

IB PHYSICS SL – SUMMARY

M Waters

I take no responsibility for the accuracy of these notes! Actually I take no responsibility for anything whatsoever. If you've got a problem, don't read the notes!

Fundamental unit: A quantity that can be measured in a simpler form, such as metre, kilogram, second, Ampere, Kelvin, mole, radian

Derived Unit: A unit that is derived from a combination of fundamental units as above. Newton is a derived unit (actually $\text{kgm}^2\text{s}^{-2}$), as is hertz, **JOULE**, watt, tesla, and coulomb, also volt.

Kilogram: The mass of a particular piece of platinum-iridium alloy that is kept in France.

Metre: The length equal to 1 650 763.73 wavelengths of a particular orange-red line of krypton-86 undergoing electrical discharge.

Second: The time for 9 192 631 770 vibrations of the cesium-133 atom.

Vector: A quantity that has both a magnitude and a direction.

Scalar: A quantity consisting of only magnitude.

Amplitude: The distance between the mean position of a wave and its maximum.

Frequency: The number of waves occurring in a second measured in hertz.

Period: The time for one complete wave.

Wavelength: The length of each complete wave.

Random uncertainty: errors due to variations in the performance of the instrument and the operator.

Systematic error: An error that causes a random set of measurements to be spread about a value rather than being spread about the accepted value.

Displacement (s): The measured distance in a given direction.

Velocity (v): Speed in a given direction, measured by $v = \frac{\Delta s}{\Delta t}$

Acceleration: The rate of change of velocity in a given direction, $a = \frac{\Delta v}{\Delta t}$

Reference frame: A point of reference at which the relative value is taken as 0. In most cases, the earth is used as the reference frame.

Instantaneous velocity: The velocity of an object at *exactly* a point in time.

Average velocity: The change in displacement divided by a change in time.

Average acceleration: The change in velocity divided by a change in time.

Mass: A measure of the inertia of a body

Weight: The force of gravity acting on a body.

Newtons first law of motion: "every object continues on a state of rest or uniform motion in a straight line unless acted upon by an external force"

Newtons second law of motion: “acceleration is directly proportional to the force acting and is in the same direction as the applied force” or, $F=ma$. It can also be defined as “force is the rate of change of the linear momentum of a body”. The connection between these two statements can be proved:

$$F = \frac{\Delta p}{\Delta t} = \frac{m(v-u)}{\Delta t} = \frac{m\Delta v}{\Delta t} = ma$$

Newtons third law of motion: “when a force acts on a particle an equal and opposite force acts on another particle somewhere in the universe”

Projectile motion: The motion of a moving object under the force of gravity, generally neglecting air resistance.

Simple harmonic motion: the periodic motion of an object oscillating on the end of a spring, perhaps also refers to an oscillating pendulum. Hooks law applies for the string, $F= -kx$

Uniform circular motion: An object that is moving with a constant acceleration, with the acceleration always pointing to the same point.

Momentum: The product of the mass and velocity of an object, $p=mv$. The more momentum an object has, the harder it is to stop it , and the greater effect it will have if it is brought to rest by impact or collision.

Impulse: The magnitude of the force multiplied by the time in which it acts, also defined as the change in momentum. This can be a measure of the damage that is applied to a particular body in a collision.

Elastic collision: A collision in which the total kinetic energy is conserved.

Inelastic collision: A collision in which the total kinetic energy is not conserved... ie the energy is transferred elsewhere: sound, heat, deformation, etc.

Work: The work done on an object by a constant force (constant in both magnitude and direction) is defined to be the product of the magnitude of the displacement times the component of the force parallel to the displacement. Ie $W=Fs$. The net work done can also be described as the change in kinetic energy, ie $W = \Delta E_k$

Energy: A concept extremely difficult to define, energy comes in many different forms.. potential, kinetic, heat, sound, deformation... many forms.

Power: Average power is defined as the rate at which work is done or as the rate at which energy is transformed.

$$P = \frac{\Delta W}{\Delta t}$$

Potential energy: The energy associated with forces that depend on the position or configuration of a body (or bodies) with the surroundings.

Gravitational potential energy: The product of an objects weight mg and its height from the ground, the energy associated with an object relative to its position from the ground.

Elastic potential energy: The energy associated with the compression / extension of an object associated with its mean position.

Solid: The state of matter such that the forces between molecules are strong enough such that molecules do not escape the mass, and that it takes a fixed shape. It is not readily compressible

Liquid: The state of matter in which molecules do not escape the mass, but the forces between molecules are such that molecules move around easily within the mass and the mass has a shape the same as the container that it is kept in. (in all directions except vertically upward). It is not readily compressible, and has a fixed volume.

Gas: The sate of matter in which molecules are free moving, and take the shape completely of the container that they are held in. It has neither a fixed shape nor a fixed volume.

Plasma: This occurs only at very high temperatures and consists of ionised atoms (electrons separated from the nucleus).

Heat: The energy transferred from one body to another because of a difference in temperature.

Internal energy: The sum of all the energy of all the molecules in an object.

Specific heat capacity: The amount of energy required to raise 1kg of a substance by 1 degree. There are a few methods of determining the specific heat of a substance. The direct method can be used, where $Q = VIt$ and

$Q = mc\Delta t$ and $\therefore mc\Delta t = VIt \Rightarrow c = \frac{VIt}{m\Delta t}$, which involves the use of an electric filament with a known

current and voltage. An indirect method can be used, which involves the use of a calorimeter. Two substances, both of known mass and one of known specific heat, are placed into contact until they reach equilibrium. The heat lost by the hotter substance is equal to the heat gained by the colder one, so $(mc\Delta t)_A = (mc\Delta t)_B$. Values can then be substituted in to solve any unknowns. Remember, however, that the delta t must be negated, that is it should be a larger minus a lower temperature, on both sides.

Specific latent heat of transformation: The amount of energy required to change kg of a substance from one phase to another

Conduction: On a microscopic level, conduction is the transfer of vibrations from molecule to molecule along a material as a result of collisions. Thus, heat is transferred along an object.

The rate of heat transfer is given by $\frac{\Delta Q}{\Delta t} = kA \frac{\Delta T}{l}$. Conduction usually takes place in solids. The difference

between substances of high and low thermal conductivity can be explained in terms of microscopic structure. The more particles that are available to move, the greater the thermal conductivity because it the mobile particles assist in conduction. The presence of free moving electrons also influences conduction for the same reason. Different densities affect the conductivity because closer molecules transfer kinetic energy more effectively and easily than ones that a further away from each other.

Convection: The process whereby heat is transferred by the mass movement of molecules from one place to another. This usually occurs in liquids and gasses.

Radiation: Consisting mainly of electromagnetic waves, radiation is the transfer of energy without a medium.

Thermal conductivity: This is the constant k in the above equation for conduction, so any problems involving conductivity, area, length and change in temperature can be solved using that (one of the PEPs has a question on it). Substances for which k is large heat rapidly and are said to be good conductors.

Pressure: Pressure is defined as the force per unit area, where the force F is understood to be acting perpendicular to the surface area A: $P = \frac{F}{A}$, and in fluids this is due to the movement of molecules, and is applied in all directions.

Volume: This is the third dimension of length measurement, and for a cube is length x width x height.

Absolute zero Temperature: If a graph of volume vs Temperature is drawn, there is a point at which there is no volume. It is at this point that there is also no temperature, and is defined as absolute zero. It is found to be -273.15°C , which is also 0 K.

Ideal gas: Basically an ideal gas consists of random point masses moving in random directions with a variety of speeds, on average far apart from each other. They are assumed to obey the laws of classical physics and *have no mass*.

Ideal gas laws: This includes the ideal gas equation, $PV=nRT$, where n represents the number of mols, R is the universal gas constant, T is temperature in Kelvin and volume is dm^3 , well actually volume often depends on what value of the universal gas constant is given. There are a number of different experiments that demonstrate the relationship between pressure, volume and temperature of a fixed mass of gas.

1) Pressure and volume:

- An example can be a moveable tube manometer. As one increases the pressure being applied to the right hand side, by moving the tube/mercury down) the volume of both the column of air and the second column below it decrease. Temperature must be kept constant.

- 2) Pressure and temperature:
 - An enclosed glass 'bulb' of air should be connected to a manometer, and placed into a beaker full of H₂O. As the H₂O is heated, the pressure should rise.
- 3) Volume and temperature:
 - a capillary tube sealed at one end, bend upward at the other, with a movable block (mercury?) at its center, can be connected to a glass bulb similar to above. As the temperature of water surrounding the glass bulb increases, the mercury bulb will move.

4)

Longitudinal wave: A wave in which the direction of vibration is in the same direction of the wave itself.

Transverse wave: A wave in which the direction of wave vibration is at a right angle to the direction of wave travel.

Medium: The substance through which the wave travels.

Displacement: distance, in terms of waves is similar to the amplitude.

Amplitude: The distance between the mean position of a transverse wave and its maximum.

Wave speed: The speed at which the wave is travelling.

Crest: A maximum in a wave.

Trough: A minimum in a wave.

Compression: In terms of longitudinal waves, a snapshot of that wave at any given time will show a series of compression/rarefactions, the compression is the section of the wave containing a greater volume of particles.

Rarefaction: As above, a rarefaction is the section of the wave containing the lesser volume of particles.

Electromagnetic wave: As a simplified definition, this is a wave that can travel without a medium, and includes all those in the electromagnetic spectrum: eg light, uv, infra red, x-rays, gamma rays, microwaves, etc.

Reflection: In terms of waves, a reflection can include the reflection at an end node of a rope, or in two dimensions the reflection of an entire wavefront as it "bounces off" a surface.

Refraction: This is the phenomenon associated with the fact that when a two or three dimensional wave traveling in one medium crosses a boundary into a medium where its velocity is different, the transmitted wave may move in a different direction than the incident wave.

Superposition: In the region where two waves overlap, the resultant displacement is the algebraic sum of their separate displacements, where a crest is considered positive and a trough negative. This phenomena is linear superposition.

Constructive interference: This is when the result of superposition is a displacement larger than the original displacements.

Destructive interference: This is when the product of superposition is a displacement smaller than the original displacements.

Youngs double slit experiment: This is the experiment in which Thomas Young helped to prove the wave nature of light by falling light from a single source on two closely spaced slits. The resulting interference pattern suggested the wave nature of light, with the light constructively and destructively interfering in ring shapes on the screen.

Beats: The phenomenon that occurs if two sources of sound are close in frequency, interfering with each other, causing the sound level to alternately rise and falls in regular spaced intensity changes called beats.

Diffraction: The phenomenon associated with the fact that waves spread when they travel, and when they encounter an obstacle they bend around it somewhat, passing into the region behind as a wider wavefront

Polarisation: E/m waves have their direction of vibration in all planes. By polarizing a wave, this vibration is restricted to a single plane.

Standing wave: If a standing wave with two fixed ends (nodes) is vibrated with just the right frequency, the two travelling waves will interfere in such a way that a large-amplitude standing wave will be produced.

Antinode: This is a point of destructive interference of a standing wave, and always occurs at closed ends (occurs in middle, too).

Node: This is a point of constructive interference of a standing wave, always occurring at open ends (but in middle as well)

Resonance: The phenomena of vibration of an object at the natural frequency of that object.

Fundamental: The lowest possible frequency of a standing wave.

Harmonic: Each multiple of the fundamental frequency is called a harmonic, the fundamental frequency is the same as the first harmonic. The third harmonic has a wavelength 1/3 the size of the first harmonic. Because of this, open pipes can only have first, 3rd, 5th, 7th and so on harmonics.

Electric potential energy: This is defined as the potential energy per unit charge, and be interpreted in a similar way to gravitational potential energy: If a charge is placed near the positive of two oppositely charged metal plates, there is a potential for work to be done. If a point charge q has electric potential energy PE_a at some point a , the electric potential V_a at this point is

$V_a = \frac{PE_a}{q}$. More importantly, the potential energy can be defined as the voltage multiplied by the quantity of the

charge, and this is particularly useful the work done on electrons moving in an electric field, as can be seen in the photoelectric effect later, $PE = eV$.

Electric charge: This is a measure of the relative potential of an object to exert an electric force, one of the 4 fundamental forces.

Electrostatic induction: If a charged object is placed near a non charged object, due to the fact that like charges repel, charge is induced on opposite sides of the non-net charged object.

Hollow conductor: This is a conductor with a hollowed out inner, and includes spheres. The net charge on the inside of a hollow conductor is 0, and this can be seen later in the principles involved with particle accelerators.

Coulombs law: The force between two charges is directly proportional to the product of the two charges and inversely proportional to the square of the distance between them.. or $F = \frac{q_1 q_2}{4\pi\epsilon_0 r^2}$ where q_1 and q_2 the values of two charges (measured in coulombs), the r is in metres and the rest is a constant.

Electric field: A region of influence around a charge or group of charges If an electric field is present at a particular place, when a second charge is placed near it, it feels a force. The stronger the force, the stronger the electric field will be.

Uniform electric field: This is an electric field where a charge will experience the same force, at same distance from field source regardless of direction.

Electric field pattern: This is a pattern used to represent electric field lines. The lines are always at right angles to their source, and go outwards from positive and inwards to negative, never crossing each other.

Potential difference: This is defined as the work done per unit charge, or the work done by the electric force to move the charge between two points. It is measured in volts.

Electric current: Defined as the net amount of charge that passes through any point in a conductor per unit time.

$$\text{Or, } I = \frac{\Delta Q}{\Delta t}$$

Ampere: the current flowing in each of two long parallel conductors 1m apart which results in a force of exactly 2×10^{-7} N/m

Emf: A source of emf is a device such as a battery or an electric generator that transforms one type of energy (chemical, mechanical, light, and so on) into electric energy. The potential difference between the terminals of such a source, when no current flows to an external circuit, is called the emf of the source.

Power: power is defined as the rate at which work is done per unit time, or $P = \frac{W}{t}$, measured in joules per second, otherwise known as watts. By substituting $W = Vq$, one can see that $P = \frac{QV}{t}$. Because q/t is simply the electric current, this can become $P = VI$. The rate of energy transformation in a resistance R can be written, using Ohms law ($V=IR$) in two more ways, $P = \frac{V^2}{R}$ and $P = I^2 R$

Resistance: Many scientists say that ohms law is the definition of resistance: $R = \frac{V}{I}$. That is, the higher the resistance, the less current for a given voltage V . On a kinetic theory level, it is the collision of charge with the molecules of the resistor that causes work to be done, and therefore potential differences are across resistors. The resistance of R of a wire is directly proportional to its length L and inversely proportional to its cross-sectional area A . That is, $R = \rho \frac{L}{A}$, where ρ is a constant called the resistivity.

Ohmic conductor: This is a conductor that follows ohms law perfectly, ie $V = IR$

Non-ohmic conductor: This is a conductor that does not follow ohms law perfectly. Most conductors are non-ohmic, but many are so close that this can be neglected.

Conventional current: When speaking of current flowing in a circuit being the direction a positive charge would flow, this term is used. Usually in physics, conventional current is used, although it is technically wrong, but assume this unless stated otherwise.

Electron flow: When speaking of current flowing in a circuit being the direction a negative charge (ie an electron) would flow, this term is used.

Resistor: All conductors are actually resistors as well, including copper cables, although usually this is small enough to be ignored. Some devices, such as wire filaments or coils, have much higher resistances. An expression for power

dissipation in resistors can be derived. Because $w = qv$ and $q = It$, $\frac{w}{t} = VI$, because power is defined as the rate

at which work is being done, $P = VI$. By further substitution using ohms law, $P = I^2 R$ and $P = \frac{V^2}{R}$;.

Internal resistance: This is the resistance *inside* a source of emf, ie between the two terminals of it (eg the two terminals of a battery).

Parallel circuit: When resistors are connected such that they have the same voltage drop across them and share the total current between them. The effective resistance of parallel resistors is less than the sum of the individual resistances.

Series circuit: This is when resistors are connected such that the separate resistances and voltage drops are equal to the total resistances and voltage drop. One current is passes through all of the resistors.

Fuse: This is a piece of wire that is designed to melt when it reaches a certain temperature, and therefore a certain resistance. This can be caused by short circuits and overloads, and by melting the wire, the circuit is broken.

Magnetic field pattern: Magnetic field patterns are lines that go from the north pole of a magnet to the south. If a compass is placed on a magnetic field line, then the North arrow will point in the direction of the magnetic field line. A magnetic field line also can consist of circles surrounding a current carrying wire, with the direction of field lines determined by the right hand rule (current out of page, then lines are anticlockwise).

Current-carrying solenoid: This is a coil of many loops, when a current is flowing through it due to the magnetic field associated with a current carrying conductor, the loops interfere in such a way that an electromagnet is created. Good diagrams of this can be seen at the top of p601, Giancoli.

Soft iron core: If a piece of iron is placed inside a solenoid, the magnetic field is greatly increased. It is referred to as soft because it acquires and loses its magnetism quite readily when the current is turned on and off.

Dc motor: By use of the motor effect rule (right hand rule), a dc motor (simplified) consists of a coil that, when applied a current, rotates in a magnetic field. It is enabled continued rotation through the use of a commutator, which reverses the current every half turn.

Lenz's law: "An induced emf always gives rise to a current whose magnetic field opposes the original change in flux"- this can be best demonstrated with a magnet being pulled in and out of a solenoid.. the polarity of the solenoid is such that it opposes whatever you are trying to do with the magnet.

Generator: The principle involved here is basically the reverse of the motor effect rule (and therefore becomes the *left* hand rule), except no commutator is used, so the current produced in the generator changes its direction every half turn. An alternating current is thus produced.

Transformer: This is a device for increasing or decreasing an ac (alternating current) voltage. When an Ac voltage is applied to the primary coil in a transformer, the changing magnetic field it produces will induce an ac voltage of the same frequency in the secondary.

Milikan's oil drop experiment: This experiment determined the precise value of the charge on an electron. Tiny droplets of mineral oil carrying an electric charge were allowed to fall under gravity between two parallel plates. The electric field E between the plates was adjusted until the oil drop was suspended in midair. The downward pull of gravity, mg , was then just balanced by the upward force due to the electric field. Thus, $qE = mg$, so the charge $q = mg/E$. The mass of the droplet was determined by measuring its terminal velocity in the absence of the electric field. Sometimes, the drop was charged negatively and sometimes positively, suggesting that the drop had acquired or lost electrons. Milikan eventually painstakingly concluded that any electric charge was an integral multiple of the smallest charge, e , that was ascribed to the electron, and that the value of e was 1.6×10^{-19} C.

Fundamental charge: As above, every charge is a multiple of the charge on 1 electron, the fundamental charge because there can be no charge smaller than it.

Charge quantisation: Once again, this is similar to above.

Thermionic emission: In a vacuum there is applied a potential difference between an anode and a cathode. If the cathode is heated so that it becomes hot and glowing, it is found that negative charge leaves the cathode and flows to the positive anode.

Cathode rays: The negative charges that flowed in thermionic emission were originally known as cathode rays, although it is now known that they are electrons.

Thompsons experiment: In this experiment Thompson was able to work out the charge to mass ratio of an electron. By accelerating a cathode ray by a high voltage and then through a magnetic field he was able to determine an equation

for the ratio of charge to mass:
$$evB = \frac{mv^2}{r} \Rightarrow \frac{e}{m} = \frac{v}{Br}$$

He then arranged an electric field such as to cancel the magnetic field out:

$$eE = evB \Rightarrow v = \frac{E}{B}$$

By substituting the two equations, he was able to calculate the mass to charge ratio of cathode rays:

$$\frac{e}{m} = \frac{E}{2B^2 r}$$

Rutherford's/Gieger and Marsen's alpha scattering experiment: This involved taking a very thin sheet of gold foil, and bombarding it with alpha particles from a radioactive source. It was discovered that while some of the alpha particles were deflected, most passed straight through the foil. Of those that were deflected, some were deflected at very large angles. Given that the foil consisted of approximately 400 layers of atoms, the scientists concluded that the atoms consisted of mostly empty space, with a highly charged central positive nucleus.

Rutherfords model of the atom: Rutherfords model of the atom stated that only a small nucleus in which all the positive charge is concentrated could account for the large deflections of the alpha particles.

Radioactive decay: This is the spontaneous emission of smaller particles or waves as a result of disintegration of the nucleus of an atom.

The reaction between N and He, and the discovery of the proton: By bombarding nitrogen gas with alpha particles, rutherford discovered that fast moving particles were produced that could travel further in the gas than the alpha particles. They were also positive because of the nature of their deflection in a magnetic field. Rutherford concluded that these particles were protons, using a cloud chamber.

Alpha particle: An alpha particle is a double positively charged helium nucleus.

Beta particle: There are two types of beta particle Firstly, beta - (${}_{-1}^0\beta^-$, actually an electron) is emitted when a neutron decays to a proton and an electron, as well as an antineutrino ($\bar{\nu}$). The second is the beta + (${}_{+1}^0\beta^+$, actually a positron) formed when a proton decays to a neutron and a positron, as well as a neutrino (ν).

Gamma radiation: Gamma rays are photons having very high energy. Like an atom, a nucleus can be in an excited state. When it jumps down to a lower energy state, it emits a photon, except the energy levels within an atom are much higher than those within electrons, and thus the photon emitted has a much higher energy.

Atomic number: The number of protons in the nucleus of an atom.

Mass number: The sum of the number of protons and neutrons in the nucleus of an atom.

Artificial transmutation: This is the transmutation of one element into another by means of a nuclear reaction.

Half life: The time taken for the mass of a sample of material to be equal to half its original amount.

OPTION B – ATOMIC AND NUCLEAR PHYSICS EXTENSION

Mass spectrometer: An instrument used to determine accurate nuclear masses. It consists of:

- 1) An ion source: Method of ionisation depends on state of matter of unknown substance eg gases are ionised by bombardment with electrons, while solids may be incorporated into actual electrodes which release ions when a PD is applied to them.
- 2) Velocity selector: This is a region of both electric and magnetic fields where ions will follow a straight line, if the electric force qE is just balanced by the magnetic force qvB , that is

$$qE = qvB \Rightarrow v = \frac{E}{B}. \text{ In other words, those ions (and only those) whose speed is } v = \frac{E}{B} \text{ will pass}$$

through undeflected and have the right direction to pass through a slit representing a perfect straight-line ion path.

- 3) Variable magnetic deflector: Ions that escape the velocity selector then travel perpendicularly into a uniform magnetic field of known intensity. Because of the magnetic force, the ions followed a curved path.

- 4) Detector at end of fixed radius: the Magnetic force will be equal to the centripetal force on the ion, so that $qvB = \frac{mv^2}{r} \Rightarrow m = \frac{qBr}{v}$, allowing the mass of the ion to be accurately found.

Chadwick's discovery of the neutron: Chadwick found that when certain elements, such as beryllium or boron, have a paraffin wax sheet placed behind them and are bombarded with α particles from radioactive polonium, the paraffin wax ejected large numbers of protons. Chadwick noticed that, by the law of conservation of motion, the energy of the protons was such that it could not have been caused by gamma rays. Chadwick reasoned that the radiation was a stream of neutral particles, and calculations showed that the particles have masses similar to protons.

Neutrino: When β decay was first studied, scientists noted that the particle had much less kinetic energy than was predicted by both the conservation of momentum and the mass defect. To account for the missing energy, it was postulated that a new type of particle was emitted in the process but was very difficult to detect, and scientists called it the neutrino.

Nuclear force: Protons repel each other through the electromagnetic force. There is no other mechanism for attraction between protons and neutrons so the strong nuclear force is postulated which is extremely strong but has a short range.

Emission spectra: The spectrum of light emitted by an element. It appears as a series of bright lines, with dark gaps between the lines where no light is emitted.

Absorption spectra: The spectrum of light absorbed by an element. It consists of a bright, continuous spectrum covering the full range of visible colours with dark lines where the element has absorbed light.

Note: The dark lines on an absorption spectra of an element fall into the same place as the bright lines on an emission spectra, and the position of these lines is characteristic of the light.

Bohr's postulates: Bohr set out to understand why, if Rutherford's planetary model of the atom was correct, that electrons were not drawn into the nucleus by electrostatic forces of attraction to the protons of the nucleus. His postulates were as follows, and applied for the hydrogen atom:

- 1) The electron travels in orbits around a positive nucleus, but only certain orbits are allowed. The electron will not radiate energy as long as it is in one of these orbits.
- 2) If the electron falls from one orbit, or energy level, to another, it loses energy in the form of a photon of light, with the difference between the energies of these orbits equal to $E = hf$, where h is Planck's constant. The frequency calculated from this corresponds to the lines found on an emission spectrum of an atom.
- 3) A Hydrogen atom can absorb only those photons of light which will cause the electron to jump from a lower energy level to a higher energy level. Thus the dark lines found on an absorption spectrum correspond to energy absorbed as an electron transitions from a lower to a higher energy level.

Einstein's energy mass equivalence: This is namely $E = mc^2$, where E is the energy (measured in joules), m is the mass in kilograms, and c is the speed of light in a vacuum.

Unified mass unit (u): This is defined as one twelfth the mass of a carbon – 12 atom.

Binding energy (E_b): The energy required to break a nuclear bond – how much energy must be put into the system to separate the two atoms to infinity. This can also be defined as the energy equivalent of the difference in mass between the nucleus of an atom and the masses of the individual protons and neutrons that make it up.

Mass defect: The amount of mass that is converted into energy in a nuclear reaction.

Nuclear fission: The process by which an atom breaks up into smaller fragments. This is often caused by the addition of neutrons to the atoms, causing it to become unstable and eventually break up, releasing energy. This breaking up may, in some cases produce more neutrons, which cause the reaction to continue.

Nuclear fusion: When two smaller nuclei fuse to form one bigger and more stable nucleus, releasing energy in the process.

Photoelectric effect: Experiments involving the photoelectric effect strongly lend themselves to the particle theory of light. When light shines on a metal surface, electrons are emitted from the surface (the effect also works on other materials, but is most easily observed on metals).

A metal plate and a smaller electrode are placed inside an evacuated glass cell, known as the photocell. The two electrodes are connected to both an ammeter and a voltage source. When the cell is placed in the dark, there is no measured current.

Using the apparatus, one thing that can be measured is the maximum kinetic energy of the emitted electrons. This is done using *reverse potential*, that is the terminals are reversed so that the electrons from emitted are repelled by the negative electrode. If this voltage is very small, the fastest electrons will still reach the cathode. There is a point where no electrons reach the cathode, and this is known as the stopping voltage, or stopping potential, V_0 , and from its measurement, the maximum kinetic energy can be determined using conservation of energy.

Loss of KE = gain in PE

$$\therefore KE_{\max} = eV_0$$

Predictions made by the wave theory of light:

Electrons should be emitted in the photoelectric effect, because the field of an EM wave could exert a force on electrons in the metal and as a result some could be ejected.

- 1) If the intensity of the light is further increased, the maximum kinetic energy and number of electrons should be increased because the higher intensity means a greater electric field amplitude, and the greater electric field should eject electrons with a higher speed.
- 2) The frequency of the light should not affect the KE of the ejected electrons. Only the intensity should effect KE_{\max} .

Predictions made by the photon theory of light:

Increasing the intensity of the light means increasing the number of photons in the beam, but the energy of each photon is changed only by frequency. Einstein predicted that an electron is ejected from the metal from a collision with a single photon, and that this photon transfers all of its energy to that electron. Einstein suggested that the energy carried by light comes in discrete packets, called quanta. The amount of energy is given by $E = hf$, where h is Planck's constant and E is measured in joules. Einstein suggested that the intensity of light is a measure of how many photons it contains. An electron near the surface of the metal can absorb the energy of a photon of light. If the frequency of the light is high enough, the electron will absorb enough energy to escape the metal surface. Any excess energy would become the kinetic energy of the electron.

For every metal there is a frequency below which no electrons are emitted, known as the threshold frequency. Above this frequency, photoelectrons are emitted. The greater the intensity of the light, the greater the photoelectron current. Increasing the retarding potential applied to the anode results in a decrease in the photo current, no matter how intense the light. This suggests the photoelectrons are all emitted with the same kinetic energy regardless of the intensity of the light. The retarding potential at which the photocurrent no longer flows is called the stopping voltage. Different frequencies of light have different stopping voltages, the greater the frequency the greater the stopping voltage. This was in direct conflict with the wave theory of light.

Thus $E = hf = W_0 + \frac{1}{2}mv_{\max}^2$ ie Energy of photon = energy required to remove electron + maximum energy of ejected electron. The work function (the minimum energy required to remove the electron), can also be given by $W_0 = hf_0$, where f_0 is the threshold frequency.

Summary: The wave theory of light predicts that there will be an increase in the maximum kinetic energy, and hence the work function, when the intensity of light is increased. In reality, this is not the case, there is only an increase in current, because more electrons are being emitted.

Reverse potential: This is used in an experiment to prevent the release of photoelectrons. A stopping voltage is applied in the opposite direction to the current induced by photoelectron emission. As the frequency of the light is increased, more energy will be required to stop these electrons. If the frequency is decreased however, there is eventually a point where no emissions will occur, and so no stopping voltage is required. Ie $hf = hf_0 + eV_s$

X rays: These are the electromagnetic waves emitted from an x-ray machine. An anode and a cathode are paced in a vacuum tube behind the anode is some photo sensitive material. There is a potential difference of about 150,000 V. The Cathode is heated to produce thermo-electrons, which accelerate towards the anode. When they are deflected by nuclei in the atom, they release energy in the form of an x-ray. There is a minimum wavelength below which no x-rays are

emitted. It is determined by the voltage being applied to the tube: $\lambda_{\min} = \frac{hc}{eV}$

X ray spectrum: This is the spectrum of radiation emitted by an x-ray machine. Because the electrons can come close or far to the nuclei, the x-ray spectrum is continuous. There are peaks in intensity on the spectrum, caused by inner shell electrons being removed. Electrons from outer shells drop down to fill the gaps, emitting this energy. The peaks are characteristic of each anode material.

De broglies equation: Given that light has a particle nature, de broglie set out to prove that particles have a wave nature. He started with the equation for linear momentum of a photon: $p = m_{\text{photon}}c$.

The mass of the photon can be calculated from $E = mc^2$ and $E = hf$.

$$m = \frac{hf}{c^2}$$

thus, $p = \frac{hf}{c}$.

c can be expressed as $c = f\lambda$.

$$\text{So } p = \frac{hf}{f\lambda} \Rightarrow \lambda = \frac{h}{p} \Rightarrow \lambda = \frac{h}{mv}$$

Linear particle accelerator: This is a device used to accelerate particles to ultra-high speeds. They are based on a series of 'tubes' through which the particles are pulled and then pushed by electric fields. The lengths of the tubes become longer and longer, because the frequency of the ac voltage being applied to them is constant. (because the particle is accelerating, it will cover a greater distance in a shorter amount of time, and therefore the tubes must be longer). The potential difference across each tube oscillates, so that when the particle reaches the end of the first tube (which is the opposite charge as the particle), it is repelled by that tube and attracted to the charge on the next tube. The net charge on the inside of a hollow conductor is 0, so the acceleration occurs only between tubes.

Circular particle accelerator: This is a particle accelerator that works on the basis of magnetic fields making the particles rotate, and when they cross between the two halves of the accelerator, it is the electric field associated with the potential difference between the two d's that makes the particle accelerate. The radius inside is defined by $r = \frac{mv}{Bq}$,

so as the velocity is increased the magnetic field must be increased to keep the radius constant.

OPTION F

Galaxy: Huge mass of stars, nebulae and interstellar material- 3 types elliptical, spiral and regular.

Cluster: A group of stars. There are two main types:

- 1) open: loose groups of a few thousand young stars drifting apart
- 2) Globular: densely packed (roughly spherical) groups of hundreds of thousands of older stars.

Nebulae: A cloud of dust inside a galaxy. There are several types:

- 1) emission nebulae: their gas emits light when stimulated by young star radiation.
- 2) Reflection nebulae: dust reflects light from stars in or around nebulae.
- 3) Dark nebulae: silhouettes since they block light from shining nebulae or stars.
- 4) Planetary nebula: gas shell drifting away from dying stella core.
- 5) Supernova remnant: gas shell moving away from stellar core at great speed after a supernova has occurred.

Red giant: A star about 70 million kilometres wide with a duration of about 100 million years. A red giant is much larger than the sun with a much lower surface temperature. Very luminous, very large.

White dwarf: A star roughly the size of the earth, consisting of the core of a red giant after the outer layer has drifted off. They are very dense, with a teaspoon weighing up to 5 ton. Eventually white dwarves cool to become a black dwarf.

Neutron star: This is the remains after a massive star has contracted to become essentially an enormous nucleus made up of neutrons. This star is *extremely* dense.

Black hole: If a surviving supernova core is large enough it contracts to form a black hole. Here gravity is so strong even light cannot escape.

Supernovae: This is when the energy of a neutron star is released in a massive explosion, as bright as the entire universe for an instant.

Pulsar: A rotating neutron star that emits electromagnetic radiation usually of radio frequency from the poles. Each time a pole lines up with the earth a pulses of radiation is detected.

Quasar: The exact nature of quasars remains a mystery. They are extremely bright objects (1000 galaxies) on the edge of the known universe. They are very distant, and are thought to be smaller than galaxies.

Parallax: This is the apparent motion of a star against a background of more distant stars, due to the earth's motion about the sun. Using parallax the distance to stars as far as 100 light years can be calculated.

Apparent magnitude: This quantity is dependent on the absolute luminosity (intrinsic brightness) of a star and its distance from the earth. It is a logarithmic scale ie a difference in apparent magnitude of 5 corresponds to a factor of 100 in brightness (?? – log base what - ??)

Apparent brightness: This is the energy received per unit time per unit area on the earth.

Absolute magnitude: This is the apparent magnitude a star would have if it was 10 parsecs away (32.6 light years).

Absolute luminosity: This is the total energy emitted by a star per unit time.

Black body radiation: Hot bodies do not emit radiation of a single wavelength but a whole spectrum of wavelengths. To understand the relationship between energy and wavelength we need a standard emitter- the perfect emitter, which is also the perfect absorber. Ie a black body. The radiation emitted by a black body peaks outside the visible spectrum. The higher the temperature of a body, the greater the intensity of its peak wavelength and the shorter the wavelength at which this occurs.

Stefan-boltzmann law: The total power emitted by a black body is its luminosity. If a black body has a total area A then its luminosity L is given by : $L = \sigma AT^4$, where σ is the Stefan-boltzmann constant.

Wien's displacement law: A relationship that gives the temperature of a black body in terms of the wavelength at

which it radiates the maximum amount of energy in its spectrum. $\lambda_{\max} = \frac{2.9 \times 10^{-3}}{T}$

Atomic spectra – chemical composition of stars: The emission spectra relates to the elements in the upper atmosphere. Absorption spectra is also related to the temperature because the elements behave (spectrally) differently at different temperatures.

Hertzsprung-russel diagram: This is a diagram of absolute magnitude of stars plotted against their surface temperature. The stars are grouped in several distinct regions, with a main sequence that contains the majority of stars. The red giants are situated towards the middle/top right of the diagram, because they are very large in size and cooler in temp, with a large luminosity. White dwarves are found in the bottom left of the diagram because they have a small size, high surface temperature and are faint. Cepheid stars can be found in the middle right.

Variable star: Luminosity of the stars in the instability strip vary periodically and for this reason such stars are called variable stars. The instability strip is between the main sequence and the red giant group.

Cepheid variables are known well. The luminosity of Cepheid variables vary because of the regular contraction of the stars outer envelope. They have a period of 1 – 50 days. There are two types of Cepheid variables:

Type 1: stars with a heavy metal element in their outer layers. They are younger, cooler and brighter.

Type 2: stars which have little heavy metal content. They are older stars, but not as bright

There are also RR Jyrae variables. They have a lower mass than Cepheid variables, with periods less than 1 day, and are found in globular clusters.

Binary star: A pair of stars so close together the naked eye cannot distinguish between them. The true binary stars are those that revolve around a common orbital centre. There are three main types:

- 1) visual binary: when a telescope is used, the two stars are distinguished
- 2) Astrometric binary: A binary system where one star is so faint that its presence can only be inferred by its effect on its partner star.
- 3) Eclipsing binary: the stars binary nature can be deduced from the fact that the stars periodically eclipse each other.

Doppler effect: When there is an approaching light source, there is a decrease in measured wavelength, called a blueshift.

Redshift: When there is a receding light source, there is an increase in wavelength, called a redshift. This means that the frequency decreases towards the red end of the spectrum.

Hubbles law: Hubble found that the lines in the spectra of galaxies were generally red shifted and therefore the amount of shift was proportional to the distance from us. $v = Hd$, where H is Hubbles constant, a somewhat dodgy number with estimated values ranging from 30 to 100 km/s/mpc.

Background (3K) radiation: Calculation shows that the helium produced by nuclear fission within stars cannot account for the amount of helium in the universe. In 1960 two physicists, Dicke and Peebles, proposed that sometime during the early history of the universe it was at sufficiently high temperature to produce helium by fusion. In this process many high energy photons would have been emitted. The photons would have a black body spectrum corresponding to the then temperature of the universe. It was established that the photons would have a black body spectrum of 3K. Dicke and Peebles were working with a microwave aerial and realised that no matter what direction they pointed in they picked up a steady background radiation, with a modern day measurement of 2276 K.

Olbers paradox: If the universe were infinite, and stars were distributed evenly throughout, then the night sky would appear infinitely bright. If the universe was not infinite then gravity would pull everything together.

The first answer one would attempt is to invoke absorption of the radiation from the intervening stars and the interstellar medium. However this does not work: over time the medium would heat up and emit as much radiation as it absorbs.

The actual answer is that if the universe was expanding, the radiation is red shifted and contains less energy. Also, stars have a finite lifetime, meaning stars have not radiated forever and will not go on forever.

There are currently three theories on the eventual fate of the universe, determined by its mass: (like we give a shit what happens in 400 gazillion years time)

Open universe: This means that density is such that gravity is too weak to stop it from expanding forever.

Closed universe: This means that gravity will eventually stop the universe from expanding, and cause it to contract.

Flat universe: This means that density is at a critical value whereby the universe will only start to contract after an infinite matter of time. (gee that makes a lot of sense).

Big bang: This is the theory that a cataclysmic explosion initiated the expansion of the universe. When this happened matter did not fly off into space but space and time itself were created.

- in the first 10^{-43} seconds, the four fundamental forces were unified.
- At 10^{-43} seconds, gravity appeared as a separate force (10^{32} K)
- Strong nuclear interaction separated from the electromagnetic and weak interaction (10^{27} K)

- Between 10^{-35} and 10^{-34} seconds, the young universe underwent rapid expansion increasing its size by a factor of 10^{50} . This is known as the **inflationary epoch**. Matter and antimatter were allowed to separate.
- At 10^{-12} s (10^{13} K), individual neutrons and protons began to exist because the temperature was low enough.
- At 2 s (10^{10} K), neutrinos ceased to interact with protons and neutrons
- At 3 min all primordial helium had been produced.
- At 300 000 years, the temperature was low enough such that energy of photons no longer caused ionisation and electrons could now combine with nuclei to form atomic hydrogen and helium. The universe was “transparent” to photons, giving rise to the 3K background radiation.