A-Level Physics Key Terms Cheat Sheet

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Mechanics

Scalar	**A quantity without direction.** Length/Distance, Speed, Mass, Temperature, Time, Energy
Vector	**A quantity with both direction and magnitude** Displacement, Velocity, Force (inc. Weight), Acceleration, Momentum
Equilibrium	When all forces acting on an object are balanced and cancel each other out. ➔ There is no resultant force
Free-body Diagram	A diagram of all the forces acting on a body, but not the forces it exerts on other things. The arrows indicate magnitude and direction.
Principle of Moments	For a body to be in equilibrium, the sum of the clockwise moments equals the sum of the anticlockwise moments.
Moment	The product of the size of the force and the perpendicular distance between the turning point and the line of action of the force.
Couple	A pair of forces with equal size which act parallel to each other but in opposite direction. E.g. turning a car's steering wheel.
Centre of Mass	The single point from which the body's weight acts through. The object will always balance around this point. To calculate for uniform objects: $\Sigma mx = M\bar{x}$
SUVAT (Constant Acceleration)	$v = u + at$ $s = 1/2\ (u+v)t$ $v^2 = u^2 + 2as$ $s = ut + 1/2\ at^2$ $s = vt - 1/2\ at^2$

Mechanics (cont)

Displacement-Time Graph	Displacement (y) against Time (x). **Gradient = Velocity** **Acceleration = Δgradient**
Velocity-Time Graph	Velocity (y) against Time (x) **Gradient = Acceleration** **ΔGradient = ΔAcceleration** **Area = Displacement**
Variable Acceleration	**🡣Differentiate🡣** x v a Δa **🡡Integrate🡡**
Acceleration-Time Graph	Acceleration (y) against Time (x). **Gradient = ΔAcceleration** 0 Gradient = No acceleration ➔ constant velocity. Constant Gradient = constant acceleration **Area = Velocity** NB: Remember to treat area below the time axis as negative!
Newtons 1st Law	The velocity of an object will not change unless a resultant force acts on it.
Newtons 2nd Law	**F = ma** The acceleration of an object is ∝ to the resultant force acting upon it. (for objects with a constant mass) **Points to remember:** • Resultant Force is vector sum of all the forces • Unit = N • Ensure mass is in kg • Acceleration is in the same direction as resultant force.
Newtons 3rd Law	If object A exerts a force on object B, then object B exerts an equal but opposite force on object A

Mechanics (cont)

Freefall	When there is only gravity acting upon an object. i.e. motion with an acceleration of g (9.81ms^{-2}) The same SUVAT equations apply, however, **u = 0** and **a = g** {{ng}} NB: 'direction' of motion, dictates the sign of g
Projectile Motion	An object given an initial velocity, then left to move freely under g. There is separate horizontal and vertical motion with time being the only common attribute. Both motion follows SUVAT equations but horizontal motion has no acceleration.
Friction	Force that opposes motion. When in a fluid (liquid or gas) it is drag, drag depends on: • Viscosity of the fluid • Speed of object • Shape of the object **For all frictional forces** • Force is in the opposite direction to motion • Can never increase speed or induce motion • They convert kinetic energy ➔ heat.
Lift	Upwards force on a object in a fluid
Terminal Speed	When frictional forces equal the driving force. For a falling object, when drag equals the force due to their mass.
Momentum	The product of the mass and velocity of an object. Momentum in **any** collision is conserved (when no external forces are involved)
Inelastic Collision	Not all of the kinetic energy is conserved. Momentum however **is** conserved.

Mechanics (cont)

Elastic Collision	Kinetic energy is conserved i.e. no energy is dissipated as heat or other energy forms.
Impulse	An extension of N2L. Impulse is the product of force and time and is equal to the momentum of that body. $F\Delta t = \Delta(mv)$ Also equal to the area under a force-time graph.
Work Done	The energy transferred from one form to another. $W = Fd$ Work Done = The force causing motion x distance moved
Power	The rate of work done over time $P = \Delta W/\Delta t$ $P = Fv$ ➔ derived from combining P and W = Fs
Force-Displacement Graph	Area = Work Done
Conservation of Energy	Energy cannot be created nor destroyed, only converted from one form to another, but the total energy of a closed system will not change.
Efficiency	useful output/input in terms of energy or power.

Materials

Density	$\rho = m/V$ A property all materials have and is independent of both shape and size.
Limit of Proportionality	The point where Hooke's law no longer applies. On a force-extension graph, the limit of proportionality is where the line is no longer straight

Materials (cont)

Hooke's Law	$F = k\Delta L$ The force is proportional to the extension of a stretched wire. **k is the stiffness constant** ➔ a measure of how hard it is to stretch
Elastic Limit	The point on a force-extension graph where the line begins to curve. Beyond this point, permanent deformation occurs where the wire will no longer return to its original shape.
Force--Extension Graph	Straight section ➔ Gradient = k Loading and unloading plot a loop, if a stretch is elastic, the curve starts and finishes in the same position (the origin). If plastic deformation occurs, the unloading line has the same gradient (k) but crosses the x axis at a different point Area = Elastic Strain Energy The area between the loading and unloading line (after plastic deformation) is equal to the work done in deforming the material
Tensile Stress	The ratio of forced applied and cross-sectional area. *stress* = F/A
Tensile Strain	The ratio of extension to original length, it has no units and is just a ratio. *strain* = ΔL/L
Youngs Modulus	The ratio of tensile stress and tensile strain $E = FL/A\Delta L$ The YM of a material is the constant value up to the limit of proportionality,
Stress-Strain Graph	Stress (y) against Strain (x). **Gradient = Young's Modulus** Area = strain energy per unit volume

Materials (cont)

Yield Point	The point on a stress-strain graph where the material stretches without any extra load.
Brittleness	When a material breaks after a certain about of force is applied. The line simply stops on a stress-strain graph. The same thing applies on a force-extension graph, the line just stops.

Thermal Physics

Kelvin	A temperature scale that is in terms of an atoms movements. °C ➔ K + 273
Absolute Zero	The lowest theoretical temperature of anything ➔ 0 K = -273°C
Internal Energy	The internal energy of a body is the sum of the randomly distributed kinetic and potential energies of all its particles
Closed System	A system where no matter or energy is transferred in or out of the system
Heat Transfer	Heat is **always** transferred from a hot area/substance to a cold area/substance.
Specific Heat Capacity	The amount of energy required to heat up 1kg of the material by 1°C/1 K $\Delta Q = mc\Delta T$ Energy Change is equal to the product of the mass, specific heat capacity and the change in temperature.

Thermal Physics (cont)

Specific Latent Heat	The specific latent heat of fusion (➔ Solid) / vaporisation (➔ gas) is the quantity of thermal energy needed/will be lost to change the state of 1kg of the substance. **Q = ml** where m is the mass and l the latent heat. When a substance changes state, there is a period where the temperature of the material is constant, as the internal energy rises, this is due to the latent heat.
Boyle's Law	At a constant temperature, pV is constant. i.e. $p_1V_1 = p_2V_2$ On a p-V plot, the higher the line, the higher the temperature.
Charles' Law	At a constant pressure: V is directly proportional to its absolute temperature T $V_1/T_1 = V_2/T_2$
Pressure Law	At a constant volume: p is directly proportional to its absolute temperature. $p_1/T_1 = p_2/T_2$
Molecular Mass	the sum of the masses of all the atoms that make up the molecule.
Relative Molecular Mass	The sum of the relative atomic masses of all the atoms.
Avogadro Constant	The number of atoms in exactly 12g of carbon isotope $^{12}_{6}C$. $N_A = 6.02 \times 10^{23}$ mol^{-1}
Molar Mass	The mass of a material containing N_A molecules

Thermal Physics (cont)

Ideal Gas Equations	pV = nRT n = number of moles R = molar gas constant pV = NkT N = number of molecules k = Boltzmann constant A way of remembering which n is which. Moles will be small, therefore small n. Number of molecules will be large so, big N.
Kinetic Theory	The pressure exerted by an ideal gas can be derived by considering the gas as individual particles. $pV = 1/3 \times Nm(C_{rms})^2$ C_{rms} is the root mean square speed. **Assumptions** • All molecules in the gas are identical • Gas contains a large number of molecules • The volume of the molecules is negligible when compared to the volume of the container/gas as a whole.
Brownian Motion	Random motion of particles suspended in a fluid ➔ helped provide evidence that the movement of the particles was due to the collisions of the fast randomly--moving particles, which supported the model of kinetic theory.
Average Kinetic Energy	$1/2 \times m(C_{rms})^2 = 3/2 \times nRT/N$ 🡻 $1/2 \times m(C_{rms})^2 = 3/2 \times RT/N_A$

Particles and Radiation

Proton & Neutrons	The 2 Baryons that make up the nucleus of an atom. Comprised of 3 quarks. Protons have a relative charge: +1, neutrons: 0. Both have a relative mass of 1 (1.67×10^{-27} kg).

Particles and Radiation (cont)

Electron	A fundamental lepton, with a charge of -1. Cannot be broken down into other subatomic particles. Relative mass of 1/2000 (9.11×10^{-31} kg)
Nuclide Notation $^{A}_{Z}X$	The general notation of elements.
Proton Number (Z)	The number of protons in an atom. Defines the element. For a neutral atom, proton no. also == the electron number
Nucleon Number (A)	AKA Mass Number - number of total nucleons (protons + neutrons)
Specific Charge	The ratio of a particles charge to its mass. Specific meaning per kg. S.C. = Charge (Q) / Mass (kg)
Isotope	Atoms with the same number of protons but a different number of neutrons. Affects the stability of a atom
Strong Nuclear Force	A **strong** force that holds atoms together at small distances, strong enough to overcome the electrostatic repulsion of the protons. **Distances** Repulsive: <0.5 fm (0.5×10^{-15}m) Attractive: 0.5 to 3 fm Rapidly falls to) after 3 fm.
Alpha Decay (α)	Occurs in big atoms (82+ protons). Atoms emits a helium nucleus (2 protons 2 neutrons). Particles is too big to be kept stable by the SNF.
Beta-Minus Decay (β^-)	Emission of a electron and anti-electron-neutrino. Happens in neutron rich particles. In nucleus structure terms, a neutron turns into a proton by changing an d quark to a u quark, emitting an electron and anti-electron-neutrino.
Beta-Plus Decay (β^+)	Emission of a positron and an electron neutrino. One of the atoms protons, changes a u quark to a d quark, changing to a neutron emitting a positron and an electron-neutrino.

Particles and Radiation (cont)

Photon	A discrete packet of electromagnetic radiation with 0 mass. E = hf = hc/λ
Antiparticle	The corresponding antiparticle to any particle has the same mass and rest energy but opposite charge.
Pair Production	When 2 of the same particles collide at high speed and produce a particle-antiparticle pair. The energy of the collisions is converted into the pair. Also occurs when a photon has enough energy to produce an electron--positron pair. $E_{min} = 2E_0$ (in MeV)
Annihilation	When a particle and antiparticle collide producing 2 photons in opposite directions. $E_{min} = E_0$ This collision is used in PET scanners to detect cancers.
Hadron	Particles that can *feel* the strong force. Either a baryon or a meson depending on its quark structure
Baryon	A hadron consisting of 3 quarks. All are unstable except a free proton - all eventually decay into a proton. Proton: uud Neutron: ddu
Baryon Number	A quantum number which is **always** conserved. Baryons have a B.N. of +1. Antibaryons have a B.N. of -1 and all other particles have a B.N of 0.
Mesons	A hadron consisting of 2 quarks - a quark-antiquark pair. There are 9 possible combinations, making either Kaons or Pions.
Lepton	A fundamental particle that **doesnt** feel the strong force. Interacts via the weak interaction.
Lepton Number	Another quantum number that is always conserved. Must be separate for lepton-electron number and electron-muon number.

Particles and Radiation (cont)

Strange Particles	Particles that have a property of strangeness - contain a strange/anti-strange quark. **Created** via the strong interaction **Decay** via the weak interaction Rules of conversation mean that strange particles are only produced in pairs.
Strangeness	Another quantum number - however it can change by ±1 or 0 in an interaction.
Quark	A fundamental particle that makes up hadrons. There are 6 types:**up/down**, top/bottom, **strange**/charm.
Quark Confinement	There is no where to get a quark on its own, when enough energy is provided, pair-production occurs, with one quark remaining in the particle.
Weak Interaction	β^+ and β^- are both examples of weak interactions, which is interaction via the weak force, the force acting between leptons.
Feymann Diagram	A diagram of particle interactions, with: Wavy Lines : Exchange Particle Straight Lines : Particles in/out of the interaction (with arrows indicating direction)

Magnetic Fields

Magnetic Field	A region where a force acts, force is exerted on magnetic/magnetically susceptible materials (e.g. iron).
Magnetic Field Lines	Lines that show a magnetic field. They run from north to the south pole of a magnet. The more dense the lines are, the stronger the field

Magnetic Fields (cont)

Magnetic Flux Density	The force on one metre of wire carrying a current of 1 A at right angles to the magnetic field. **AKA The strength of the magnetic field** B = F/Il Magnetic flux density is the force by the current meter
Magnetic Field around a wire	When current flows, a magnetic field is induced. **Right hand rule:** • Curl Fingers around "wire". • Stick up thumb **Thumb**:Direction of current **Fingers**: Direction of magnetic field
Solenoid	A cylindrical coil of wire acting as a magnet when carrying electric current. Forms a field like a bar magnet.
Force on a Current-Carrying Wire	A current-carrying wire, running through a magnetic field generates a resultant field of the one induced by the current and the pre-existing one. The direction of the force is perpendicular to the current direction and the mag. field.
LeFt-hand Rule	For finding the direction of the **F**orce. • Thumb upwards • First finger forwards • Second finger to the right (perpendicular to f.f.) **Thumb**:Force/Motion **First Finger**:Field **Second Finger**:Current
Charged Particles in a mag. field	F = BQv

Magnetic Fields (cont)

Circular Path	For a charge travelling perpendicular to a field is always perpendicular to the direction of motion ➔ The condition for circular motion. $F = mv^2/r$ can be combined with $F = BQv$. Rearranged for r, this shows that: • r increases if mass or velocity increases • r decreases if the mag. field strength is increased or the charge increases • $f = v/2\pi r$ •Combined with $r = mv/BQ$ ➔ $f = BQ/2\pi m$
Particle Accelerator	A cyclotron consists of 2 hollow semiconductors, with a uniform magnetic field applied perpendicular to the plane of the D magnets. An A.C. is applied. Charged particles are fired into the D's. They accelerate across the gap between magnets, taking the same amount of time for the increasing radius.
Magnetic Flux	The number of flux lines through a certain area hence{{n}}Φ = BA In other words its the amount of flux passing through an area
Electromagnetic Induction	Relative motion between a conductor and a mag. field, causes an emf to generate at the ends of the conductor as the electrons accumulate at one end.

Magnetic Fields (cont)

Flux Linkage	The amount of field lines being cut $N\Phi = BAN\cos(\theta)$ where θ is the angle between the normal to the coil and the field. (if it is perpendicular, θ = 0°
Faraday's Law	Induced e.m.f. is proportional to the rate of change of flux linkage... $\varepsilon = N\Delta\Phi/\Delta t$
Lenz's Law	The induced e.m.f. is **always** in such a direction that it opposes the change that caused it.
e.m.f in a rotating coil	$N\Phi = BAN\cos(\omega t)$ $\varepsilon = BAN\omega\sin(\omega t)$ Flux Linkage and Induced e.m.f. are 90° out of phase.
Generator	E_k is converted into electrical energy, the kinetic energy turns a coil in a magnetic field so that they induce a electric current.
Right-hand Rule	For **G**enerators. • Thumb upwards • First finger forwards • Second finger to the **left** (perpendicular to f.f.) **Thumb**:Force/Motion **First Finger**:Field **Second Finger**:Current
Alternating Current	Current that's direction changes over time. The voltage across the resistance goes up and down.
Root Mean Squared (rms) Power	$V_{rms} = V_0/\text{sqrt}(2)$ $I_{rms} = I_0/\text{sqrt}(2)$ $P_{rms} = I_{rms} \times V_{rms}$

Magnetic Fields (cont)

Transformer	A device that uses electromagnetic induction to change the size of a voltage for an alternating current. An alternating current flowing in the **primary coil** causes the core to magnetise/demagnetise continuously in opposite directions. This produces a **rapidly changing magnetic flux** in the core (made of **magnetically soft material**. The changing flux passes through the **secondary coil** induces a alternating e.m.f. if the same frequency but **different** voltage (if the no. of turns is different)
Transformer Equations	**P.Coil**: $V_p = N_p \times \Delta\Phi/\Delta t$ **S.Coil**: $V_s = N_s \times \Delta\Phi/\Delta t$ Combines to: $\mathbf{N_s/N_p = V_s/V_p}$
Inefficiencies in a Transformer	• Eddy Currents (looping currents induced by changing flux) ➔ create opposing magnetic fields reducing its strength ➔ **reduced by laminating the core so that current cannot flow between the cores layers** • Heat Generation ➔ due to the resistance in the coils ➔ **reduced by using a wire with a low resistance** • Magnetising/Demagnetising the core ➔ energy is wasted as the core is heated ➔ **reduced by using a magnetically soft core, which has a small hysteresis loop, this the energy required to create/collapse the field is minimised** **Efficiency Equations** **efficiency** = $\mathbf{I_s V_s / I_p V_p}$ ➔ $power_{out}/power_{in}$

Engineering

Moment of Inertia	A measure of how difficult it is to rotate an object or change its rotational speed $\mathbf{I = \Sigma mr^2}$ This equation means that the moment of inertia is dependent in the masses, and their distribution, so a solid disk may have a lower moment of inertia than a hoop.
Rotational Kinetic Energy	The rotational kinetic energy of an object is dependant on its moment of inertia. $\mathbf{E_k = 1/2 \times I\omega^2}$
Rotational SUVAT	The SUVAT equations can be applied directly to rotational motion, but with rotational's counterparts: **s ➔ θ (rads)** **u ➔** ω_0 **v ➔ ω** **a ➔ α** **t ➔ t**
Torque	When a force causes an object to turn, the turning effect is torque. $T = Fr$ $T = I\alpha$
Work & Power	The work done is the product of the force and the angle turned by: $\mathbf{W = T\theta}$ Power is the amount of work done in a given time: $\mathbf{P = T\omega}$ as $\Delta\theta/\Delta t = \omega$ Frictionalk Torque occurs in real world systems therefore: $T_{net} = T_{applied} - T_{frictional}$

Engineering (cont)

Flywheels	A flywheel is a heavy wheel that has a high moment of inertia, meaning once spinning it is hard to stop. They are charged as they are spun, turning T into rotational kinetic energy. It is used as a energy storage device ➔ if energy is needed, the wheel decelerates and provides some of its rotational energy to another part of the machine. Flywheels maximused for energy storage are dubbed flywheel batteries. **Factors that effect storage:** • Mass ➔ If the mass is increased, the moment of inertia and hence the r. E_k • Angular Speed ➔ if the angular speed is increasd, the energy stored increases with angular speed^2, so increasing the a.speed, greatly increases energy storage. • Spoked Wheel ➔ this again increases the moment of inertia as the mass is distributed further away from the center. • Material ➔ Carbon fibre is generally used as it is strong and allows for higher angular speeds • Friction Reduction ➔ lubrication is used to reduce friction as well as superconducting magnets to stop contact and therefore friction. Vacuums are also used so air resisitance is not a factor. **Uses** • Smoothing Torque ➔ Flywheels are used to keep systems relying on torque running smoothly • Breaking ➔ especially in F1 cars, flywheels are used to harness some of the force when breaking to allow for faster acceleration afterwards • Wind Turbines ➔ to provide stable power for days without wind and/or peak times

Engineering (cont)

Angular Momentum	Angular Momentum = Iω $I_{initial} \times \omega_{initial} = I_{final} \times \omega_{final}$ **Angular Momentum** IS** conserved
Angular Impulse	Impulse = Δ(Iω) = TΔt
1st Law of Thermodynamics	**Q = ΔU + W** If energy is transferred **to** the system: Q = +ve If work is done **on** the gas: W = -ve If the internal energy **increases**:U = +ve For closed systems, the first law can be applied, also known as non-flow processes as no gas flows in or out. To apply the law, it is assumed to be an Ideal Gas.
Isothermal (Constant temperature) Change	**ΔU = 0** Therefore Q = W There is no change in internal energy... no change in temperature therefore: pV = Constant. pV plot is a curve, with higher lines indicating a higher temperature. The work done is the area under the line. Expansion is ⬇➔ and is positive. Compression is ⬆⬅ and is negative.
Adiabatic (No heat transfer) Change	**Q = 0** Therefore ΔU = -W pV^{γ} = constant Steeper gradient than a isotherm's plot. There is a greater amount of work done for an adiabatic change than a isotherm

Engineering (cont)

Isobaric (Constant Pressure) Changes	$W = p\Delta V$ Therefore V/T is constant No work done.
Isometric (Constant Volume) Changes	**W = 0** Therefore $Q = \Delta U$ and p/T is constant Work done = area under straight line
Cyclic Process	A System that undergos a number of combinations of processes. They start at a certain pressure and volume and return to it at the end of a cycle.

Engineering (cont)

4-Stroke Petrol Engine	• Induction ➔ The piston starts at the top of the cylinder, and moves down increasing the volume of the gas above it. A air-fuel mixture is drawn in through an open inlet valve. Pressure remains constant just above atmospheric. • Compression ➔ The inlet valve is closed, the piston moves up the cylinder. Work is done on the gas, and the pressure increases. Just before the end of the stoke, a spark ignites the air-fuel mixture. Temperature and pressure increase. • Expansion ➔ The explosion expands and pushes the piston back down. Work is done as the gas expands, there is also a net output. Just before the bottom, the exhaust valve opens and the pressure reduces. • Exhaust ➔ The piston moves up the cylinder and the burnt gas leaves through the exhaust valve, the pressure remains constant just above atmospheric.
4-Stroke Diesel Engine	Induction Stroke ➔ Only air is drawn. Compression ➔ The air is compressed enough to have a temperature to ignite diesel fuel ➔ just before the end of the stroke, diesel fuel is sprayed in and ignites. Expansion & Exhaust ➔ The same as petrol

Engineering (cont)

Indicated Power	$P_{indicated}$ = Area of p-V loop x cycles per second x no. of cylinders The net work done by the cylinder in one second.
Output Power	The useful power at the crankshaft P = Tω
Friction Power	The power lost due to friction **between moving parts** $P_{friction} = P_{ind} - P_{brake}$
Engine Efficiency	P_{inp} = Calorific Value x Fuel Flow Rate **Mechanical Efficiency = P_{brake}/P_{ind}** Affected by energy lost due to moving parts **Thermal Efficiency = P_{ind}/P_{inp}** Heat energy transferred into work **Overall Efficiency = P_{brake}/P_{inp}**
2nd Law of Thermodynamics	Heat engines must operate between a **heat source** and a **heat sink** Engine Efficiency = $W/Q_H = (Q_H - Q_C)/Q_H$ Max Theoretical Efficiency = $(T_H - T_C)/T_H$
Heat Engine	A Source of heat (T_H) ↓ Q_H ↓ Heat Engine → W ↓ Q_C ↓ Heat Sink (T_C)
Reverse Heat Engine	Hot (T_H) ↑ Q_H ↑ Heat Engine ← W ↑ Q_C ↑ Cold (T_C)

Engineering (cont)

Refrid-gerator	A reverse heat engine where the cold space is the actual fridge. Whilst the hot space is the surroundings, the fridges aim is to extract as much heat from the cold space to the surroundings.
Coefficient of Preformance	$COP_{ref} = Q_c/W = Q_c/(Q_h-Q_c) = T_c/(T_h-T_c)$ $COP_{hp} = Q_h/W = Q_h/(Q_h-Q_c) = T_h/(T_h-T_c)$

Electricity

Current (I/A)	The rate of flow of charge. Conventionally running from + to -. Measured my an Ammeter (in series) **$I = \Delta Q/\Delta t$**
Potential Difference (V/V)	The work done in moving a unit charge between 2 points. 1 V = $1JC^{-1}$. Measured by a voltmeter (in parallel) **V = IR** / **V = W/Q**
Resistance (R/Ω)	A measure of how difficult it is to move current around the circuit. **R = V/I**
Ohmic Conductor	Under constant physical conditions, I is proportional to V. On a graph of I (y) against V (x), the gradient is equal to 1/R.
Filament Lamp	A filament lamp has an IV characteristic of a cubic (s shape) going through the origin. The heat in the filament causes the resistance to increase - the particles in the filament vibrate more, meaning its harder for the current-carrying electrons to move through it, therefore resistance increases as the current increases.

Electricity (cont)

Diode	A diode only allows current to flow in one direction. The IV characteristic is virtually no current until the threshold voltage, where the voltage increases exponentially. The threshold voltage is approx. 0.6V
Resistivity	How difficult it is for current to flow through a material. Depends on: • Length of the wire • Cross-sectional area • Resistance. $\rho = RA/L$ Unit: Ωm The lower the resistivity, the better it is at conducting electricity. For Reference: Copper: 1.68×10^{-8} Ωm
Semiconductor	A group of materials that arent as good as conducting as metals, however, if more energy is supplied, the resistance lowers ➔ more charge carriers are released.
Superconductor	A metal that can be cooled, and the resistivity is reduced. There is no resistivity below the critical. The main uses are for strong electromagnets, power cables with no energy loss and fast electronic circuits with minimal energy loss.
Power (P/W)	The rate of transfer of energy. $1W = 1JS^{-1}$ **$P = E/t = IV = V^2/R = I^2R$**
Energy (E/J)	**$E = ItV = V^2t/R = I^2Rt$** kWh ➔ J kWh x 3.6×10^6

Electricity (cont)

Electromotive Force (e.m.f.)	The amount of electrical energy the battery provides and transfers to each coulomb of charge. $\varepsilon = E/Q$
Internal Resistance	The resistance inside cells. $\varepsilon = I(R + r)$
Kirchhoff's First Law	The total current entering a junction is equal to the total current leaving it, i.e. current is split when it reaches a junction
Kirchhoff's Second Law	The total emf of a series circuit, equals the sum of the pd across each component, i.e. pd is split between components in series but not parallel. $\varepsilon = \Sigma IR$
Resistance across Circuits	Series: $R_T = R_1 + R_2 + R_3 + ...$ Parallel: $1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + ...$
Potential Divider	A circuit with a voltage source and resistors in series. The voltage of one of the resisitors can vary and therefore be used to detect certain changes when thermistors and LDRs are used.

Gravitational Fields

Force Field	A region in which a body experiences a non-contact force.
Newtons Law of Gravitation	The force a body experiences due to gravity is dependant on its weight, the weight of the object exerting the force and the distance between them ➔ An inverse square law. **$F = GmM/r^2$** **NB** The result of this is the magnitude of the force, the direction is **always** towards the centre of the mass causing the gravitational force.

Gravitational Fields (cont)

Gravitational Field Strength	The force per unit mass, depending on the location of the body in a field. g = F/m Also a vector quantity, directed towards the centre of the mass causing the force. **g = -ΔV/Δr**
Earth's g	≈ 9.81 Nkg^{-1}
Radial Field	Point masses have a radial gravitational field (such as planets): **g = GM/r^2**
Gravitational Potential	The gravitational potential energy that a unit mass would have. It is negative on the surface of a mass and increases with the distance from the mass. It can also be considered as the energy required to fully escape the body's gravitational pull **V = -GM/r**
Gravitational Potential Difference	The energy required to move a unit mass. When an object is moved, work is done against gravity ➔ **ΔW = mΔV**
Equipotentials	Lines/Planes that join points of equal gravitational potential ➔ similar to contour lines on maps. Along these lines both ΔV and ΔW are zero, the objects energy isn't changing.
Satellite	Are smaller objects orbiting a larger object, they are kept in orbit by the force due to the larger body's gravitational field. In terms of planets ➔ Orbits are ≈ circular, therefore circular motion equations apply.

Gravitational Fields (cont)

Orbital Period Proportionality	**$T^2 \propto r^3$** **PROOF** • Combine F=mv^2/r and F = GmM/r^2 ➔ Solve for v • T = 2πr/v 🡐 Sub in v
Escape Velocity	The minimum speed an powered object needs to leave the gravitational field of a planet
Synchronous Orbit	When an orbiting object has an orbital period equal to the rotational period of the object its orbiting
Geostationary Orbit	An satellite in orbit of a body that remains in the same place ➔ it has the same time period. It would have to be over the equator to be a true geostationary orbit
Low Orbiting Satellite	Satellites that orbit between 180 and 2000 km above Earth. They are designed for communication and as they are low-orbit, they're cheaper to launch and require less powerful transmitters.

EM Radiation and Quantum

Photoelectric Effect	The emission of electrons from the surface of a metal in response to an incidence light, where the frequency of the incidence light is above that of the metals threshold frequency.
Threshold Frequency	The lowest frequency of light that can cause electrons to be emitted from the surface of a metal.
Work Function	The minimum quantity of energy which is required to remove an electron to infinity from the surface of a given solid, usually a metal. Φ = hf_0

EM Radiation and Quantum (cont)

Maximum Kinetic Energy	The energy a photon is carrying minus any other energy loses. These energy loses explain the range of kinetic energies of the photons. The max is equal to hf, with no energy loss. $hf = \Phi + 1/2(m)(v_{max})^2$
Stopping Potential	The potential difference required to stop the fastest moving electrons travelling at $E_{k(max)}$ $eV_s = E_{k(max)}$
Electron Volt	The kinetic energy carried by an electron after it has been accelerated from rest to a pd of 1 V. $1eV = 1.6 \times 10^{-19}$ J
Ground State	The lowest energy level of an atom/electron inside an atom.
Excitation	The movement of an electron to a higher level in an atom, requiring energy. $\Delta E = E_1 - E_2 = hf$
De-Excitation	An electron moving towards ground state releasing energy equal to the difference between the states in the form of a photon.
Fluorescent Tubes	The tubes contain mercury vapour, when a high voltage is passed across, producing free electrons, which collide with the mercury electrons exciting them. When they return to the ground state, they release a photon in the UV range. These then collide with the tubes phosphorus coating exciting it's electrons, and then when they return to the ground state they release photons in the visible light range
Line-Emission Spectra	A series of bright lines against a black background, with each line corresponding to a wavelength of light.

EM Radiation and Quantum (cont)

Line-Absorption Spectra	When light with a continuous spectrum of energy (white light) pass through a cool gas. Most of the electrons will stay in their ground states but some will be absorbed and excite them to higher states, these photons are then missing from the spectrum causing black lines on the continuous spectrum.
Diffraction	When a beam of light passes through a narrow gap and spreads out.
Wave-Particle Duality	An entity behaving with both particle and wave-like behaviour. Light has a relationship between wavelength and momentum: DeBroglie's Wavelength: $\lambda = h/mv$
Electron Diffraction	When electrons are accelerated and sent through a graphite crystal, they pass through the spaces between the atoms producing a diffraction pattern

Waves

Reflection	When a wave is bounced back when hitting a boundary
Refraction	When a wave changes direction as it enters a different boundary medium. The change in direction is as a result of the wave changing speed in the new medium
Diffraction	When a wave spreads out as it passes through a gap or around a obstacle.
Displacement (x/m)	The distance a wave has moved from its undisturbed position/its starting point. It is a vector quantity
Amplitude (A/m)	The maximum magnitude of displacement.
Wavelength (λ/m)	The length of one whole oscillation of the wave.

Waves (cont)	
Period (T/s)	The time taken for a whole wave cycle. T = 1/f
Frequency (f/Hz)	The number of whole waves per second, passing a given point. f = 1/T
Phase	A measurement of the position if a certain point along the wave cycle
Phase Difference	The amount by which one wave differs from another
Wave Speed	c = fλ
Transverse Wave	The displacement of the particles/field is at a right angle to the direction of energy transfer. e.g. a spring shaking up and down as displacement ↕ and energy transfer is ➞
Longitudinal Wave	The displacement of the particles/fields is along the line of energy transfer
Polarisation	A wave passing through a filter resulting in a polarised wave that oscillates in one direction only. 2 polarising filters at right angles blocks all light as it blocks both directions. Polarising filters are common sunglasses
Glare Reduction	Polarising filters reduces the amount of reflected light therefore reducing the intensity of the light on your eyes
TV Signals	TV signals are polarised by the rod orientation on the transmitting aerial. If the rods are lined up, you receive a good signal.
Superpostion	When 2 waves pass through each, at the instance where the wave cross, the displacement is combined, then each wave continues.

Waves (cont)	
Constructive Interference	When 2 waves meet and their displacements are in the same direction, the displacements combine to give a bigger one.
Destructive Interference	When 2 waves meet and their displacement is in opposite directions, they cancel out 'destroying' the displacement. The displacement of the combined wave is the sum of the individual displacements.
Exactly Out of Phase	When 2 points on a wave are a odd multiple of 180°/Π apart.
In phase	When the phase difference of 2 points is 0 or a multiple of 360°/2Π.
Stationary Wave	The superposition of 2 progressive waves with the same frequency/wavelength and amplitude moving in **opposite** directions
Node	A point on a stationary wave where no movement occurs - zero amplitude. There is total destructive interference.
Antinode	Points on a stationary wave with maximum amplitude - constructive interference
Resonant Frequency	When the stationary wave produced has an exact number of half-wavelengths
First Harmonic	When the stationary wave is at its lowest possible frequency - a single loop with one antinode and a node at each end. To find the freq of the nth harmonic, multiply the 1st harmonics freq. by n. **f = 1/2l x sqrt(T/μ)** where μ is the mass per unit length, T is the tension in the string and l is the length of the vibrating string.
Second Harmonic	Twice the frequency of the 1st harmonic. With 2 loops, 2 antinodes and 3 nodes (one in the center)

Waves (cont)

Amount of Diffraction	When a wave is passed through a narrow gap. Gap > Wavelength ➔ No diffraction Gap = n x Wavelength ➔ Minimal Diffraction Gap = Wavelength ➔ Maximum Diffraction
Monochromatic Light	Light of a signal wavelength/frequency and therefore a single colour. Best for producing clear diffraction patterns.
White Light Diffraction	When white light is diffracted, the different wavelengths of light diffract by different amounts. The result is a diffraction pattern of spectra instead of single coloured fringes
Two-Souce Interference	When waves from 2 sources interfere to produce a pattern. In order to get a clear pattern, the sources must be monochromatic and coherant
Coherancy	If the waves produce have the same wavelength/frequency **and** have a fixed phase difference.
Double-Slit Formula	Young's double-slit formula relate a waves fringe spacing (w/m), its wavelength(λ/m), the slit separation(s/m) and the distance from the screen(D/m) into a single formula $w = \lambda D/s$

Waves (cont)

Diffraction Grating	Lots of equally spaced slits very close together, produces a sharp interference pattern, therefore allowing more accurate measurements. The formula relates the distance between slits (d/m), the angle to the normal (θ/°), the wavelength (λ/m) and the order of maximum(n) $d\sin(\theta) = n\lambda$ The order of maximum is the number of bright spots away from the central spot (which has order 0)
Refractive Index	A measure of how optically dense a material is - the more optically dense, the higher refractive index. $n = c/c_s$ where c is the speed of light and c_s is the speed of light in the material. **Common Refractive Indexes** Vacuum = 1 Glass ≈ 1.5 Water ≈ 1.33 At a boundary: $_1n_2 = c_1/c_2 = n_2 / n_1$ The relative refractive index from material 1 to material 2. Note when using the refractive indexes of the materials its 2/1 rather than 1/2 with the speeds.
Snells Law	$n_1\sin(\theta_1) = n_2\sin(\theta_2)$ When a ray of light travels from one refractive medium to another.
Critical Angle	The angle of incidence at which the angle of refraction = 90° i.e. $\sin(\theta_{crit}) = n_2/n_1$ where $n_1>n_2$
Total Internal Reflection	When all light is completely reflected back into a medium at a boundary with another medium instead of being refracted. Occurs when $\theta_i > \theta_{crit}$

Waves (cont)

Optical Fibre	A very thin flexible tube of glass/plastic fibre in which light signals are carried across long distances and around corners by applying TIR. The fibres are surrounded by a cladding with a high refractive index and a core of a lower refractive index. The light is refracted where the mediums meet and travels along the fibre.
Signal Absorbtion	When some of the signals energy is absorbed by the material of the fibre. The final amplitude is reduced.
Signal Dispersion	When the final pulse is broader than expected, which can cause information loss as it may overlap with another signal.
Modal Dispersion	Light entering at different angles and taking different paths, resulting in signals arriving in the wrong order ➔ Single-mode fibre is used to prevent this - light is only allowed to folllow a very narrow path.
Material Dispersion	Different amounts of dispersion depending on wavelength. ➔ Monochromatic light prevents this.

Nuclear

Rutherford Scattering	An experiment that proved the current model of the atom ➔ that it is mostly empty space. Rutherford set up an experiment, with an alpha emitter pointed at gold foil. He observed the deflection of the particles and it showed that atoms have a concentrated mass at the centre and are mostly empty space, which disproved the plum-pudding model which was accepted previously. It showed that: • Atoms = mostly empty space • Nucleus has a large positive charge, as some of the +ve charged alpha particles are repelled and deflected • Nucleus must be tiny due to few particles being deflected by an angle > 90° • Mass must be concentrated in the nucleus

Nuclear (cont)

Distance of Closest Approach	$E_k = E_{elec} = Q_{nucleus}q_{alpha}/4\pi\varepsilon_0 r$ where r is the distance of closest approach
Electron Diffraction	λ≈hc/E where the first minimum occurs at: sinθ ≈ 1.22λ/2R
Nuclear Radius	$R = R_0A^{1/3}$
Alpha Decay (α)	Charge(rel): +2 Mass(u): 4 Penetration: low Ionising: high Speed: slow Affected by mag. field: y Stopped by: paper/~10cm air Used for: Smoke alarms ➔ if the particles cant reach the detector, the smoke must be stopping them
Beta Decay(β^±)	Charge(rel): ±1 Mass(u): n/a Penetration: mid Ionising: weak Speed: fast Affected by mag. field: y Stopped by: ~3mm of aluminium Used for: PET Scanners, In production of metals ➔ the levels penetrating through the metal can be used to control the thickness.
Gamma Decay(γ)	Charge(rel): 0 Mass(u): 0 Penetration: low Ionising: very weak Speed: c (speed of light) Affected by mag. field: n Stopped by: several cm of lead. Used for: PET Scanners ➔ produced through annihilation, cancer treatment.

Nuclear (cont)

Background Radiation	The low level of radiation that always exists. Must be taken into account when measuring radiation.
Sources of Background Rad.	• The Air ➔ Radioactive radon gas released from rocks • Ground/Buildings ➔ Nearly all rock contains radioactive materials • Cosmic Radiation ➔ nuclear radiation from particle collisions due to cosmic rays • Living things ➔ living things are made of carbon, some of which is radioactive carbon-14 • Man-Made ➔ Radiation from industrial/medical sources
Intensity	$I = k/x^2$ Intensity (Wm^{-2}) = constant of proportionality (W)/distance from source (m)
Radioactive Decay	It both spontaneous and random. **Spontaneous**: Decay is not affected by external factors **Random**: It cannot be predicted when the next decay occurs
Decay Constant	The probability of a specific nucleus decaying per unit time. It is a measure of how quickly a isotope will decay.
Activity (Bq)	The number of nuclei that will decay each second. $A = \lambda N$ where λ is the decay constant, and N is the number of unstable nuclei in the sample It can also be written as: $\Delta N/\Delta t = -\lambda N$ (ΔN is always a decreasing number hence the neg sign) $A = A_0 e^{-\lambda t}$ A_0 is the activity at t=0

Nuclear (cont)

Number of unstable Nuclei (N)	$N = N_0 e^{-\lambda t}$ where N_0 is the original number of the unstable nuclei $N = nN_A$ where n is the number of moles and N_A is Avogadro's constant
Half-Life ($T_{1/2}$)	The average time the isotope takes for the number of nuclei to halve. **$T_{1/2} = \ln 2/\lambda$** (Derived from $N = N_0 e^{-\lambda t}$)
Uses of Radiation	• Carbon Dating ➔ Using the amount of C-14 left in the organic material. Problems are that the material may have been contaminated, high background count, uncertainty in c-14 in the past and sample size may be too small • Medical Diagnosis ➔ Tracers that emit radiation to track things in the body
Instability	Nuclei are unstable when: • Too many/not enough neutrons • Too many nucleons • Too much energy If they nuclei lies on the N=Z line they are generally stable. If they lie above, they undergo β^- decay, if they lie below, the undergo β^+ decay. If they have a Z number of over ~82 (Protons) they undergo α decay.
Mass Defect	The mass of a nucleus is less than the mass of its constituents. This energy difference is the mass defect and is lost to energy as **$E = mc^2$**, energy and mass are equivalent.
Binding Energy	If you were to pull a nucleus apart, this binding energy would be the energy required to do so, equal to the energy released when the nucleus formed.

Nuclear (cont)

Average Binding Energy	Average Binding energy per nucleon = Binding Energy/Nucleon number
Nuclear Fission	When large **unstable** nuclei randomly split into smaller more stable nuclei. Energy is released as the smaller nuclei have a higher avg. binding energy **per nucleon**
Nuclear Fusion	When 2 smaller nuclei combine to form a larger nuclei. **A lot** of energy is released because the new heavier nucleus has a higher avg. binding energy (if the 2 original nuclei are light enough). This is the energy that keeps stars burning

Nuclear (cont)

Nuclear Fission Reactors	• **Control Rods** ➔ Usually made of carbon, they are lowered and raised to control the rate of fission. The amount of fuel required to produce one fission per fission is the critical mass. Any less (sub-critical) then the reaction will eventually fizzle out. Any more, and the reactor could go into meltdown, which is why control rods are used. • **Moderator** ➔ Fuel rods are placed in the moderator, this slows down/absorbs neutrons to control the rate. The choice of moderator needs to slow down the neutrons enough to slow down neutrons enough to keep the rate of fission steady. It slows down neutrons through elastic collisions, a moderator with a similar nucleon-mass to the neutrons. • **Coolant** ➔ is sent around the reactor to remove heat produced by the fissio. The material is either liquid or gas at room temp. Often it is the same water (heavy-water) as the moderator and can be used to make steam and turn turbines. • **Shielding** ➔ Reactors are surrounded by thick concrete, which shields and protects from radiation escaping and anyone working there. • **Emergency Shut-down** ➔ All reactors have an emergency shutdown where the control rods are completely lowered into the reactor, thus absorbing all the neutrons produced and slowing the reaction down as quickly as possible. • **Waste** ➔ Unused uranium only produces α so can be easily contained. Spent uranium however emit β & γ radiation. Once removed from the reactor they are cooled and ten stored in sealed containers until the activity is at a low enough level.

Further Mechanics

Radian	Objects in circular motion travel through angles, mostly measured in radians. Rads to Deg: Angle in deg x $\pi/180$
Angular Speed	The angle an object rotates through per second. $\omega = \theta/t = v/r = 2\pi/T = 2\pi f$
Frequency	The number of revolutions per second. $f = 1/T$
Time Period	The time taken for a complete revolution.
Centripetal Acceleration	Objects travelling in a circle are accelerating as their velocity is changing constantly. The acceleration is **always** acting towards the centre of the circle. $a = v^2/r = \omega^2 r$
Centripetal Force	Is the resolved force which is always directed towards the centre of the circle. $F = mv^2/r = m\omega^2 r$
Simple Harmonic Motion	An object undergoing SHM is oscillating to and fro, either side of an equilibrium position. It is defined as **An oscillation in which the acceleration of an object is directly proportional to its displacement, which is *always* directed towards the equilibrium position**
Displacement (x)	Displacement varies as a cosine/sine wave with a maximum value of A (Amplitude) **$x = A\cos(\omega t)$**
Velocity (v)	Is the gradient of the displacement time graph. Its maximum value is **ωA** **$v = \pm\omega$ x sqrt(A^2 x^2)** **$v_{max} = \omega A$**

Further Mechanics (cont)

Acceleration (a)	Is the gradient of the velocity time graph. Its maximum value is **$\omega^2 A$** **$a = \omega^2 x$**
Mass-Spring System	A mass on a spring is a **simple harmonic oscillator**. When the mass is pulled/pushed from the equilibrium position, there is a force directed back towards the equilibrium position. $F = k\Delta L$ where k is the spring constant and ΔL is the displacement. The Time period for a M-S System is given by: $T = 2\pi$ x sqrt(m/k)
Pendulum	A pendulum is an example of a Simple Harmonic Oscillator. The time period for a pendulum is given by: $T = 2\pi$ x sqrt(l/g)
Free Vibration	Free vibrations involve no transfer of energy to/from the surroundings. If a mass-spring system is stretched, it will oscillate at its natural frequency f_n.
Forced Vibration	Forced Vibration occurs when there is an external driving force. A system can be forced to vibrate by a periodic external force. This is called the driving frequency, f_d. $f_d << f_n$ ➔ Both are in phase $f_d >> f_n$ ➔ The oscillator will **not** be able to keep up and will end up out of control. i.e. completely out of phase.

Further Mechanics (cont)	
Resonance	As $f_d \rightarrow f_n$, the system gains more and more energy from the driving force, thus the amplitude rapidly increases. The system is now considered to be resonating. At resonance, the phase difference between the driver and the oscillator is 90°.
Damping	Any oscillating system loses energy to its surroundings ➔ damping. System are also deliberately damped to stop them oscillating or minimise resonance. **Light Damping** ➔ Take a long time for oscillation to stop, the amplitude is decreased slowly. Displacement-Time Graph: sharp peak. **Heavy Damping** ➔ The amplitude decreases rapidly, and oscillation takes much less time to stop.Displacement-Time Graph: flat peak. **Critical Damping** ➔ Oscillation is stopped in the shortest amount of time possible. **Over Damping** ➔ Systems with even heavier damping, they take longer to reach equilibrium than a critically damped system.