Chapter 1. Measurement

Apparatus:	Accuracy:
Vernier calipers:	0.1mm/0.01cm
Metre rule:	0.1cm/1 mm
Micrometer screw gauge:	0.01mm
Voltmeter/Ammeter:	Half smallest division

Chapter 2. Kinematics

Displacement:	Straight-line distance from one object to another
Distance:	How far something moves (Not necessarily straight)
Speed:	Distance/Time
Velocity:	Displacement/Time
Acceleration:	Velocity/Time

Graphs of motion of objects:

Non-moving object:	Displacement remains constant, Velocity at 0, Acceleration at 0
Object at uniform velocity of 1m/s:	Displacement increases by 1m every second, Velocity remains constant at 1m/s, Acceleration at 0
Object at increasing non-uniform velocity/acceleration:	Displacement increases at increasing rate, Velocity increases at increasing rate, Acceleration increases at increasing rate
Object at decreasing non-uniform velocity/acceleration:	Displacement increases at decreasing rate, Velocity increases at decreasing rate, Acceleration decreases at decreasing rate
Object at uniform acceleration:	Displacement increases, Velocity increases at constant rate, Acceleration constant
Object at uniform deceleration:	Displacement increases, Velocity decreases at constant rate, Deceleration constant

For velocity/speed-time graphs, displacement/distance travelled is the area under the graph.

Air resistance: When an object’s speed increases, air resistance increases. When air resistance = weight of object, object reaches **Terminal Velocity**, where acceleration = **0**

Chapter 3. Forces

Drawing of vector diagrams: No way of drawing it here so do it yourself

Newton's 1st law: Objects at rest or motion will stay in that way until a resultant force acts on it.

Newton's 2nd law: When a resultant force acts on an object of constant mass, the object will accelerate in the direction of the resultant force. The product of the mass and acceleration of the object gives the resultant force. (F = m(kg)a)

Newton's 3rd law: When one body exerts a force AB on another body, the body will exert an equal and opposite force BA on the first body. (Action-Reaction pairs)

Chapter 4. Mass, Weight, Density

Mass: Does not change with location. Measured in kg.

Weight: Changes based on gravitational force. Measured in N. (Weight is a force)

Inertia: The reluctance of an object to change its state of rest or motion due to its mass. The larger the mass of an object, the harder it is for the object to start moving, slow down, move faster or stop.

Density: The mass of an object per unit volume. (Formula: Mass/Volume)

Chapter 5. Turning effect of Forces

Moment of a force: The product of a force F and the perpendicular distance from the pivot to the line of action of force. (FxD)

Principle of Moments: When a body is in equilibrium, the sum of clockwise moments about a pivot is equal to the sum of anticlockwise moments about the same pivot.

Centre of Gravity: The point on an object where all its weight acts on. For objects of uniform density, this is the geometrical centre of the object.

Stability: The measure of an object's ability to return to its original position after it is slightly displaced.

Types of equilibrium:

Stable Equilibrium:	Unstable Equilibrium:	Neutral Equilibrium:
When the object is slightly tilted, its centre of gravity rises before returning to its original height. As the line of action about its weight still lies within its base, the moment of its weight about the point of contact causes the cone to return to its original position.	When the object is slightly tilted, its centre of gravity drops and the line of action about its weight lies outside its base. The moment of its weight about the contact point causes the cone to topple.	When the object is slightly tilted, its centre of gravity remains at the same height. The lines of action through its weight and the contact point coincide, thus the moment about its weight above the contact point is 0, and the object stays in its displaced position,

Chapter 6. Work, Energy, Power

Energy: The capacity to do work. Measured in Joules (J)

Types of energy:	Definition:	Examples:	Formula (if any)
Kinetic energy	Energy of an object due to its motion	Wind, rolling ball	$\frac{1}{2} mv^2$ (m= mass in kg, v= speed of body)
Chemical potential energy	Energy stored in a body due to position of atoms or electrons in the body	Food, batteries	N.A. (not learnt yet)
Elastic potential energy	Energy stored in a body due to elastic deformation	Spring, rubber band	N.A. (not learnt yet)
Gravitational potential energy	Energy stored in a body due to its height from the ground	Bouncing ball going up and down, lifted object	mgh (m= mass in kg, g= gravitational force in N, h= height of object in m
Electrical energy	Energy of an electric charge due to its motion and position	Electricity	Covered in more detail in chapter 17 and 19
Light	An electromagnetic wave visible to the eye	Light bulbs, LEDs	N.A. (not learnt yet)
Thermal energy	Energy stored in a body due to its temperature	Fire	$mc\Delta\theta$ (m = mass of substance, c = specific heat capacity of substance, $\Delta\theta$ = change in temperature)

Nuclear energy	Energy released during a nuclear reaction	Nuclear power plants	N.A. (not learnt yet)

Principle of conservation of energy: Energy cannot be created or destroyed, but can be converted from one more to another. The total energy in an isolated system remains constant.

Efficiency: Useful energy output / total energy input x 100%

Work done (in J): Constant force (in N) x distance moved by object in direction of force (in m)

Power (in W): The rate of work done (work done / time)

Chapter 7. Pressure

Pressure: The measure of force acting per unit area. Measured in P (pascals) or force (in N) / area (in m^2)

Water pressure: Calculated with h$\boldsymbol{P}$g (h= height in m, $\boldsymbol{P}$= density in kg/m^3, g =gravitational field strength in N/kg

Pascal's principle: When pressure is applied to an enclosed liquid, the pressure is transmitted equally to all parts of the liquid.

Chapter 8. Temperature

Thermometric substance: A substance that increases its volume directly proportional to the temperature (e.g. mercury, alcohol)

Ice point: Used as the lower fixed point of the thermometer. It is the temperature of pure melting ice at 1 atmosphere and its value is 0℃. To determine the ice point, place the bulb and lower end of the thermometer into a funnel containing pure melting ice. When the level of the substance remains constant, make a marking on the thermometer. This is the ice point.

Steam point: Used as the upper fixed point of the thermometer. It is the temperature of water boiling at one atmosphere and its value is 100℃. To determine the steam point, place the bulb of the thermometer just above boiling water. When the level of the substance remains constant, make a marking on the thermometer. This is the steam point.

Calculating temperature with a thermometric substance thermometer/resistance thermometer: Use the formula $\theta = \frac{x\theta - x0}{x100 - x\theta} x100℃$, where θ is the unknown temperature and x is the length/resistance of the substance/wire at 0℃, θ℃ , and 100℃.

Calculating temperature with a thermocouple: Use the formula $\epsilon \propto \Delta\theta$, where ϵ is the e.m.f. produced in V and $\Delta\theta$ is the temperature difference between the junctions in ℃.

Chapter 9. Kinetic Model of Matter

Kinetic model of matter: The kinetic model of matter states that the tiny particles that make up matter are always in continuous random motion.

State of matter:	Properties:	Particle arrangement:	Particle movement:
Solid	Fixed shape and volume (Relatively) High density Incompressible	Closely packed together in a regular pattern occupying minimal space Large number of particles per unit volume (Hence high densities)	Particles vibrate about fixed positions and they are held in position by very strong attractive forces between particles (Hence they have fixed volume and shape)
Liquid	Fixed volume but no fixed shape (Relatively) High density Incompressible	Randomly arranged with the particles slightly further apart than in solids Slightly smaller number of particles per unit volume compared to solids (Hence relatively high densities)	Particles are free to move about within the liquid but there are attractive forces between the particles (Hence they have fixed volume but no fixed shape)
Gas	No fixed shape and volume (Relatively)Low density Compressible	Randomly arranged and far apart from one another Small number of particles per unit volume (Hence low densities)	Particles have very little attractive forces between them and move about randomly at high speeds, occupying any available space (Hence they have no fixed shape and volume and are compressible)

Brownian motion: The random movement of particles suspended in a fluid. When the temperature increases, the particles in the fluid move faster and more vigorously.

Pressure of a gas: Because the air particles are in continuous random motion, they collide against the walls of the container. By Newton’s Third Law, this creates an equal but opposite force on the molecule. As many such collisions occur, an average force is exerted by the molecules on the walls of a container, hence there is pressure from the gas.

Pressure-Temperature relationship in gases (Directly proportional:$p \propto T$) : As the temperature increases, the pressure of the gas increases. When the temperature rises, the air particles gain more heat energy and hence more kinetic energy. They then bombard the walls of the container more vigorously and frequently, causing the average force exerted on the walls of the container by the air particles to increase. Hence, since the volume of the container is fixed, the pressure of the gas increases.

Pressure-Volume relationship of a gas (Inversely proportional: $p \propto \frac{1}{v}$): As the volume of the gas decreases, the pressure of the gas increases. When the volume of the gas decreases, the number of molecules per unit volume increases. Hence, the gas particles bombard the walls of the container more frequently, increasing the average force exerted on the walls and hence the pressure of the gas.

Volume-Temperature relationship of a gas (Directly proportional: $V \propto T$): As the temperature of the gas increases, the volume of the gas increases. When the temperature of the gas increases, the air particles gain more heat energy and hence more kinetic energy. They then bombard the walls of the container more vigorously and frequently, causing the average force exerted on the walls of the container by the air particles to increase. This creates an upwards force of the walls of the container, expanding the volume of the container and the volume of the gas.

Chapter 10. Transfer of Thermal Energy

Flow of thermal energy: Thermal energy always flows from a region of higher temperature to a region of lower temperature. Net flow of thermal energy only occurs when there is a difference in temperature.

Conduction: The transfer of thermal energy through a medium without any flow of the medium.

Conduction in non-metals: In non-metals, the particles at the heated end vibrate vigorously around their fixed positions. They collide with neighbouring particles, making them vibrate more vigorously and makes them become hotter. This continues until the whole object is the same temperature.

Conduction in metals: In metals, the same process as in non-metals (see above) occurs. However, free electron diffusion also occurs in metals, where free electrons in the metal gain thermal energy and hence kinetic energy. These electrons can move freely throughout the metal, hence they reach the cooler ends of the metal and transmit thermal energy to the particles there via the motion of the free electrons. This continues until the whole object is the same temperature.

Conduction in liquids and gases: As the particles in liquids and gases are not as close together as those in solids, there are less collisions between the particles in liquids and gases than in solids, hence they are poor conductors of heat.

Convection: The transfer of thermal energy by means of convection currents in a liquid or gas, due to a difference in density. When a liquid or gas is heated, it increases in volume, hence becoming less dense. The heated liquid or gas then rises up to the top. Since the upper region of the liquid or gas is cooler, it is denser and therefore it sinks. This sets up a convection current which continues until the whole liquid or gas is at the same temperature.

Convection cannot occur in solids as it involves the bulk movement of the fluid that carries the thermal energy.

Radiation: The transfer of thermal energy in the form of electromagnetic waves such as infrared radiation without the aid of a medium. All objects and surfaces emit and absorb infrared radiation. Dull and black surfaces emit and absorb infrared radiation at a faster rate than shiny and silvery surfaces. The higher the surface temperature of the object, the faster the rate of emitting infrared radiation is. The higher the surface area of an object, the faster the rate of emitting and absorbing infrared radiation is.

Chapter 11. Thermal Properties of Matter

Internal energy: The total energy of all the particles in a substance.

Heat capacity (C): The amount of thermal energy required to raise the temperature by 1 K or 1 ℃. It is represented by the formula C = $\frac{Q}{\Delta\boldsymbol{\theta}}$, where Q is the thermal energy required in joules (J) and $\Delta\boldsymbol{\theta}$ is the change in temperature in ℃.

Specific heat capacity (c): The amount of thermal energy needed to raise the temperature of a unit mass of a substance by 1 K or 1 ℃. It is represented by the formula c = $(\frac{1}{m})\frac{Q}{\Delta\boldsymbol{\theta}}$, where m is the mass of the substance in kilograms (Kg), Q is the thermal energy required in joules (J) and $\Delta\boldsymbol{\theta}$ is the change in temperature in ℃.

Melting: During melting, thermal energy is absorbed to break the strong bonds between particles, allowing them to move out of their fixed positions and be further from one another, causing the change in state from a solid to a liquid.

Freezing: During freezing, thermal energy is released to form strong intermolecular bonds, causing them to be held in their fixed positions and be closer to one another, causing the change in state from a liquid to a solid.

Boiling: During boiling, thermal energy is absorbed to break the strong bonds between particles, allowing them to move about randomly and be further from one another, causing the change in state from a liquid to a gas.

Condensation: During condensation, thermal energy is released to form bonds between particles, causing them to be closer to one another, causing the change in state from a gas to a liquid.

Latent heat of fusion(L_f): It is the amount of thermal energy needed to change a substance from the solid state to a liquid state without a change in temperature. It is measured in joules (J).

Specific latent heat of fusion($l_f = L_f/m$): It is the amount of thermal energy needed to change a unit mass (m) of a substance from the solid state to a liquid state without a change in temperature. It is measured in joules per kilogram (J/Kg).

Latent heat of vaporisation(L_v): It is the amount of thermal energy needed to change a substance from the liquid state to a gaseous state without a change in temperature. It is measured in joules (J).

Specific latent heat of vaporisation($l_v = L_v/m$): It is the amount of thermal energy needed to change a unit mass (m) of a substance from the liquid state to a gaseous state without a change in temperature. It is measured in joules per kilogram (J/Kg).

Evaporation: In a liquid, the molecules are always moving randomly at different speeds. At the surface of the liquid, the liquid molecules with enough energy to overcome the downward attractive forces of the other liquid molecules and the atmospheric pressure escape into the atmosphere. The remaining molecules have less kinetic energy, hence the average kinetic energy in the liquid decreases, thus the average temperature in the liquid decreases.

Factors affecting the rate of evaporation:

- Temperature: The higher the temperature, the faster the rate of evaporation. A warmer liquid means more molecules have the energy to escape the liquid.
- Humidity: The higher the humidity, the slower the rate of evaporation. This is because less water vapour is able to evaporate at high humidities.
- Surface area of the liquid. The larger the surface area of the liquid, the faster the rate of evaporation. This is because evaporation only occurs at the surface of the liquid, hence more molecules can escape from the liquid.
- Boiling point of the liquid: The lower the boiling point, the faster the rate of evaporation. This is because the bonds between liquid particles are weaker when the boiling point is low, hence less kinetic energy is needed to escape the liquid.
- Movement of air: The faster the surrounding air, the faster the rate of evaporation. This is because the moving air removes the liquid molecules as soon as they escape from the liquid surface, thus making the surrounding air less humid.
- Pressure: As the atmospheric pressure decreases, the rate of evaporation is faster. This means that less kinetic energy is needed for the molecules to escape from the liquid.

Chapter 12. Light

Laws of reflection:

- The first law of reflection states that the incident ray, reflected ray and the normal at the point of incidence all lie on the same plane.
- The second law of reflection states that the angle of incidence is equal to the angle of reflection.

Refraction: The bending of light as it passes from one optical medium to another.

Laws of refraction:

- The first law of refraction states that the incident ray, refracted ray and the normal all lie on the same plane.
- The second law of refraction states that for two given media, the ratio of the sine of the angle of incidence i to the sine of the angle of refraction r is a constant. This is known as Snell's Law (Formula: sin(i) / sin(r) = a constant)

Refractive index: The ratio of the speed of light in a vacuum to the speed of light in the medium.

Critical angle: The angle of incidence in an optically denser medium for which the angle of refraction in the optically less dense medium is 90°(Calculation: $\sin^{-1}$(1/refractive index)).

Total internal reflection: The complete reflection of a light ray inside an optically denser medium at its boundary with an optically less dense medium.

Focal length: The distance between the optical centre and the focal point.

Chapter 13. Waves

Properties of waves:

- Made up of periodic motion (motion repeated at regular intervals).
- The source of a wave is a vibration or an oscillation.
- Waves transfer energy from one point to another.
- Waves transfer energy without transferring the medium.

Transverse waves: Waves that travel perpendicular to the direction of the vibration.

Longitudinal waves: Waves that travel parallel to the direction of the vibration.

Parts of a transverse wave:

- Amplitude: The maximum displacement of a point of a wave from its rest position. Its SI unit is metre (m).
- Crest: The highest point of a transverse wave.
- Trough: The lowest point of a transverse wave.
- Phase: Points along a wave are in phase if they have the same direction of motion, speed, and displacement from their rest positions.
- Wavelength(λ): The shortest distance between any two points in phase. Its SI unit is metre (m).
- Period: The time needed for the wave to travel a distance equivalent to its wavelength. Its SI unit is second (s).
- Frequency: The number of complete waves produced per second. Its SI unit is hertz (Hz). Its formula is $f = 1/(\text{period})$.
- Wave speed: The distance travelled by a wave per second. Its SI unit is metres per second (m/s). Its formula is ($v = \lambda/(\text{period})$) or ($v = f\lambda$).

Chapter 14. Electromagnetic Waves

Properties of electromagnetic waves:

- Electromagnetic waves are all transverse waves.
- Electromagnetic waves can travel through a vacuum and do not need a medium to travel from one point to another.
- Electromagnetic waves transfer energy from one point to another.
- The wave speed equation ($v = f\lambda$) applies to all electromagnetic waves.

- When an electromagnetic wave travels from one medium to another, its speed and wavelength change but its frequency remains the same.
- Electromagnetic waves obey the laws of reflection and refraction.
- Electromagnetic waves carry no electric charge.
- All electromagnetic waves travel at the same speed of 3.0×10^8 m/s in a vacuum.

Type of electromagnetic wave:	Wavelength:	Frequency:	Use:
Radio waves:	3 m	10^8 Hz	Radio waves are used in radios as they have long wavelengths which travel around obstructions(buildings, hills) better than those of shorter wavelengths.
Microwaves:	3×10^{-2} m	10^{10} Hz	Microwaves are used in microwave ovens to transfer energy to the food that needs to be cooked.The microwaves penetrate the food, causing the water molecules within the food to vibrate vigorously and generate heat that eventually spreads throughout the food.
Infrared:	3×10^{-4} m	10^{12} Hz	The human body naturally gives off infrared radiation. Ear thermometers use this principle to measure body temperature by measuring the amount of infrared radiation emitted from the eardrum.
Visible light:	1×10^{-6} m	5×10^{14} Hz	Visible light is the light that allows people to see the things around them.
Ultraviolet:	1×10^{-8} m	3×10^{16} Hz	Ultraviolet (UV) radiation is used in sunbeds for artificial tanning. Overexposure of UV radiation may lead to premature aging and even skin cancer, thus the exposure to UV rays must be limited.
X-rays:	1×10^{-10} m	3×10^{18} Hz	X-rays have high frequencies and hence transfer high amounts of energy. This makes X-rays good for screening baggage in airports for potential threats efficiently and effectively.
Gamma rays:	1×10^{-12} m	3×10^{20} Hz	Gamma rays are the most energetic in the electromagnetic spectrum. Exposure to these rays can kill living cells, hence they are used in Gamma

			Knife surgery where gamma rays are focused onto a brain tumour to kill the tumour while leaving the other brain cells untouched.

Effects of electromagnetic waves:

- Exposure to ionising radiation (UV radiation, X-rays, and Gamma rays) can damage biological molecules like proteins or DNA and lead to abnormal patterns of cell division. Ionising radiation is radiation that has enough radiation to remove electrons from atoms or molecules, creating ions. This may cause cancer or a developing foetus to become deformed.
- Infrared heating. When something is cooking, heat can be felt if standing close to the flame. This is because the heat from the flame is infrared radiation that is absorbed by the skin and clothes, making one feel warm.

Chapter 15. Sound

Sound: A form of energy transferred from one point to another as a longitudinal wave. It is a series of compressions and rarefactions that are made out of compressed layers of the medium the sound is transmitted through. Sound requires a medium to travel from one point to another.

Range of audible (hearable) sounds for humans: 20 Hz - 20000 Hz (20KHz)

Ultrasound: Sound with frequencies above the upper limit of sounds that humans can hear (>20KHz)

Pitch: The higher the frequency of the sound wave, the higher the pitch.

Loudness: The higher the amplitude of the sound wave, the louder the sound.

Pure tone: A sound of a single frequency that has a sinusoidal (like sine/cosine graph type) waveform. Instruments like tuning forks produce such tones. Instruments like violins produce impure tones that do not have a sinusoidal waveform.

Chapter 16. Electrostatics

Positively charged objects: When number of negative charges (electrons) < number of positive charges (protons)

Negatively charged objects: When number of negative charges (electrons) > number of positive charges (protons)

Like charges **REPEL** and opposite charges **ATTRACT**

Electric charge: Measured in Coulombs (C)

	Electrical insulators:	Electrical conductors:
Motion of charged particles:	Not free to move about	Free to move about
Ability to conduct electricity:	Low	High
Method(s) of charging:	Friction (rubbing)	Induction
Charge after charging:	Depends on objects	With 2 conductors: Conductor nearest to rod is opposite charge of rod, conductor further from rod is same charge as rod. With 1 conductor: Charge of conductor is always opposite to charge of rod.

Charging by friction: At the beginning, both objects used are electrically neutral. When the two objects are rubbed together, the atoms at their surfaces are disturbed and some electrons from the surface of object A are transferred to object B. As object A loses electrons, it becomes positively charged. As object B gains electrons, it becomes negatively charged. (Note: Both objects must be insulators for this to work. This is because mobile electrons can be easily transferred to and away from conductors)

Charging two spheres by induction: Place two conductors (metal spheres) labelled A and B on insulating stand side to side such that they are touching each other. Bring a (negatively / positively) charged rod near (but not touching) sphere A. This causes the (electrons in both spheres to be repelled to the far end of sphere B./ the electrons in both spheres to be attracted to the side of sphere A facing the rod.) While holding the charged rod in place, pull sphere B away from sphere A. Remove the charged rod. Now, both spheres have an equal number of opposite charges. Both spheres have been charged by induction. (Note: If using a negatively charged rod, sphere A is positive while sphere B is negative. If using a positively charged rod, sphere A will be negative while sphere B will be positive.)

Charging one conductor by induction: Bring a (positively / negatively) charged rod near a conductor on an insulating stand. The free electrons in the conductor are (attracted to the side of the conductor nearest to the rod / repelled to the side of the conductor furthest away from the rod). Without removing the rod, earth the opposite end of the conductor by touching it with your hand. This (neutralises the positive charges on that end of the conductor / removes the free electrons from the conductor). Remove your hand from the conductor and then the charged rod. The (negative / positive) charges redistribute themselves throughout the conductor. The conductor is now (negatively / positively) charged.

Discharging charged insulators:

1. Discharging by heat:
    - Bring the charged insulator near a flame.
    - Intense heat from the flame ionises the nearby air particles.
    - These ions neutralise the excess charges on the charged insulator, and the insulator is discharged.

2. Discharging by humid conditions:
    - Moisten the air around the charged insulator.
    - Water molecules in the air are electrical conductors.
    - Excess charges on the charged insulator are transferred to the water molecules from the charged insulator.

Discharging charged conductors:

1. Earthing a negatively charged conductor:
    - Touch the conductor while being connected to the ground.
    - The excess electrons will flow away from the conductor to the ground.
2. Earthing a positively charged conductor:
    - Touch the conductor while being connected to the ground.
    - Electrons will flow from the ground to the conductor, to neutralise the excess positive charges.

Electric force: The attractive or repulsive force that electric charges exert on one another.

Electric field: A region in which an electric charge experiences an electric force.

Chapter 17. Current Electricity

Conventional current: ‘Flow’ of positive charges from the positive terminal to the negative terminal.

Electron flow: Flow of electrons from the negative terminal to the positive terminal.

Electric current: The rate of flow of an electric charge. (I (current in A) = Q (charge in C) / t (time taken in s))

Ammeter: Measures the current in a circuit. Connected in **series** to the rest of the circuit. (Reason: When circuit is in series, current is the same at all parts of circuit)

Electromotive force: The work done by the source in driving a complete charge around a complete circuit. (ε (Electromotive force in V) = W (Work Done in J) / Q (Amount of charge in C)

Voltmeter: Measures the voltage across one part of the circuit. Connected in **parallel** to the rest of the circuit. (Reason: When circuit is in parallel, voltage is the same at all parts of circuit)

Resistance: The ratio of the voltage across a component to the current flowing through it. (R (resistance in Ω) = V (voltage in V) / I (current in A)).

Ohm’s Law: The current passing through a metallic conductor is **directly proportional** to the potential difference across it, provided that physical conditions (like temperature) remain constant. Conductors that obey Ohm’s Law are known as ohmic conductors.

Non-ohmic conductors:

Non-ohmic conductor	Function	Description of graph
Filament lamp	Converts electricity to light and heat energy	As the current increases, the device generates more heat and thus increases their temperature. As temperature increases, the resistance of the filament lamp increases. (Resistance increases with temperature)
Semiconductor diode	A device that allows current to flow in one direction only	When the voltage is applied in the forward direction, the current flow is relatively high. This means that the resistance is low in the forward direction. When the voltage is applied in the reverse direction, there is almost no current flow. This means the resistance is very high in the reverse direction.

* The resistance of both ohmic and non=ohmic conductors generally increases with temperature.

The resistance of a conductor depends on 4 things:

1. Temperature: As temperature increases, resistance increases (Ohm's Law).
2. Material: Some materials are better conductors than others, and hence have lower resistance.
3. Length: When the length of a conductor is increased, its resistance increases proportionally. Hence, the resistance of a conductor is directly proportional to its length when the cross-sectional area and type of material are the same. (Formula: Resistance (R) ∝ Length (L)) ----(1)
4. Cross-sectional area: When the cross-sectional area of a conductor is increased, its resistance decreases proportionally. Hence, the resistance of a conductor is inversely proportional to its cross-sectional area when the length and type of material are the same. (Formula: Resistance (R) ∝ 1 / Cross-sectional area (A)) -----(2)

Comparing equations (1) and (2), we get the result (Resistance (R in Ω) = p (Resistivity, a fixed property of the wire's material, in Ωm) x (Length (L in m)) / (Cross-sectional area (A in m^2))

Rewriting the equation, we get p = RA/L. The unit of resistivity is the **Ohm metre** (Ωm).

Chapter 18. D.C. Circuits

Circuit:	Voltage:	Current:	Resistance:

Series:	Total voltage = sum of voltage across the circuit.	Current is constant throughout the circuit.	Effective resistance = sum of all the resistances.
Parallel:	Voltage is constant throughout the circuit.	Total current = sum of current across the circuit.	(Effective resistance)$^{-1}$ =(1 / R_1 + 1 / R_2 + ….. 1 / R_n)

Potential Divider Formula: V across R_2 = (Total V / Total R) x R_2.

Input transducers: Electronic devices that convert non-electrical energy to electrical energy.
- Thermistors: Resistors that resistances vary with temperature. As the temperature increases, its resistance decreases, and vice versa.
- Light-Dependent resistors (LDRs): A resistor that resistance decreases as the amount of light shining on it decreases, and vice versa.

Chapter 19. Practical Electricity

Power (in watts (W)) = Voltage (in V) x current (in A). It can also be expressed in the form I^2R(Resistance) or V^2/R.

Electrical energy (in J) = P x t (time in s) or VIt or I^2Rt or tV^2 / R.

Kilo-watt hour (kWh): The energy consumed by a 1kW device in 1 hour = 3.6 x10^6 J.

Dangers of electricity:
- Damaged insulation: When the insulation (usually non-conductors of electricity like rubber) that covers wires is damaged, causing the wires to become exposed which can cause electric shocks if touched.
- Overheating of cables: When the temperature of the wires gets too hot and causes a fire. This is usually caused by overloaded power sockets which have a large amount of current flowing through them, causing there to be a higher temperature and thus more heat. Another reason is the use of inappropriate wires, where the use of a thin wire when a thick wire should be used instead causes the thin wire to heat up to the point of causing a fire. (Reason: Chapter 18)
- Damp environments: As water is a good conductor of electricity, using damaged electrical appliances near water is likely to cause an electric shock.

Safety features of circuits:
- Circuit breakers: Safety devices that switch off the current in a circuit when large currents flow through them. They are connected to the **live wire** and can be reused.
- Fuses: Safety devices that act the same as a circuit breaker, except they cannot be reused. They have ratings of 1A, 2A, 3A, 5A, 10A, 13A.
- Switches: Devices designed to break or complete an electrical circuit. They should be fitted to the **live** wire of the appliance.
- Earthing: Using 3 wires in a circuit instead of just 2. The 3 wires are as follows:
  - Live wire: The wire that is connected to the main voltage. Its colour is brown.
  - Neutral wire: The wire that completes the circuit. Its colour is blue.

    - Earth wire: The wire connected to the metal casing of appliances to direct away current from exposed wires. Its colour is green and yellow. This wire is not needed for the appliance to function.
- 3-pin plug: Connects the appliance to the mains supply. It has a fuse in it to break the circuit if there is too much current flowing through it.
- Double insulation: For appliances that use 2-pin plugs, they use non-metallic casings to cover the electric cables and the internal components, protecting the user from electric shocks.

Chapter 20. Magnetism

Magnetic materials: Materials that can be attracted to a magnet. They are Iron, Nickel, Cobalt and Steel.

- Magnets are strongest at their poles. (Their magnetic effects are strongest there).
- When a freely suspended magnet comes to a rest, it will be in the north-south direction. (Facing towards the North pole).
- Like poles repel, unlike poles attract.

How to determine whether an object is a magnet:

- If the object is a magnet: When one end of the object is placed near a pole of a suspended bar magnet, the magnet will be repelled. If the object is attracted, place the other end of the object near the magnet. If repulsion occurs, the object is a magnet.
- If the object is made out of a magnetic material: Both ends of the object will be attracted by the magnet.
- If the object is a non-magnetic material: The magnet will remain stationary.

Magnetic induction: The process where an object made of a magnetic material becomes a magnet when it is near or in contact with a magnet.
Magnetic domains: A group of atomic magnets pointing in the same direction.

What happens during magnetism: In an unmagnetised bar, the magnetic domains point in random directions. There is no net magnetism since the domains cancel one another out. During magnetisation, magnetism is induced by aligning the domains. The magnetic domains all point in the same direction, producing a net magnetisation. The atomic magnets at both the ends are “free”, producing the effects of the N and S poles at the ends.

Methods of magnetising magnetic materials:

1. Stroking: Stroke the material from one end to the other in one direction with one of the poles of a permanent magnet. The stroking magnet should be lifted sufficiently high above the material between successive strokes. The pole produced at the end of the material where the strokes finish is opposite to the stroking pole used.
2. Electrical method: When a large **direct** current flows through coils of wire (a solenoid), a strong magnetic field is produced. This magnetic field aligns the magnetic domains in the material. After a period of time, the material will be magnetised. To determine the poles of the magnet, “grip” the solenoid with the right end. Curl the fingers in the direction of the current flow in the solenoid. The direction in which the extended thumb points is the direction of the north pole.

Methods of demagnetising magnetic materials:

1. Heating: Strongly heating a magnet and allowing it to cool in an east-west orientation will cause a magnet to lose its magnetism, as the atoms of the magnet vibrate vigorously when heated, causing the magnetic domains to lose their alignment,
2. Hammering: Hammering a magnet placed in the east-west direction alters the alignment of the magnetic domains, causing the magnet to lose its magnetism.
3. Electrical method: Place a magnet inside a solenoid in the east-west direction. Connect the solenoid to an alternating current (a.c.) supply. Withdraw the magnet with the alternating current still flowing in the solenoid.

Magnetic field: The region surrounding a magnet, in which a body of magnetic material experiences a magnetic force.

Magnetic shielding: By placing equipment sensitive to magnetic fields within a closed hollow iron container, the equipment inside will not experience a magnetic field as the magnetic field will be attracted to the iron container.

Soft magnetic materials: Magnetic materials that are easily magnetised and demagnetised. An example of this is Iron.

Hard magnetic materials: Magnetic materials that are not easily magnetised and demagnetised. An example of this is steel.

Chapter 21. Electromagnetism

Right-hand grip: Direction of current is direction of thumb, direction in which fingers curl is direction of magnetic field (clockwise or anti-clockwise). When the direction of current in a current-carrying wire is reversed, the direction of the magnetic field is also reversed. The strength of the magnetic field can be increased by increasing the current.
Methods to increase magnetic field in a solenoid/coil:

- Increase the current flow through the solenoid/coil
- Increase the number of turns in a solenoid/coil
- Placing a soft iron core in the solenoid/coil

Motor effect: When a current-carrying conductor is placed in a magnetic field, the conductor experiences a force. This effect on the conductor is called the motor effect.

Fleming’s left hand rule: Fleming’s left hand rule gives the direction of resultant force when the direction of the magnetic field and current are known. The direction of the force is reversed when the direction of current or magnetic field changes.

Conductors carrying currents in opposite directions repel each other as the combined magnetic field causes a repulsive force on the wires. Conductors carrying currents in the same direction attract each other as the combined magnetic field causes an attractive force on the wires.

The direction of the force on a beam of charged particles is reversed when the current is reversed, the particles are oppositely charged or when the direction of the magnetic field is reversed.

The turning effect on a current-carrying coil can be increased by increasing the number of turns in the wire coil, inserting a soft iron core into the coil, or increasing the current in the wire coil.

How a D.C. motor works:
- Structure of a D.C. motor: The wire coil is mounted on an axle that allows the coil to rotate about the axle. The coil and the axle are positioned between the poles of a permanent magnet. The ends of the wire coil are connected to a split-ring commutator, which reverses the direction of the current in the coil every half a revolution and turns with the coil. Two carbon brushes press lightly against the commutator to complete the circuit. A practical D.C. motor has hundreds of turns of wires with a soft iron core in the centre.
- Explanation to how a D.C. motor works: Using Fleming's left hand rule, we know that a (downward/upward) force acts on (section of wire) and a (downward/upward) force acts on (other section of wire). This causes the coil to rotate (clockwise/ anti-clockwise) about the axle until it reaches a vertical position. At the vertical position, the current is cut off since the split-ring commutator is no longer in contact with the carbon brushes. The momentum of the coil allows it to be carried past the vertical position. The direction of the currents flowing through the wire sections are now reversed. A (downward/upward) force now acts on (section of wire) and a (downward/upward) force acts on (other section of wire). Hence, the coil continues to rotate in the (clockwise/anti-clockwise) direction.

Chapter 22. Electromagnetic Induction

Electromagnetic induction: The process where an induced e.m.f. is produced in a conductor due to a changing magnetic field. The magnitude of the induced e.m.f can be increased by increasing the number of turns in the solenoid (increases magnetic field strength), increasing the strength of the magnet, or increasing the speed at which the magnet moves with respect to the solenoid(increases rate of change of magnetic flux).

Faraday's Law of electromagnetic induction: The magnitude of the induced e.m.f. in a circuit is directly proportional to the rate of change of the magnetic flux in the circuit.

Lenz' Law: The direction of the induced e.m.f. , and hence the induced current in a closed circuit, is always such that its magnetic effect opposes the motion or change producing it.

How an A.C. generator works:
- Structure of an A.C. generator: A rectangular coil of wire is mounted on an axle with a handle between two permanent magnets. By turning the handle, the coil rotates between the poles of two permanent magnets. As the coil rotates in the magnetic field, the change in magnetic flux creates an induced e.m.f. and hence an induced current in the coil. The slip rings are always in contact with the carbon brushes when

they rotate such that the induced current in the coil is transferred to the external circuit.

- When the plane of the coil is parallel to the magnetic field, the arms of the coil cut across the magnetic field lines at the greatest rate. Since the rate of change of magnetic flux is maximum, the magnitude of the induced e.m.f. is maximum. When the plane of the coil is perpendicular to the magnetic field, the arms do not cut across the magnetic field lines. Since the rate of change of the magnetic flux is zero, the magnitude of the induced e.m.f. is zero. After the coil rotates half a cycle, it is again parallel to the magnetic field. The magnitude of the induced e.m.f. is maximum, but the direction is opposite since the arms are now moving in opposite directions.
- Fleming's right hand rule: In A.C. generators, when the directions of the magnetic field and force are known, this rule gives the direction of the induced current.
- How to increase the magnitude of the induced e.m.f.: Increasing the number of turns in the coil, using stronger permanent magnets, increasing the frequency of rotation of the coil, and winding the coil around a soft iron core to increase the magnetic flux in the coil.
- Practical A.C. generator: Also known as a fixed coil generator. It does not require carbon brushes, is less likely to break down from overheating and is more compact than a simple A.C. generator.

How a transformer works:

- A transformer is a device that can change a high alternating voltage (at low current) to a low alternating voltage (at high current) or vice versa.
- Structure of a transformer: Two coils are wrapped around a laminated soft iron core. Each coil has a certain number of turns. The soft iron core comprises thin sheets of soft iron. Soft iron is used because it is easily magnetised and demagnetised. This ensures better magnetic flux linkage between the two coils. The lamination reduces heat loss.
- The primary coil of the transformer is connected to an alternating voltage, which creates a varying magnetic field in the iron core. This induces an e.m.f. in the secondary coil, inducing a current in the closed circuit.
- The voltages, currents, and turns in the primary and secondary coils are related by this formula: $V_{secondary}/V_{primary} = N_{secondary}/N_{primary} = I_{primary}/I_{secondary}$ and power in the primary coil = power in the secondary coil.
- To reduce power loss in distribution of electricity, thick cables can be used to reduce the resistance such that the power lost as heat (I^2R) is minimal. Thicker cables increase the cable and construction costs. Reducing the magnitude of the current I can be done by using a step up transformer.

Cathode-Ray-Oscilloscopes(CRO):

- Adjusting the Y-gain of the oscilloscope varies the voltage per division on the screen.
- Adjusting the time base of the oscilloscope varies the frequency of the time base.