon the glass having a much higher refractive index than the cladding.
      - **MULTIMODE FIBRES**
        - In multimode fibres, signals can be sent at different angles, including a number of light rays at the same time.
        - However, this suffers the problem of having a time difference, since something at a shallower angle would move further in the same time than a steeper angle.
        - This is a large issue when the distances become much larger **(MULTIMODE DISPERSION)** – therefore use of monomode fibres.

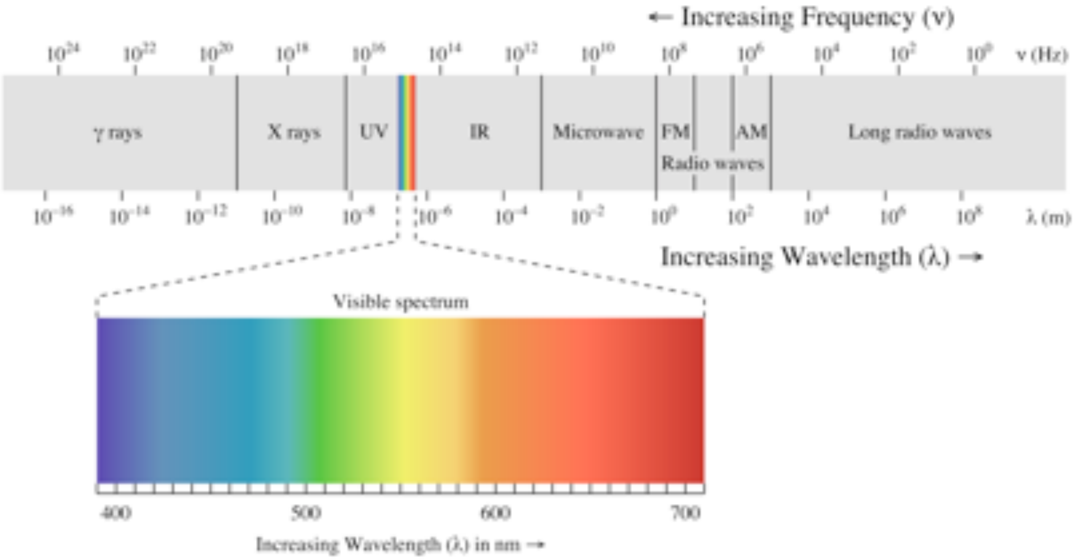
- **MONOMODE FIBRES**
  - The core diameter is made very small - <10um – as this ensures that the light wave cannot take multiple paths and is forced to travel parallel to the axis of the fibre.
  - From here, to ensure that attenuation is reduced as much as possible, the amount of scattering by impurities in the glass must be reduced.
    - Rayleigh Scattering becomes more serious the lower the wavelength.
    - Same reason sky is blue.
  - Therefore, higher wavelength the better.
  - Also, to ensure that the specific molecules in the glass do not absorb this part of the spectrum – looking at the absorption spectra of the glass – and minimising this as much as possible.
  - In the end, the chosen wavelength is around 1.5mm (upper end of IR)

Photons (2.7)

- Einstein showed the energy of photos was proportional to the frequency of the light, with the constant being the Planck Constant (6.63×10^{-34})
  - $E = hf$
- **PHOTOELECTRIC EFFECT**
  - If light is shines on a negatively charge plate of a gold leaf electroscope, there is a movement of electrons – therefore meaning the gold leaf returns to the normal (unmoved) position.
    - However, the fact that it is the movement of electrons can be shown by the fact that UV light has no effect upon a positively charged plate – since electrons would still be moving – but the gold leaf would not return to the neutral position.
  - Experiment can be carried out using a vacuum photocell, experimenting with this can show the following:
    - There is a characteristic threshold frequency, below which no electrons are emitted whatever the intensity of the radiation.
    - There is a linear relationship between the max kinetic energy and the frequency.
    - If electrons are emitted, Ekmax is independent of the radiation intensity.
    - If electrons are emitted, the number of electrons emitted per second is proportional to the intensity of the radiation.
  - Explanations:
    - Electomagnetic radiation consists of specific packets of energy – $E = hf$
    - When a photon impacts an electron in a metal surface, it's entire energy is transferred.
    - An electron interacts with a single photon.
    - There is a minimum energy of a photon (ϕ) – the work function, which is needed to remove an electron from a metal surface.
    - $Ek_{max} = hf - \phi$ (**EINSTEIN's PHOTOELECTRIC EQUATION)**
  - **Radiation Intensity**
    - Photons are passing through a plane
    - Total energy = Number of Photons x Energy per Photon
    - $I = NE_p$
    - $I = Nhf$
    - $I = Nhc/\lambda$
    - Considering how the intensity changes over distance r

        - $I = I_0/(4\pi r^2)$
        - Therefore $I=(Nhf)/(4\pi r^2)$
- **WAVE-PARTICLE DUALITY**
    - **LIGHT**
        - Wave
            - Diffracts
            - Refracts
            - Interference
        - Particle
            - Emission and absorption of light appears to show light as a particle
            - Can travel without a medium – travel through a vacuum.
            - Instead of particles oscillating as an EM wave travels, it is the Electric Field Strength and the Magnetic Field Strength that oscillate at each point.
    - **ELECTRONS**
        - Single slit and double slit experiments (as for lights) can also show the similar results for electrons.
        - **ELECTRON DIFFRACTION TUBE**
            - 

            - Metal-Coil Cathode connected to an AC supply – heats up and emits electrons by thermionic emission.
            - Accelerated to the Anode – by using a high voltage.
            - Hit 9 (Graphite), which diffracts the electrons and the beams hit the phosphor (11), producing a series of circular rings.
- **EM SPECTRUM**

- 

- **ATOMIC SPECTRA**
  - **Atomic Energy Levels**
    - Atoms must be a part of discrete number of energy states – since the electrons can be at excited states, or indeed at ground states.
    - Conventionally, electrons outside of an atom have 0 energy
      - In atom, they have a negative energy, since energy must be given to the electron to allow it to escape the atom.
      - GROUND STATE is the minimum (most negative) energy state of the electron.
      - The negative value of the ground state is known as the **ionisation energy** of the atom.
        - n is also used as the number of principal quantum number of the energy state (number of possible energy states at which the electron can exist).
    - **Atomic Absorption Spectra**
      - The light which can be absorbed by atoms correspond to the various differences in energy levels between the different energy levels of the atom.
      - For atoms with only one electron – H, He+, Li2+ etc.
        - $En\ (eV) = \ -13.6\frac{Z^2}{n^2}\ \{Z\ is\ atomic\ number\}$
  - **Atomic Emission Spectra**
    - The photons which are emitted have energies close to the energy level difference of the atom – since this reduction in Kinetic Energy has resulted in the production of the photon.
    - The atomic spectra can be viewed by using a gas discharge tube – with the ability for a potential difference to be applied to the tube – this partially ionises the gas and allows it to be raised to a higher energy level – and then drop down (when voltage is removed), hence emitting the colours of the Atomic Emission Spectra, hence the formation of the Aurorae (Boralis and Australis)
- **MOMENTUM**
  - **Momentum of Particles (Louis de Broglie)**
    - λ = h/p
      - p is momentum
      - h is plancks constant

- **Momentum of Photons**
  - P = h / λ = hf/c
  - P = IAΔT/c
  - Force applied by a photon on surface:
    - $F = \frac{I\,(Intensity)A}{c}$
    - $Pressure = \frac{I\,(Intensity)}{c}$

Lasers (2.8)

- **USES**
  - Surgery – cutting and cauterising
  - Distance Measurement
  - Data transmission
  - Laser Printers
- Lasers are effective because they produce coherent light – they have **spatial coherence** as different points across the width of the laser beam are in phase with one another and **temporal coherence** as there are no sudden changes in phase.
- **STIMULATED EMISSION**

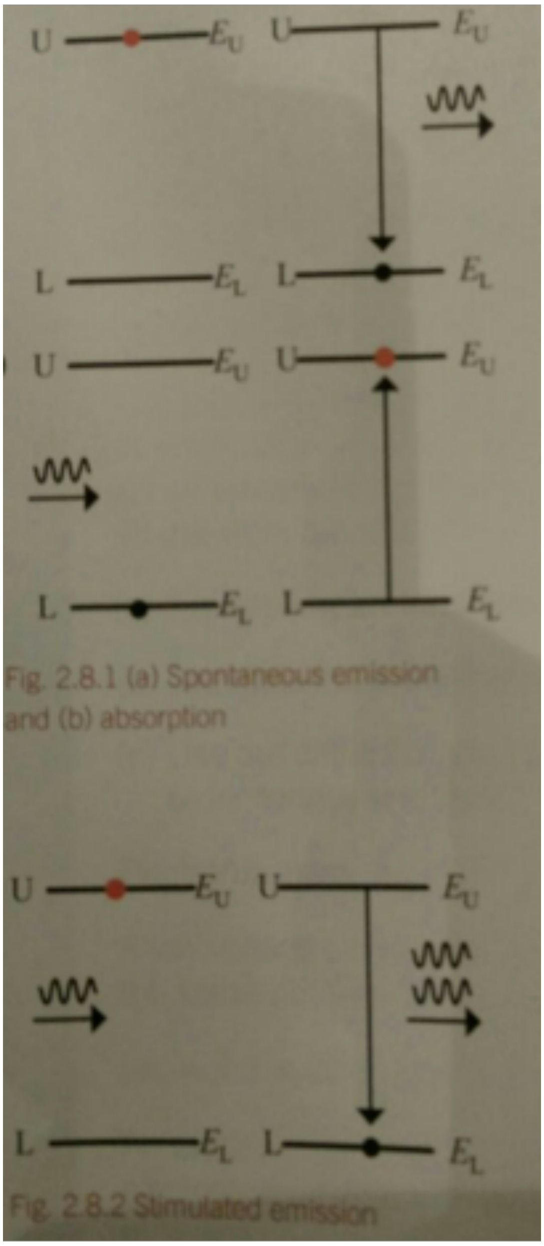
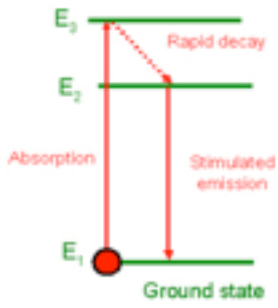
- 

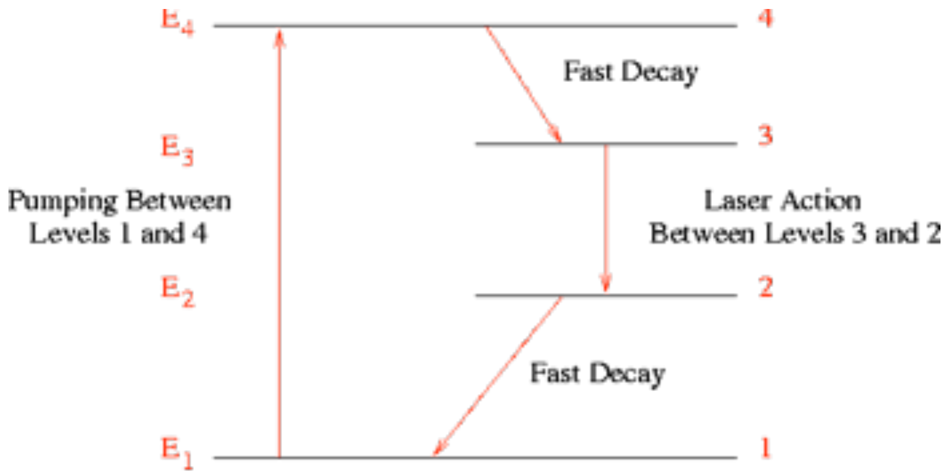
Fig. 2.8.1 (a) Spontaneous emission and (b) absorption

Fig. 2.8.2 Stimulated emission

- An atom in the upper energy state is stimulated into moving down into the lower energy state by another photon of the same energy (difference in the energy states).
- Hence, it emits another photon which is: **in phase with the original photon and travelling in the same direction.**
- This forms a chain reaction as each of these photons can then interact with another atom in the upper state, meaning the number of atoms will double each time.
- **ACHIEVING A POPULATION INVERSION**
  - **Population Inversion –** when the number of atoms on upper energy states is greater than the number of atoms in the ground state.
  - The population inversion is required for efficiency of the stimulated emission as the photon must come upon an atom in the upper energy state.
  - Achieving the population inversion is known as **PUMPING**
  - **Three-State Laser Systems**

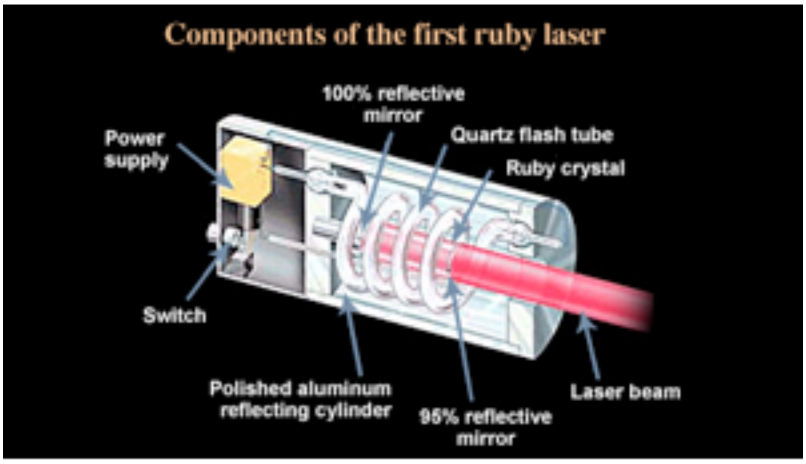
- 

- E3 = Pumped State (P)
- E2 = Upper State (U)
- E1 = Ground State (G)
- Optical Pumping occurs by raising the state from the ground state by using photons of Energy (Ep – Eg). Other pumping technologies are electrical, chemical and nuclear fission.
- If the pumping is fast enough, the number of atoms in the U state will always be greater than the number in the G state, therefore allowing for stimulated emission.
- However, this is highly inefficient, and so, mostly, four state laser systems are used.

- **FOUR STATE LASER SYSTEMS**
  - 

  - In this, very few atoms will be in E2 (the lower state), since there is a fast decay to the ground state.
  - This means it is very easy to create a population inversion since atoms will linger in state E3

- **LASER CONSTRUCTION**
  - RUBY LASER

- 

    - Quartz pumps the ruby crystals.
    - Aluminium cylinder reflects stray pumping light back into the ruby to increase its effect.
    - Mirror concentrates the light and ensures all light is parallel – while many photons are sent back to stimulate more production of light.
    - Dynamic Equilibrium is formed where production of photons = emission of photons.
  - SEMICONDUCTOR LASER
    - Electrically pumped.
    - Very efficient – 70%
    - Mass produced very cheaply.
- **MASERS**
  - Masers occur especially in space, where microwaves are naturally stimulated (in a laser like process)
  - Since the production of the microwaves is so dependent on the length of the stimulated emission pathway, this allows astronomers to be able to take measurements and learn about the things in the sky producing these microwaves.

Nuclear Decay (3.6)

Definitions

- **Nuclear Decay:** Process by which the nucleus of an atom loses energy by emitting (nuclear) radiation.
- **Nuclear Radiation:** Emission of energy in the form of waves or particles from the atomic nucleus. The term is also used for the emitted waves or particles themselves.
- **Alpha Decay:** Nuclear decay by emission of an alpha particle, which comprises two proton and two neutrons.
- **Beta Decay:** Nuclear decay by emission of an electron or positron.
- **Gamma Decay:** Nuclear decay by the emission of a photon.

Intro

- Three types of nuclear radiation, each with different penetrating powers, which was called alpha, beta and gamma radiation.
- Alpha range: 3cm of air; 0.02 mm of glass
  - Alpha particles have a well defined energy.
- Beta range: 1m of air; 0.5mm aluminium
  - Beta particles are produced with a continuous spectrum of energies.
- Gamma range: 500m of air; 20cm aluminium; 5cm lead

Alpha Decay

- **Alpha Radiation** is the most weakly penetrating type of nuclear radiation. It consists of helium nuclei.
- This combination of two protons and two neutrons is particularly stable, able to exist for reasonable periods of time without reacting.
- Can be shown by floating Thorium (a strong alpha emitter) on Mercury. Therefore, it can pass into a gas discharge tube, leaving the characteristic lines of helium.
- Alpha decay only happens in heavy element. The lightest known alpha decay nuclide is tellurium-106.

Beta Decay

- The most common form is B- decay, which takes place in neutron rich nuclei. The neutron decays, via the weak interaction, into a proton with the emission of an electron and an electron anti-neutrino.
- $n \to p + e^- + \overline{v_e}$
- Some nuclei, created in fusion processes, can decay by the emission of a positron, rather than an electron. In the context of radioactivity, this is called B^+ radiation.
- $p \to n + e^+ + v_e$

Gamma Decay

- The daughter nucleus from an alpha and beta decay often forms in an excited state.
- The proton or neutron can therefore drop into a lower energy state and release a photon – (leaves the proton and nucleon numbers unchanged).

Electron Capture

- Occurs in some proton-rich nuclei.
- $p + e^- \to n + v_e$

Proton Emission

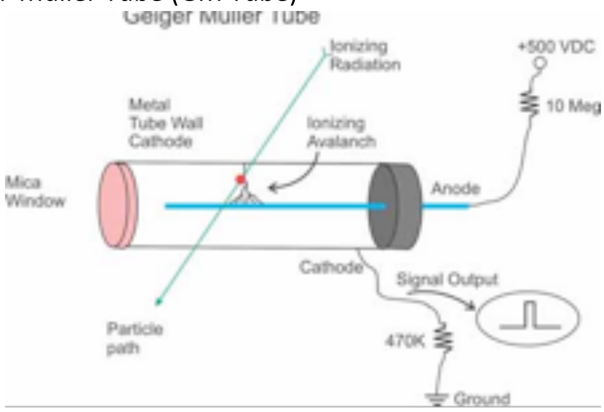
- This only happens in very light nuclei with large proton excess, e.g. Li6.
- Neutron emission is also possible in the context of a nuclear fission event.

INTERACTIONS OF NUCLEAR RADIATION

- ALPHA PARTICLE
    - As it passes through an atom, it will attract electrons.
    - It doesn't need to collide directly with an electron – the electron attraction will cause an energy transfer and pull several electrons from the atom.
    - The effect on the alpha particle is to slow it down slightly, so it passes through the next atom a bit more slowly, increasing the ionising effect.
    - Eventually, it runs out of energy, and combines with a couple of stray electrons and becomes a helium atom.
- BETA PARTICLE
    - More weakly ionising as they move much faster than alpha particles.
    - Still manages to kick out electrons.
- GAMMA PARTICLE
    - Can only affect an atomic electron if they pass very close – therefore on average need to pass through a large number of atoms before interacting.
    - Therefore, they lose all their energy in one interaction.
- **Absorbing radiation**
    - The more dense the material, the more effective a material is at absorbing radiation.

- This is because there are more protons and neutrons per unit volume. Therefore, there are more electrons per unit volume.

DETECTING AND MEASURING RADIATION

- Geiger-Muller Tube (GM Tube)
  - 

  - The nuclear radiation ionises argon atoms, with the liberated electrons attracted to the positively charged metal needle and pick up enough kinetic energy to cause further ionisation.
  - The resulting pulse of current produces a voltage pulse across the resistor which is registered on the counter.
- Solid State Detector
  - Solid State Detectors are diodes with the n-type region connected to the positive. The n region is very thin, so that alpha radiation can penetrate the depletion zone.
  - Here it ionises silicon creating a pulse across the resistor, registered by the counter.
- **Correcting for background radiation**
  - By subtracting the background count from the count with the source present (over the same period of time), you can eliminate the background radiation from the system.
- **DISTINGUISHING BETWEEN A, B and Y particles**
  - **Using penetrating power**
  - **Deflection of radiation in a magnetic field**
    - Beams of charged particles constitute electric currents and so are deflected in magnetic fields.
    - Alpha particle and beta particles are deflected in opposite directions while the gamma particles would be entirely unaffected as they are uncharged.
    - $r = \frac{p}{qB}$ **is the radius of the deflection**
      - **B = flux density**
      - **P = momentum of particles**
      - **Q = charge of particles**

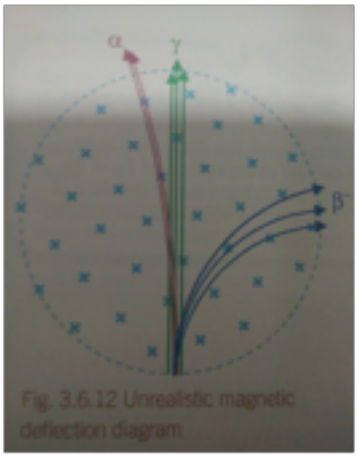
- 

Fig. 3.6.12 Unrealistic magnetic deflection diagram

  - $p = \sqrt{2mE}$ where p is the momentum of the particle.

Exponential Decay of Radioactive Substances

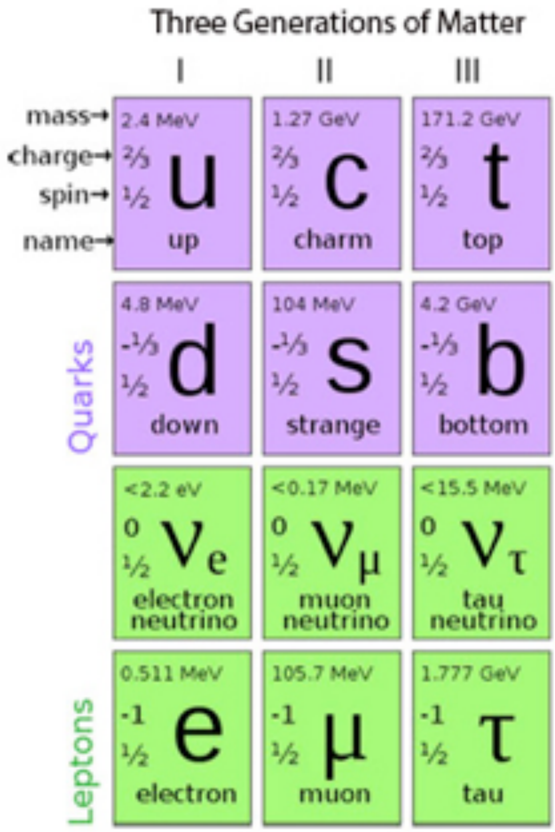
- **Activity** is the number of radioactive decays per unit time.
  - $A = \lambda N$
- **Decay Constant** is the fraction of the atoms of a radioactive nuclide which decay per unit time.
- **Half Life** is the time taken for the amount (or rate of decay) of a substance to halve.
- $N = \frac{N_0}{2^x}\ AND\ A = \frac{A_0}{2^x}$ where x is the number of half-lives elapsed – not necessarily an integer.
- $N = N_0 e^{-\lambda t}\ AND\ A = A_0 e^{-\lambda t}$
  - WHEN t = t½ (at half-life)
  - A = ½ A0
  - $e^{-\lambda t_{\frac{1}{2}}} = \frac{\frac{1}{2}A_0}{A_0} = \frac{1}{2}$
  - $-\ln(2) = -\lambda t_{\frac{1}{2}}$
  - $\lambda = \frac{\ln(2)}{t_{\frac{1}{2}}}$

Particles and Nuclear Structure (3.7)

- **Rutherford Alpha Scattering Experiment**
  - Suggested an underlying structure to atoms.
  - Postitively charged atomic nucleus which contains nearly all the mass of the atom – the alpha particles generally passed straight through the gold foil.
  - Positive charge concentrated in the nucleus. Some particles were deflected a little, while others were deflected entirely.
  - Force can be found using Coulomb's Law
    - $\boldsymbol{F = \frac{Qq}{4\pi\varepsilon r^2}}$
    - Finding nearest approach:
      - Initial PE + Initial KE = Electrical PE + KE at point of nearest approach
      - 0 + KEofAlphaParticle = $\frac{Qq}{4\pi\varepsilon_0 r} + 0$ where r is the point of nearest approach
- **Plum Pudding Model**
  - Atom is composed of a sea of positively charged particles with negatively charged particles in this sea.
  - Plum is the positive particles while the pudding are electrons.

- 
- This doesn't explain the results of the deflection of the alpha particles because there would be no repulsive force in the plum pudding model.

- **DEFINITIONS**
  - **LEPTONS**
    - Low mass, elementary particles – e.g. electron, neutrino
  - **QUARK**
    - Elementary particle, not found in isolation, which combines to form hadrons
  - **HADRON**
    - Non-elementary particles consisting of a number of quarks and anti-quarks
  - **BARYON**
    - Hadron composed of 3 quarks
    - Nucleons and Deltas
      - D++
        - uuu
      - D+
        - uud
      - D-
        - ddd
      - D0
        - udd
  - **ANTIBARYON**
    - Hadron composed of 3 anti-quarks
  - **MESON**
    - Hadron consisting of a quark and an antiquark.
  - **PION**
    - 1^{ST} generation of mesons
- **Units of Mass and Energy**
  - Energy is normally expressed in electron Volts – eV
  - An electron accelerated through a PD of 1V gains a kinetic energy of 1eV, since it has a charge of e.
    - **E = QV**
    - **1eV = 1.602 x 10^{-19} J**
  - **ALSO**
    - E = mc^2
    - Mass can be written in eV/c^2
    - Electron has an electronic mass of 0.511MeV/c^2

- 

- Neutrinos
  - Very low mass – only interact via the weak force
  - Interacts very rarely happen
  - Found through conservation of momentum – since otherwise the conservation of momentum wouldn't be met.
- **Collisions**
  - Particle + Antiparticle annihilate – mass energy, manifests as two photons of em radiation.
    - *Electron + positron → y + y*
    - *Each has a kinetic energy of 100keV, calculate the energy of each photon:*
      - *Total mass energy = 1 = 511 + 511 = 1022 keV*
      - *Total kinetic energy = 200 keV*
      - *Total energy out = 1222 keV*
      - *=> y energy = 611 keV*
  - **PAIR PRODUCTION**
    - A high energy photon can produce an electron and a positron
  - Composition of Hadrons
    - Proton = uud
    - Neutron = udd
    - Pions:
      - U(d) – brackets will be used for anti-particles
      - U(u)
- **Interactions between Particles**

INTERACTION	**AFFECTS**	**RANGE**	**COMMENTS**	**Particle**
Gravitational	All matter	Infinite	Negligible	Graviton

Weak	All particles	~10^-18m	Negligible in comparison to EM and strong – significant otherwise	W+, W- and Z bosons
EM	All charged particles	Infinite	Also affects neutral hadrons because quarks have charges	Photons
Strong	All quarks	~10^-15m	Also affects interactions between hadrons. Becomes stronger as the distance increases **Holds the nucleus together – opposes EM repulsion between two protons.**	Gluons

- **CONSERVATION LAWS**
    - **Conservation of Lepton Number**
    - **Conservation of Baryon Number**
    - **Conservation of total Quark Number**
        - **Change of ±1 of individual quark number with the weak force**
        - **ONLY IN WEAK FORCE INTERACTIONS, IS THERE NEUTRINO INVOLVEMENT.**

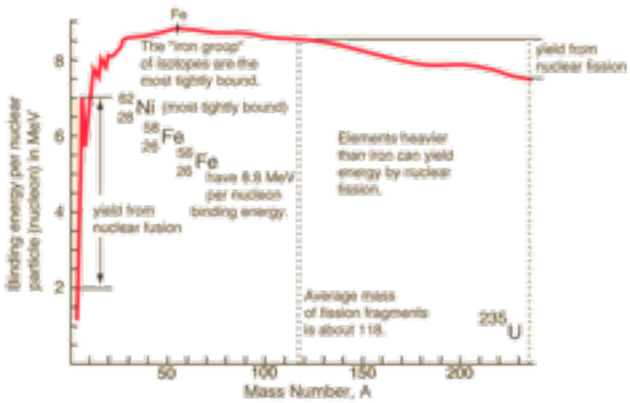
Nuclear Energy (3.8)

Mass Energy

- In developing Special Theory of Relativity, Einstein concluded that mass and energy are two aspects of the same quantity, with the energy (and therefore mass) are conserved.
- Mass-energy can be expressed in terms of mass (kg) or energy (J)
- $E = mc^2$
    - Any mass changes in a reaction isn't in fact lost but released as energy of an equivalent mass-energy.
    - E.g.
        - When Carbon and Oxygen combines, the CO2 is lighter as the atoms are more tightly bound together – they have a lower potential energy – than the reactants.

Binding Energy

- HOW TO FIND OUT THE BINDING ENERGY
- Calculate the mass deficit of the nucleus. The nuclear mass is less than the sum of the masses of the individual protons and neutrons. The difference is the mass deficit.
- Calculate the binding energy using E = mc^2 or just the energy equivalence – 1u = 931.5 MeV
- **BE / nucleon**
    - To determine how tightly the individual nucleons are bound
    - BE / nucleon = Binding Energy / Nucleon Number
- **Stability of low-mass nuclei**
    - NUCLEAR BINDING ENERGY CURVE
        - Plot of the binding energy per nucleon against nucleon number for known nuclides.

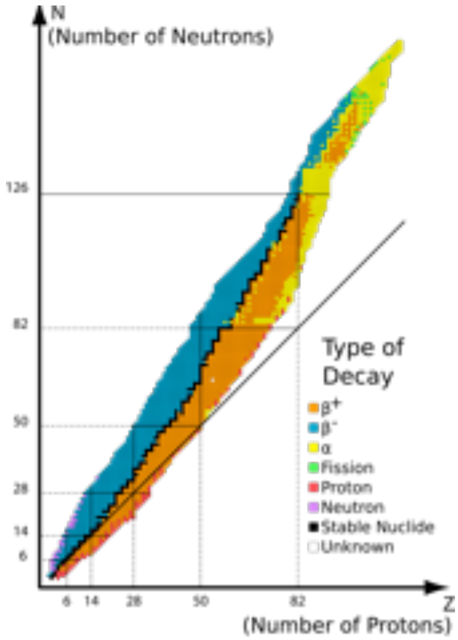
- 

- Positive correlation of BE/nuc with nucleon number (A): as we progress up the along the Periodic table, the nuclei become more and more stable up the region.
- Another thing to node is the fact that there are spikes at specific points (areas of particularly high binding energies)
    - 4He2
    - 12C6
    - 16O8
    - 20Ne10
    - 2p + 1n is the structure.

- **Conservation of Momentum and Energy**
    - In the case of alpha particles, we can look at the kinetic energies of the products and the velocity of the products, we can create two equations for the velocities and therefore solve the equations.

Physical Properties of Nuclei

- **Finding Nuclear Radius**
    - In the Rutherford Scattering Experiment, the number of alpha particles which were scattered was found to depend on the angle of scattering, according to:
        - $N \, \alpha \frac{1}{{E_k}^2 \sin^4\left(\frac{\theta}{2}\right)}$
        - From this, we can calculate an upper limit for the size of a gold nucleus by considering the head-on collision of an alpha particle.
    - Applying the potential energy formula
        - $E = \frac{Qq}{4\pi\varepsilon_0 r}$, therefore allowing one to calculate the value of r.
- **NUCLEAR DENSITY**
    - Analysing data of radius of nucleus vs number of nucleons, gives a relationship of:
        - $r = kA^3 \; with \; k \; \approx 1.1 \; fm$
    - The density of a nucleus is approximately constant

- 

- **NUCLEAR COMPOSITION AND STABILITY**
  - The NZ stability plot shows that there is approximately a line next to which the nucleons are stable and away from, they are not very stable at all.
  - No stable nuclides with more than 83 protons.
  - The ratio of neutrons to protons in stable light nuclei is very close to 1 – it becomes higher as the number of nuclides increases, circa 1.5
  - Nuclides above the line of stability (an excess of neutrons) are B- unstable and below the line is the B+ instability region.

NUCLEAR FISSION AND FUSION

- When you move up the up the steep curve (in the nuclear binding energy curve), this is fusion, while going up the gradual curve is fission.
- **Nuclear Fission**
  - **Primordial Nuclide** is one which has existed in its current form since the Earth formed, i.e. all the stable nuclides plus very long lived unstable nuclides.
  - **Spontaneous Fission** is the splitting of a nucleus without stimulation by an incident neutron
  - **Induced Fission** is the splitting of a nucleus caused by the absorption of a neutron
  - **Thermal Neutrons** are relatively slow-moving. They have a kinetic energy of the order of 1/40eV, equivalent to kT at room temperature.
  - **Very high mass nuclides which can split into other two larger fission fragments**
  - ONLY PRIMORDIAL NUCLIDE is U235 -> 125Sn + 107Mo + 3n
    - Both the daughters is B- radioactive as they have an excess of neutrons (1.55 vs 1.3 – 1.4 stable values)
    - If it absorbs a neutron, the nucleus is likely to split in a process called **induced fission**. Even more likely to happen with **thermal neutrons.**
      - Fast neutrons are much less likely to induce fission.
    - A chain reaction is possible in which the neutrons from fission events go on to induce further fissions.
      - *Controlled Chain Reaction* in a nuclear reactor, in which excess neutrons are absorbed by Control Rods, so that only one neutron goes on to induce fission (and is slowed down by a moderator).
      - *Uncontrolled Chain Reaction leads to a nuclear weapon.*

- **Nuclear Fusion**
  - If we combine low mass nuclei, the resulting nucleus is more tightly bound, so we obtain an energy output.
  - Peak of 4He2 allows for energy to be extracted from above this point too.
  - 1H1 + 1H1 -> 2H1 + 0e+1 + Ve
  - **But, relatively LOW YIELD**
    - Energy lost in the neutrino and it is a weak interaction (and therefore unlikely to happen)
  - Reaction is the base of the proton-proton chain in the Sun where proton has a lifetime of 10^9 years before successfully colliding.
  - Better reaction is:
    - Deuterium + Tritium -> 4He2 + neutron
    - Governed by strong interaction, so should react more easily.
    - Both positively charged, so requires lots of force (very high temperature) to overcome Coulomb repulsion.

Magnetic Fields (3.9)

Definitions

- **Magnetic Field** exists in a region in which a moving electric charge experiences a force, but a stationary charge does not.
- **The direction of a magnetic field in a certain place is the direction in which the North Pole of a small freely pivoted magnet tends to point.**
- **The North pole of a magnet is** the end that tends to point roughly geographically north if only the Earth's magnetic field is present.
- **Magnetic Field Lines** is a line whose direction at every point is the direction of the magnetic field at that point.
- **Magnetic Flux Density** is a vector of magnitude B = F / ILsin(theta), where F is the force on a short wire of length l, carrying current I.
- **A Uniform Magnetic Field** is a region in which the magnetic flux density doesn't vary in magnitude or direction from place to place.

Magnetic Field Line

- Properties
  - Lines never cross or meet.
  - Closed (end-less) loops.
  - When field lines become closer together, the field is becoming stronger – as near the poles of the magnet.

Finding force on a current carrying conductor

- Direction by Fleming's Left Hand (Motor) Rule
  - First Finger = Magnetic Field
  - Second Finger = Current
  - Thumb = Force (Thrust)
- **Magnitude**
  - $\boldsymbol{B = \frac{F}{Ilsin\theta}}$, $\boldsymbol{lsin\theta}$ **is the length of the wire perpendicular to the Magnetic Field.**
  - $\boldsymbol{I = nAvq}$
  - $\boldsymbol{F = BnAvqlsin(\theta)}$
  - **Force per electron:**

- $F = \frac{BnAvqlsin(\theta)}{nAl} = Bqvsin\theta$

Path of charged particle moving in a uniform magnetic field

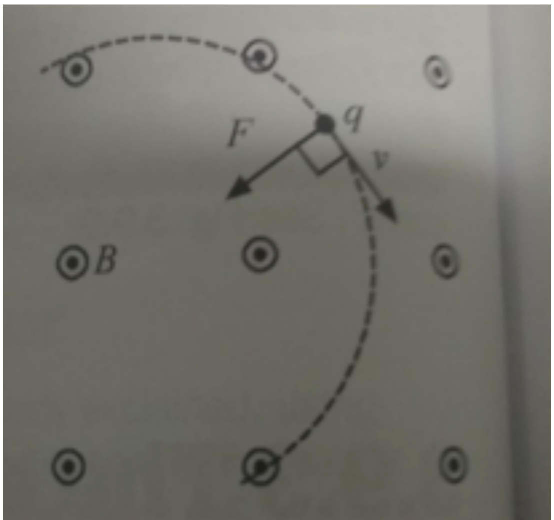
- Theta = 90
  - It will continue to do so, moving in a circular path.
  - Bqv = mv^2 / r
  - Therefore r = mv / Bq
  - 

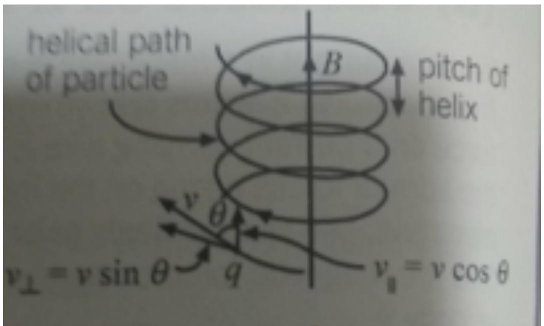
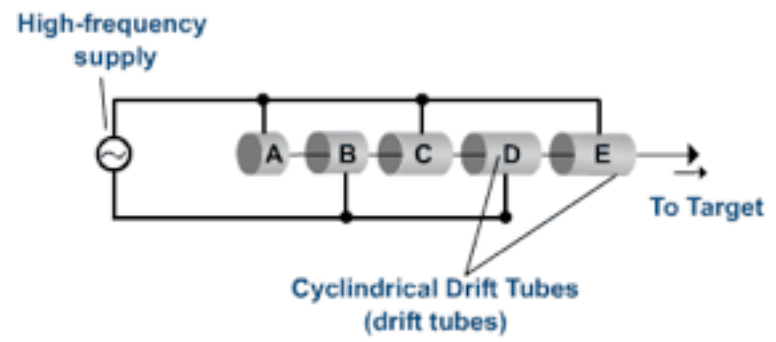
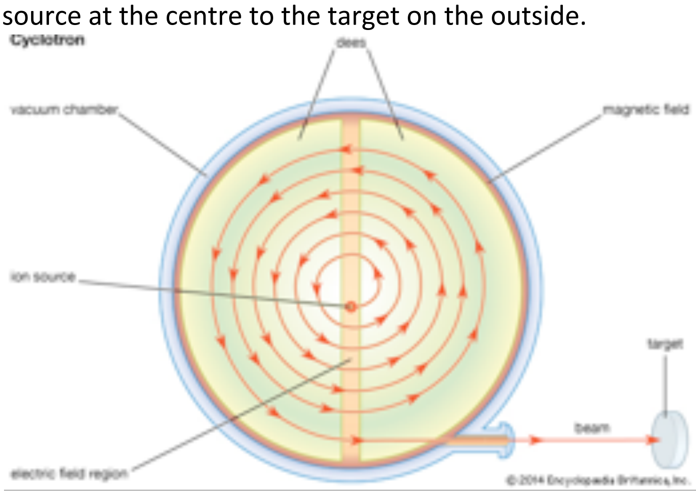
Fig. 3.9.12 Force on a + charge moving in a uniform magnetic field
- **If theta = 0**
  - **Moving parallel to magnetic field so no force.**
- **If Theta is not = 0 or 90**
  - **Moves in a helical path**
    - Look at the vertical and horizontal component.
    - Horizontal component leads to a circular motion and vertical component leads to straight line motion.
    - 

Fig. 3.9.14 Helical path of particle in uniform magnetic field

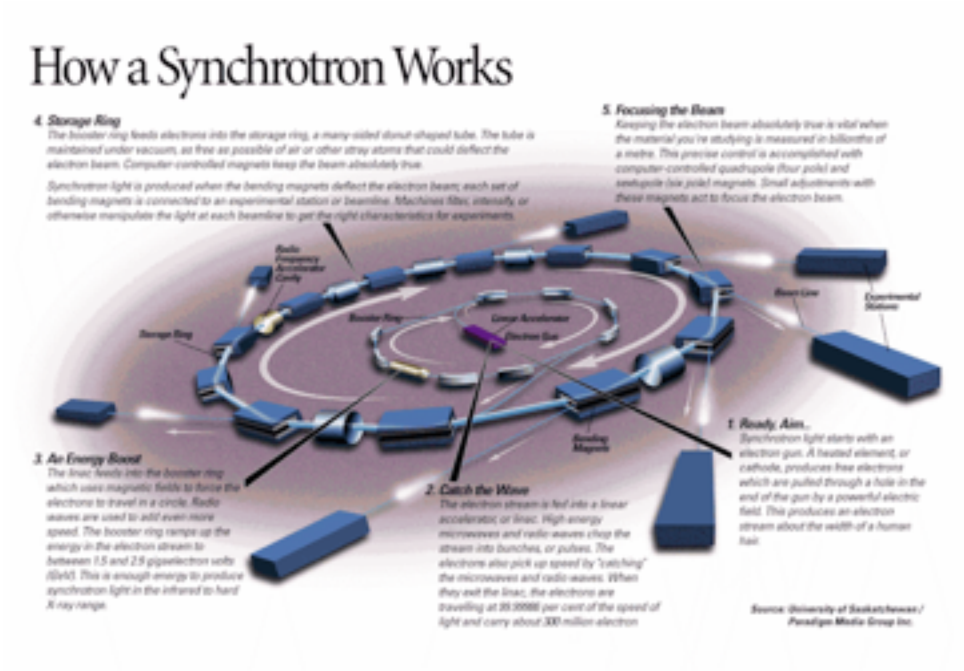
PARTICLE ACCELERATORS

- **LINEAR ACCELERATORS**
  - Charged particles are accelerated in a straight line (whereas in a circular accelerator magnetic fields are used to move the particles in a circular trajectory - see the cyclotron next).
  - The diagram below shows the principle of operation of a LINAC.

- 

    - alternating p.d. is connected across adjacent cylindrical electrode tubes. Charged particles are accelerated across the gaps between electrodes.
    - By the time the particle reaches the next gap the polarity of electric field has changed
    - **Therefore, the drift tubes get longer and longer.**
    - **But, it gets larger very quickly and so there is a limit to how large an accelerator you can easily make.**
- **Cyclotron**
    - The length limitation can be overcome by making the charged particles follow a circular path. In a cyclotron charged particles are accelerated across the gap between two 'D' shaped electrodes.
    - Meanwhile a perpendicular magnetic field moves the particles in a circle. The radius of the circle increases after each successive acceleration, so the path spirals out from the source at the centre to the target on the outside.
    - 

    - $F = \frac{Bq}{2\pi m}$, this frequency is independent of the velocity and radius of the particles.
        - Therefore, a consistent simple alternating frequency can be used to change the charge of the dees.
- **SYNCHROTRON**

- 

- **Field is applied at various parts of the synchrotron where the particle is accelerated.**
- **Particles must be inserted at high speeds – often created using a linear accelerator.**
- **The frequency must be constantly changed, depending on the velocity of the particles to be accelerated..**
- Photons of upto X-Rays are emitted by the charged particles as they are deflected by the electromagnets. Though this does mean that there must be energy added to account for this energy loss, these photons can be used for other experiments.

Electric and Magnetic Fields combined

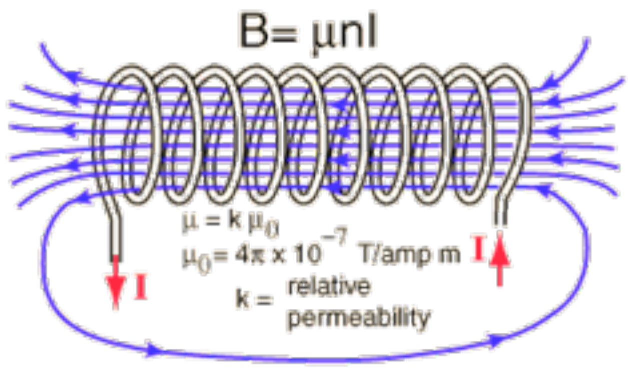
- **In a vacuum**
  - If they are at right angles and a charge particle is sent at right angles to both of the fields.
  - If there is no resultant force and the forces would be in opposite direction:
  - Bqv = Eq => Bv = E
    - This allows a method of filtering the velocity of particles. If you set the ratio of E/B as a set value only particles of the specific velocity would be able to pass through without being deflected.
- **In a conductor**
  - **HALL EFFECT SENSOR**
    - When a magnetic field is applied to a conductive wafer carrying a small current, there is a force on the electrons within the wafer, forcing them to one side. Therefore, there would be a potential difference between the two sides of the wafer.
    - $\boldsymbol{E = vB}$
    - **Vh = Ew (E = V/d)**
    - $\boldsymbol{Vh = Bvw}$**, where w is the width of the wafer**
    - $\boldsymbol{I = nAve = nvewt}$
    - $\boldsymbol{Vh = \frac{BIw}{nwte} = \frac{BI}{nte}}$
    - Therefore, using this equation, the measured voltage can be used to find the magnitude of the magnetic field.
    - **Other things**
      - 1 / ne is the Hall Coefficient

- **Main point is that Vh is proportional to B, the magnetic flux density.**

Magnetic Field due to a current in a long straight wire

- Circular – direction given by the right hand grip rule
- Magnitude
  - $B = \frac{\mu_0 I}{2\pi r}$, mu nought is the permeability of free space
    - = 4pi x 10^-1 Hm^{-1}

Magnetic Field due to a current in a coil



- *n is number of turns per unit length*
  - *n = N/L*

Electromagnetic Induction (3.10)

Magnetic Flux

- When you have a larger surface area, you get a 'larger' field, even if the magnetic flux density remains exactly the same. Therefore,
- $\boldsymbol{B = \frac{\Phi}{A}}$
- **Magnetic Flux is defined by $\Phi = ABcos\phi$, where ϕ is the angle between the normal to the area and the flux density.**
- **This magnetic flux is conserved.**
- *Using an Iron Core*
  - *The flux density and flux can be increased by making use of an Iron core, as the iron itself creates a magnet and therefore the two fields of the coil and the iron core combine together creating a stronger magnet.*

Induced EMF

- The EMF is induced in a conductor when it moves in such a way that it moves across lines of magnetic flux.
  - Direction can be found using Fleming's Right Hand Generator Rule
    - Thumb = direction of motion
    - First finger = field
    - Second finger = induced current
- Can be increased by strengthening the magnetic field, lengthening the wire within the field and moving the wire faster.
  - $\boldsymbol{\varepsilon\ (EMF) = Blv}$

Faraday's Law

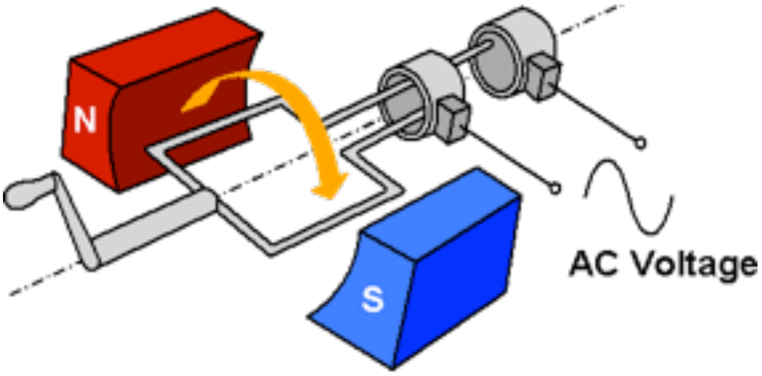
- When the magnetic flux through a circuit changes, an emf is induced in the circuit, proportional to the rate of change of flux linkage.

- For a circuit with N identical turns, $\varepsilon = -\frac{\Delta(N\Phi)}{\Delta t}$
- **For examples, look at textbook – page 172**

Lenz's Law

- The direction of an induced emf is such that its effects oppose the change producing it.

Simple AC Generator



- When the normal to the coil is at angle x to the field, the magnetic flux is:
- $\boldsymbol{BAcosx\ (A = one\ side\ length\ of\ coil\ \times other\ side\ length\ of\ coil}$
- For a coil of n turns, the flux linkage = nBAcosx
- At time t, x = wt + x0
- Therefore, Flux linkage = nBAcos(wt + x0)

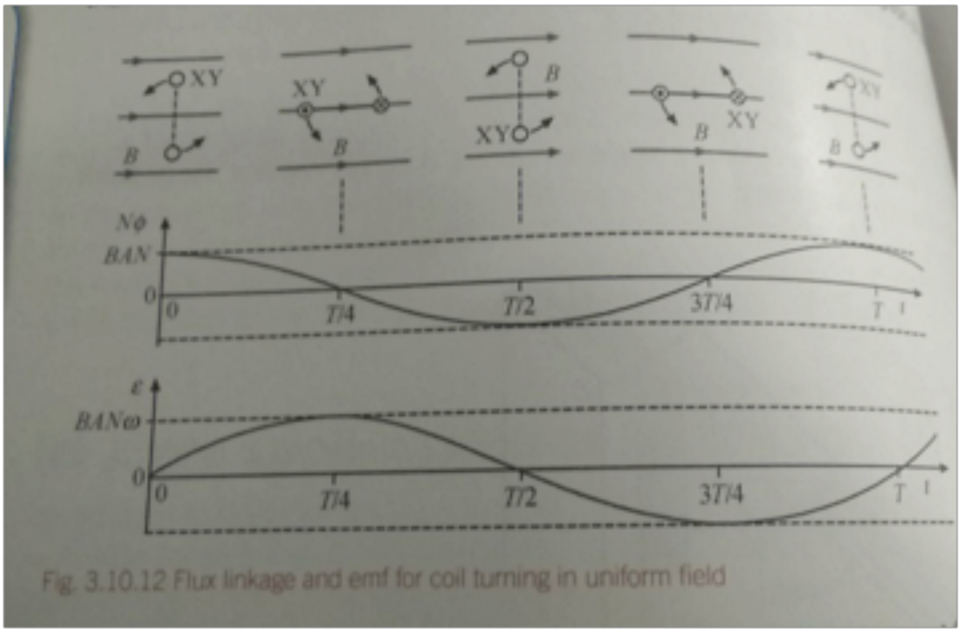


Fig. 3.10.12 Flux linkage and emf for coil turning in uniform field

- **EMF = nBAwsin(wt + x0) (DIFFERENTIATE)**
- Therefore peak EMF = nBAw