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6091 O-Level Pure Physics

Formulae, Definitions, Laws & Principles List 2024

GENERAL PHYSICS (Measurements & Mechanics)

FORMULAE

- Instantaneous v $= \frac{\Delta s}{\Delta t}$
- Constant v $= \frac{s}{t}$
- Average v $= \frac{\text{Total s}}{\text{Total t}}$ [for all types of motion]
- Average v $= \frac{1}{2}(u + v)$ [only for constant a]

4 Kinematics Equations: *(OPTIONAL TO USE FOR O-LEVEL)*
Note: These equations apply only when acceleration a is constant

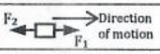
- $s = \frac{1}{2}(u + v)t$
- $s = ut + \frac{1}{2}at^2$
- $v = u + at$ [From $a = \frac{v-u}{t}$]
- $v^2 = u^2 + 2as$

[u: initial velocity | v: final velocity | s: displacement]

- s = area under v-t graph
- v = gradient of s-t graph
- a = gradient of v-t graph

- Resultant force, $F_R = ma$

[F_R=Forward force F_1 - Opposing force F_2]



- $W = mg$

[g: gravitational field strength, 10 N kg^{-1}]

- Density, $\rho = \frac{m}{V}$

- Moment of a force about a pivot, $M = Fd$

[M: in Nm, NOT J]

- G.P.E. or $E_p = mgh$

[g: gravitational field strength, 10 N kg^{-1}]

- K.E. or $E_k = \frac{1}{2}mv^2$

- Work done, $WD = Fs$ [for a constant force, F]

[s: distance moved in the direction of force]

- $P = \frac{W}{t}$ or $\frac{\Delta E}{t}$

[ΔE: energy transferred]

- Efficiency (in %) $= \frac{\text{Useful output energy or power}}{\text{Total input energy or power}} \times 100\%$

- $p = \frac{F}{A}$ [for all states of matter]

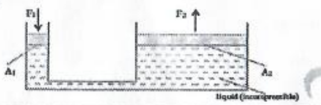
Pressure of a column of fluid (liquid or gas only):

- $p = h\rho g$

[g: gravitational field strength, 10 N kg^{-1} | ρ: density of fluid]

Hydraulic press: (Pressure equally transmitted throughout liquid)

- Pressure on piston 1 = Pressure on piston 2
  $\frac{F_1}{A_1} = \frac{F_2}{A_2}$ [As A ↑, F ↑]
  [Applying a small force (F_1) on a small area (A_1) results in a *larger force* (F_2) on a *larger area* (A_2)]
- Work done by piston 1 = Work done by piston 2
  $WD_1 = WD_2$ [$F_1d_1 = F_2d_2 \Rightarrow$ As F ↑, d ↓]
  [However, by Principle of COE, the smaller force F_1 has to be applied over a larger distance d_1 (for the same amount of work)]



DEFINITIONS

Physical quantity: A quantity that can be measured and consists of a numerical magnitude and a unit

7 Base quantities: mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol)
[Note: 'Luminous intensity (candela)' not required for O-level]

Distance, s: Total length moved by an object in motion.
Displacement, s: Distance moved along a straight line in a specified direction

Speed, v: Rate of change of distance
[OR: Change of distance per unit time]
Velocity, v: Rate of change of displacement
[OR: Change of displacement per unit time]
Average speed (velocity), v: Total distance (displacement) divided by total time

Acceleration, a: Rate of change of velocity
OR: Change of velocity per unit time
Uniform acceleration: Constant rate of change of velocity
OR: Constant change of velocity per unit time

Free fall: Object falls with constant acceleration due to gravity (ie. no air resistance acting on object)
Terminal velocity: Constant, maximum velocity of a *falling* object when its weight is equal to air resistance → no resultant force

Scalar quantity: Physical quantity having magnitude only
[E.g.: time, length/distance, speed, mass, volume, density, energy, work done, power, current, voltage, resistance]
Vector quantity: Physical quantity having magnitude & direction
[e.g.: displacement, velocity, acceleration, force (weight, tension, etc.), moments → clockwise/ anti-clockwise]

Force: A push or pull that one object exerts on another.
[It produces/stops motion, or tends to produce/stop motion]

Mass, m: Amount of matter in a body
Weight, W: Amount of gravitational force acting on an object

Density, ρ: Mass per unit volume

Inertia: Reluctance of an object to change its state of rest or motion [depends only on mass]

Gravitational force: Force acting on a mass due to gravity
Gravitational field: Region in which a mass experiences a gravitational force
['... field': 'Region in which a ... experiences a ... force')
→ Direction of field is towards the centre of the Earth/ planet
Gravitational field strength, g: Gravitational force per unit mass [g of Earth: 10 N kg^{-1}]

Moment of a force (about a point/ pivot) [OR: Turning effect of a force/ Torque]: Product of force and perpendicular distance from the point/ pivot to the line of action of force

Centre of gravity: Point on an object through which its whole weight appears to act, for any orientation of the object

Stability: Ability of an object to return to its original position after it has been tilted slightly
For object in
1. **Stable equilibrium**: It returns to original position when tilted slightly (line of action of weight lies within base area)
   → C.G. rises then falls back
2. **Unstable equilibrium**: It topples to new position when tilted slightly (line of action of weight falls outside base area)
   → C.G. falls & continues to fall further
3. **Neutral equilibrium**: It remains in its new (similar) position when displaced slightly (line of action of weight is in line with normal contact force)
   → C.G. neither rises or falls

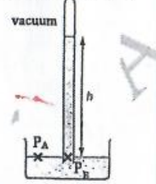
Energy: Capacity to do work
Gravitational potential energy: Energy in the gravitational potential store of a body because of its position relative to the ground
Elastic potential energy: Energy in the elastic potential store of an elastic material (e.g. spring) because it is compressed/stretched
Chemical potential energy: Energy in the chemical potential store of food/ fuels/ batteries
- Kinetic energy: Energy in the kinetic store of a body in motion

Work done, W (by a constant force): Product of the force on an object and the distance moved in the direction of the force

Power, P: Work done or energy transferred per unit time

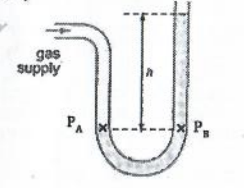
Pressure, P: Force acting (normally) per unit area
Atmospheric pressure, P_{atm}: Pressure exerted by the layer of air surrounding Earth on Earth's surface

Barometer: Instrument used to measure P_{atm} (given by height of mercury column, h)



$P_A = P_B$
$\therefore P_{atm} = P_h$

Manometer: Instrument used to measure differences in pressure of gases (given by height difference of both liquid levels, h)



$P_A = P_B$
$\therefore P_{gas} = P_{atm} + P_h$ (for above diagram)

LAWS & PRINCIPLES

Newton's First Law of Motion: Every object will continue in its state of rest or uniform motion in a straight line, unless a resultant force acts on it.
Newton's Second Law of Motion: 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 is equal to the resultant force.
Newton's Third Law of Motion: If body A exerts a force on body B, then body B will exert an equal but opposite force on body A.

Principle of Moments: *When a body is in equilibrium*, the sum of clockwise moments *about a point* is equal to the sum of anti-clockwise moments *about the same point*.

Conditions for a body in equilibrium:
1. Resultant force is zero
2. Resultant moment about pivot (or any point) is zero

Principle of Conservation of Energy:
i. Energy cannot be created or destroyed.
ii. It can only be transferred from one store to another.
iii. The total amount of energy in an isolated system is constant.

THERMAL PHYSICS

FORMULAE

- $Q = mc\Delta\theta$ & $Q = C\Delta\theta$

[c: specific heat capacity, J /(kg °C) or J / (kg K)]
[C: heat capacity, J $°C^{-1}$ or J K^{-1}]

- $Q = ml_f$ & $Q = L_f$
- $Q = ml_v$ & $Q = L_v$

[l_f, l_v: specific latent heat of fusion/ vaporisation, J kg^{-1}]
[L_f or L_v: latent heat of fusion/ vaporisation, J]

DEFINITIONS

Brownian motion: Constant & random motion of heavier (e.g. smoke) particles suspended in a fluid, caused by uneven collisions by surrounding lighter, fast-moving particles of fluid (e.g. air), causing heavier particles to move (in direction of resultant force)

Gas pressure: Pressure caused by gas particles as they collide with the (inner) walls of the containers, exerting a force per unit area

Conduction (mainly in solids): A process of energy transfer where energy is transferred through the passing on of vibrational motion from one particle to another. → Metals: conduction occurs also due to free-electron diffusion
Convection (in fluids only): A process of energy transfer by means of convection currents in a fluid, due to a difference in density
Radiation (in all matter): A process of energy transfer by electromagnetic waves (i.e. infra-red radiation), transmitted without the aid of a medium
[Dull, black surfaces are better emitters/absorbers of infra-red radiation than shiny, white surfaces]

Internal energy: Energy store that is made up of the total kinetic energy associated with the random motion of the particles and the total potential energy between the particles of the system. It is the sum of energies in the potential & kinetic stores of particles.
1. **Energy in kinetic store (of particles)**: Due to vibration of particles in solids (or movement of particles in fluids)
   →Directly related to temperature
2. **Energy in potential store (of particles)**: Depends on force of attraction between particles and how far they are
   →During changes of state, only energy in potential store changes.

Heat capacity, C: Change of its internal energy per unit change in its temperature
Specific heat capacity, c: Change of its internal energy per unit mass for each unit change in its temperature
→ Good thermal conductors have low specific heat capacity

Latent heat of fusion, L_f: Energy transferred to change a substance between solid and liquid states at constant temperature
Specific latent heat of fusion, l_f: Energy transferred per unit mass of a substance to change between solid and liquid states at constant temperature
Latent heat of vaporisation, L_v: Energy transferred to change a substance between liquid and gaseous states at constant temperature
Specific latent heat of vaporisation, l_v: Energy transferred per unit mass of a substance to change between liquid and gaseous states at constant temperature

Melting: Change from the solid state to the liquid state when energy is transferred to the substance without a change in temperature
Boiling: Change from the liquid state to the gaseous state when energy is transferred to the substance without a change in temperature

Evaporation: Process in which more energetic particles escape from the surface of a liquid *at any temperature*, leaving behind less energetic particles (i.e. smaller average kinetic energy)

Factors affecting evaporation:
1. Temperature (of liquid)
2. Surface area (of liquid)
3. Boiling point (of liquid)
4. Humidity (of surrounding air)
5. Movement of air/ wind
6. Atmospheric Pressure

Differences between boiling and evaporation:

Boiling	Evaporation
Occurs at a particular temperature	Occurs at any temperature
Relatively fast	Relatively slow
Takes place throughout liquid	Takes place only at liquid surface
Bubbles are formed	No bubbles are formed
Temperature remains constant	Temperature may change
External source of energy is needed	Energy is usually supplied by the surrounding medium (e.g. air)

LIGHT, WAVES & SOUND

FORMULAE

- Refractive index of medium, $n = \frac{\sin i}{\sin r}$ (air to medium)

$\rightarrow n = \frac{\sin \text{'larger angle'}}{\sin \text{'smaller angle'}}$

[n: no unit and the other medium is vacuum]

- $n = \frac{\text{Speed of light in } vacuum\text{, c}}{\text{Speed of light in medium, v}}$

$\rightarrow$ *Definition of n*: Ratio of speed of light in vacuum to speed of light in medium

- $n = \frac{\text{real depth}}{\text{apparent depth}}$
- $n = \frac{1}{\sin c}$ (medium to air)

For converging lens: *(OPTIONAL TO USE FOR O-LEVEL)*
- Real image: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$
- Virtual image: $\frac{1}{f} = \frac{1}{u} - \frac{1}{v}$

- $v = f\lambda$ [f: frequency, λ: wavelength]

1. v $\rightarrow$ depends on medium
   - for light: optical density, n $\rightarrow$ as n↑, v↓
   - for water: depth of water, d $\rightarrow$ as d↑, v↑
   - for sound: $v_{solid} > v_{liquid} > v_{gas}$
2. f $\rightarrow$ depends on source/ origin of wave
3. λ changes as v and/or f changes

- $f = \frac{1}{T}$ [f: frequency in Hz, T: period in s]

- Components of Electromagnetic Spectrum:

Radio waves	Micro-waves	Infra-red	Visible light	Ultra-violet	X-rays	Gamma rays
←λ↑						f↑→ (more dangerous)

[Remember: 'Ronald McDonald Is Very Ugly Xcept Gary']

- Uses of components of Electromagnetic Spectrum:

1. Radio waves: Radio and television communication, astronomy, RFID tags2. Microwaves: Microwave ovens, satellite TV, mobile (cell) phone telecommunications
3. Infra-red: Heating, remote controllers, ear thermometers, intruder alarms, thermal imaging
4. Visible light: Optical fibres, human sight
5. Ultraviolet: Sunbeds, bank note authentication, disinfecting water6. X-rays: Medical radiology, industrial defect detection, scanner for airport security
7. Gamma rays: Sterilising food, Cancer detection and treatment (by directing rays at tumours)

- Colours of visible light:

... Infra-red	Visible light	Ultra-violet ...

Red	Orange	Yellow	Green	Blue	Indigo	Violet
←λ↑						f↑→

[Remember: 'ROY Gave Birth In Vain' (ROYGBIV)]

DEFINITIONS

Reflection: The bouncing back of a particle or wave that strikes the boundary between two media

Refraction: The change in speed of a wave (and hence the direction) when it travels through two different media

Angle of incidence/ reflection/ refraction: The angle between the incident/ reflected/ refracted ray and the normal to the surface at the point of incidence

Normal: Imaginary line drawn perpendicular to a reflecting/ refracting surface, at the point of incidence

Real image: Image can be captured on a screen & light rays from object actually pass through image

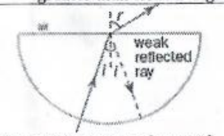
Virtual image: Image cannot be captured on a screen & light rays appear to come from image (but do not pass through it)

Refractive index, n: Ratio of speed of light in *vacuum* to the speed of light in medium

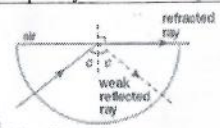
Critical angle, c: Angle of incidence in the optically denser medium for which the angle of refraction in the optically less dense medium is 90°

Total internal reflection: Complete reflection of light inside an optically denser medium, when it strikes the boundary between two media at an angle of incidence greater than the critical angle of the optically denser medium

Conditions for total internal reflection:
1. The light ray travels from an optically denser medium to an optically less dense medium
2. The angle of incidence in the optically denser medium is greater than critical angle of the optically denser medium



(Normal refraction: when $i < c$)



(At critical angle, c when $i = c$)

(At total internal reflection: when $i > c$)

Optical centre, C: Midpoint between the surfaces of the lens on its principal axis

Principal axis: Horizontal line passing through the optical centre of the lens

Focal point/ Principal focus, F:
Point at which all rays parallel to the principal axis converge after refraction by the lens

Focal length, f: Distance between the optical centre and the focal point of the lens

Focal plane: Plane which passes through the focal point and is perpendicular to the principal axis

Waves/ Wave motion: Periodic motion/ travelling disturbance repeated at regular intervals, which transfers energy from one point to another without any transfer of matter (source of waves is a vibration or oscillation)

Oscillation: A complete to-and-fro motion from one extreme position to the other extreme position and back

Transverse waves: Waves that travel in a direction perpendicular to direction of vibration of particles

Crest: Highest point of a transverse wave

Trough: Lowest point of a transverse wave

Longitudinal waves: Waves that travel in a direction parallel to direction of vibration of particles

Phase: Any 2 points on a wave are in phase when they
- move in the same direction, and
- have the same speed and displacement from the rest position

Wavelength, λ: Shortest distance between 2 points in phase on a wave
- For transverse waves: distance between two consecutive crests or troughs
- For longitudinal waves: distance between two consecutive compressions or rarefactions

Amplitude, A: Maximum displacement of a particle from the rest position in a wave

Period, T: Time taken for one complete oscillation/ wave

Frequency of wave, f: Number of complete oscillations/ waves per unit time

Wavefront: Imaginary line joining all points on the waves that are in phase

Electromagnetic waves: Transverse waves which travel at the speed of light in vacuum (3.0×10^8 m/s). They consist of electric and magnetic fields that oscillate at 90° to each other.

Ionisation: Process of ion formation, where a particle becomes electrically charged by losing or gaining electrons.

Sound: A form of energy transferred by vibrating sources placed in a medium, comprising of a series of compressions and rarefactions in the medium

Compression: Region in a sound wave when particles are closer together & (air) pressure is higher than surrounding pressure

Rarefaction: Region in a sound wave when particles are further apart & (air) pressure is lower than surrounding pressure

Echo: Sound reflected off hard, flat surfaces

Ultrasound: Sound with frequencies above the upper limit of the human range of audibility

Pitch: Directly related to frequency of a sound wave

Loudness: Directly related to amplitude of a sound wave

LAWS & PRINCIPLES

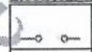
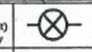
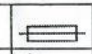
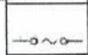
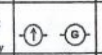
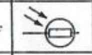
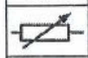
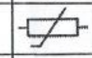
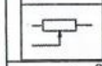
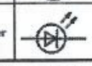
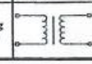
Laws of Reflection:
1. The incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane.
2. The angle of incidence is equal to the angle of reflection.

Laws of Refraction:
1. The incident ray, the refracted ray and the normal all lie in the same plane.
2. For two particular media, ratio of sine of the angle of incidence to sine of the angle of refraction is a constant.

ELECTRICITY & MAGNETISM

FORMULAE

Electrical circuit symbols (common):

	d.c. (direct current) power supply		lamp		Fuse
	a.c. (alternating current) power supply		galvanometer		light-dependent resistor (LDR)
	rheostat/ variable resistor		diode		thermistor
	potentiometer		light-emitting diode (LED)		transformer

- $I = \frac{Q}{t}$ [Q: electric charge in coulomb, C]

- E.m.f., ε (of electrical source) $= \frac{W}{Q}$
- P.d., V (across electrical component/2 pts) $= \frac{W}{Q}$

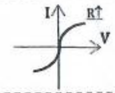
[E.m.f.: Electromotive force | p.d.: potential difference]

I-V graphs:

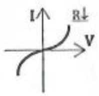
For ohmic conductors
1. Metallic conductors: (e.g. resistors) $V = IR$ ($I \propto V$)

For non-ohmic conductors
2. Diode:
   - Reverse-biased: infinite R
   - Forward-biased: normal R

3. Filament lamp: R↑ as temperature↑ (as V and I↑) $\rightarrow$ as lamp gets hotter



4. Thermistor: R↓ as temperature↑ (as V and I↑)



- $R = \frac{\rho L}{A}$ [ρ: resistivity of material, Ω m]

For series circuit: [current I is constant]
- E.m.f., ε $= V_1 + V_2 + V_3 + ...$
- Total resistance, R $= R_1 + R_2 + R_3 + ...$

For parallel circuit: [p.d. V is constant]
- E.m.f., ε $= V_1 = V_2 = V_3 = ...$
- Total current, I $= I_1 + I_2 + I_3 + ...$
- Total resistance, R: $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...$

[For two resistors in parallel only: $R = \frac{(R_1)(R_2)}{R_1 + R_2} \rightarrow \frac{\text{'product of R'}}{\text{'sum of R'}}$]

P.d. for potential divider circuit (2 or more resistors in series):
- $\frac{V_1}{V_2} = \frac{R_1}{R_2}$ ($V \propto R$ as I constant)

[As R↑, V↑ $\Rightarrow V_1 = \frac{R_1}{(R_1 + R_2)} V$, where V is the total p.d. across both resistors]

Current flow for **only two** resistors in parallel:
- $\frac{I_1}{I_2} = \frac{R_2}{R_1}$ ($I \propto \frac{1}{R} \Rightarrow$ As R↑, I↓)

Input transducers:
- Thermistors
  - As temperature↑, resistance, R↓
- Light-dependent resistors (LDRs)
  - As light intensity↑, resistance, R↓

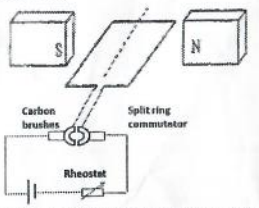
- $P = IV$
- $P = I^2R$ [To compare P of series resistors - I constant]
- $P_{loss} = I^2R$ [joule heating due to heating effect of I]
- $P = \frac{V^2}{R}$ [To compare P of parallel resistors - V constant]

- $P = \frac{\Delta E}{t} \Rightarrow \Delta E = IVt = I^2Rt = \frac{V^2 t}{R}$

Brightness of light bulbs:
(brightness depends on power, $P = IV$)

- For series circuit (I constant):
  $\rightarrow P \propto V$ $\Rightarrow P = \frac{V^2}{R}$: brightness depends on V
- For parallel circuit (V constant):
  $\rightarrow P \propto I$ $\Rightarrow P = I^2R$: brightness depends on I

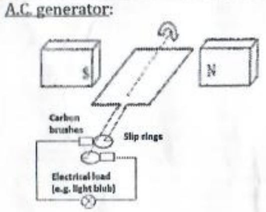
D.C. motor:



How it works: Interaction of magnetic fields of magnet & current-carrying coil produces a resultant magnetic field (and thus resultant force) on coil

- Split-ring commutator: To reverse direction of current *in the coil* every time the coil passes its vertical position (so that the force acting on the side of coil near the same magnetic pole is always in the same direction)
- Carbon brush: To electrically connect coil and split-ring commutator
- Rheostat: To control speed of the motor

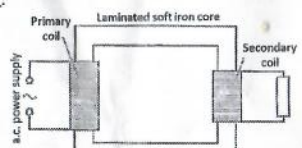
A.C. generator:



How it works: As coil turns and cuts magnetic field lines of magnet, it experiences a change in magnetic flux. An induced e.m.f. (and hence induced current since closed circuit) is produced.

- Slip rings: To prevent the coil from entangling, and ensure that the induced current transferred to external circuit is alternating.

Transformer:



How it works:
1. Alternating current in pri. coil produces changing magnetic field
2. Magnetic field is linked to sec. coil through soft iron core
3. Sec. coil experiences a change in magnetic flux. An induced e.m.f. is produced across sec. coil.

- Soft iron core: To link magnetic field from pri. coil to sec. coil
- Laminated soft iron core: To reduce power loss in soft iron core due to eddy currents

For all transformers:

- Turns ratio $= \frac{N_s}{N_p}$; $\frac{N_s}{N_p} = \frac{V_s}{V_p}$

For ideal transformers:
$P_p = P_s \Rightarrow I_P V_P = I_S V_S \Rightarrow \frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}$

- Power loss in power transmission, $P_{loss} = I^2R$

[joule heating due to heating effect of current]

DEFINITIONS

Electrostatics: Study of static/ non-moving electric charges (negative charges)

Electrostatic charging by induction: Process of charging a metallic conductor due to movement of free electrons when it is placed near a charged object

Electric field: Region of space where an electric charge experiences an electric force
→ Direction of field is direction of force acting on a positive charge (field lines point outwards from a positive charge)

Electrostatic shielding/ screening: The use of *electrical conductors* to divert any surrounding electric fields from the sensitive areas of (electronic) equipment (as the electric field lines tend to pass within these *electrical conductors* instead)

Current/ Conventional current, I: Rate of flow of electric charge, Q
→ positive charges flow from +ve to -ve terminal of a cell
Electron flow: Flow of electrons
→ electrons flow from –ve to +ve terminal of a cell

Electromotive force/ E.m.f., ε (of an electrical source): Work done per unit charge by electrical source in driving charges around complete circuit
Potential difference, V (across a component/ between 2 points in a circuit): Work done per unit charge in driving charges through a component/ between the 2 points in a circuit

Resistance, R: Ratio of potential difference across an electrical component to the current flowing through it

Transducers: Electronic devices that convert changes in physical conditions, such as temperature, light intensity or pressure into electrical signals so that these physical conditions can be measured

Kilowatt-hour, kWh: Unit of electricity usage,
= (No. of kW) × (No. of h)
[1 kWh: Amount of energy used by 1 kW device in 1 h]

Live wire: Wire of an electrical circuit at a high potential (Current flows from mains when working normally)
Neutral wire: Wire of an electrical circuit at zero potential (Current flows back to mains when working normally)
Earth wire: Low resistance wire usually connected to metal casing of appliance, which provides low resistance conducting path for current flow to earth if the casing becomes 'live' (No current flow when working normally)

Renewable energy sources: Energy sources that can be replaced/ will not run out, e.g.: sunlight, wind, running water
[Note: NOT 'can be used again/ reused']
Non-renewable energy sources: Energy sources that cannot be replenished at a sustainable rate, e.g.: coal, natural gas, petroleum

Comparison of Renewable & Non-renewable Energy Sources:

	Nuclear energy	Fossil fuels	Solar energy	Wind energy	Hydro-electric power
Energy transfer	Energy in Nuclear store → Energy in internal store → Energy transferred electrically	Energy in Chemical potential store → Energy in internal store → Energy transferred electrically	Energy transferred through propogation of visible light → Energy transferred electrically	Energy in Kinetic store → Energy transferred electrically	Energy in Gravitational potential store → Energy transferred electrically
Energy transfer efficiency	Highly efficient – small amount of uranium to generate large amount of energy.	Most have well-established technology & energy distribution systems.	Higher efficiency when daylight & minimal cloud cover. Excess energy can be stored.	Efficiency depends on wind direction & speed.	Most efficient, as water flow is concentrated & can be controlled.
$ per kWh	Additional cost of radioactive waste disposal.	Rising cost due to declining fossil fuel supply & rising energy demand.	High cost of solar panels. Sunlight is free.	Falling cost due to technology. Wind is free. Maintenance cost.	High cost of dam & power plant, & maintenance.
Environmental impact	Waste from uranium mining can contaminate water sources.	Negative impact on ecosystem due to fossil fuel mining. Air pollution.	Clean energy. Requires large areas for solar panels.	Clean energy. Noise pollution from spinning turbines. Large open areas needed.	Clean energy. Building of dam disrupts ecosystems.

Safety features in home electrical circuits:

1. **Circuit breaker**: Safety device that switches off electrical supply (due to electromagnetism) when a large current flows through → can be re-set
2. **Fuse**: Safety device that melts when a large current (above its rated value) flows through (due to an electrical fault)
3. **Switch**: Designed to break or complete a circuit

   } Both the fuse and the switch are placed in the *live wire* - so that the appliance is at low/ zero potential when switch is open; and the appliance is safe to touch

4. **Earthing**: In case of electrical fault (e.g. live wire touching metal casing), a large current will flow to earth through the low-resistance earth wire (if fuse on live wire does not melt yet) → protects user
5. **Three-pin plugs**: Neutral (blue), Earth (green & yellow), Live (brown) wires
6. **Double insulation**: Safety feature with 2 levels of insulation (normally for appliances with non-metallic casings and that use two-pin plugs)
   - electric cable insulated from internal components
   - internal components are insulated from external casing

Temporary Magnets: Magnets made of *soft* magnetic materials, which are easy to magnetise and demagnetise.
Permanent Magnets: Magnets made of *hard* magnetic materials, which are difficult to magnetise and demagnetise.

Induced magnetism/ Magnetic induction: Magnetic materials *behaving* like magnets, when near or in contact with a magnet.
→ magnetic materials: iron, steel, cobalt or nickel
(Note: Induced magnets behave like magnets but are not *temporary magnets*.)

Magnetic field: Region where a magnetic object experiences a magnetic force.
→ Direction of field is the direction the tip of the compass needle (N-pole) will point to, when placed in the magnetic field

North/ South pole (of a magnet): The pole that points towards the geographic north/ south when a magnet is freely suspended.

Magnetic shielding/ screening: The use of magnetic materials to prevent any surrounding magnetic fields from reaching and affecting the sensitive areas of equipment (magnetic field lines will pass within these magnetic materials instead)

Electromagnetism: Study of the force produced on a current-carrying conductor/ moving charges, due to the interaction of magnetic fields (of the current and that of the magnet)

Alternating current: An electric current that periodically reverses its direction of flow

Electromagnetic induction: Study of the e.m.f. induced in an electrical conductor (and induced current if circuit is closed), due to change in magnetic flux with the conductor

LAWS & PRINCIPLES

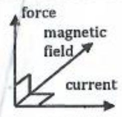
Law of Electrostatics: Like charges repel, unlike charges attract

Ohm's Law: Current flowing through a metallic conductor is directly proportional to potential difference across its ends, if physical conditions (e.g. temperature) remain constant

Law of Magnetism: Like magnetic poles repel, unlike poles attract

Right Hand Grip Rule:
1. **For current flowing in a wire**: the thumb represents the direction of the current flow and the fingers of the right hand represent the direction of the magnetic field
2. **For current flowing in a flat coil / solenoid**: the thumb represents the direction of the magnetic field in the flat coil / solenoid and the fingers of the right hand represent the direction of the current flow

Fleming's Left Hand Rule: The direction of the force produced can be represented by the thumb when the forefinger represents the direction of the magnetic field (N to S) and the second finger represents the direction of the current; and all three fingers are perpendicular to each other.



Faraday's Law of Electromagnetic Induction: The magnitude of the induced e.m.f. is directly proportional to the rate of change of magnetic flux with the electrical conductor.
Lenz' Law: The direction of the induced e.m.f. (and hence the direction of the induced current in a closed circuit) is such that its magnetic effect opposes the motion or change causing it.

Fleming's Right Hand Rule: The direction of the induced e.m.f. (and hence the direction of the induced current in a closed circuit) can be represented by the second finger when the thumb represents the direction of the force and the forefinger represents the direction of the magnetic field (N to S); and all three fingers are perpendicular to each other

RADIOACTIVITY

FORMULAE

- Relative charge of proton: +1
- Relative charge of electron: -1
- Relative charge of neutron: 0
- Number of neutrons = Nucleon (Mass) Number – Proton (Atomic) Number
- Nuclide Notation: $^{235}_{92}U$ [U: Chemical symbol, 92: Proton (Atomic) Number, 235: Nucleon (Mass) Number
- Alpha decay: [Eg] $^{226}_{88}\text{Ra} \longrightarrow ^{222}_{86}Rn + ^{4}_{2}\text{He}$
- Beta decay: [Eg] $^{14}_{6}\text{C} \longrightarrow ^{14}_{7}\text{N} + ^{0}_{-1}\beta$
- Gamma decay: [Eg with release of alpha-particle and 2 gamma rays] $^{238}_{92}\text{U} \longrightarrow ^{234}_{90}\text{Th} + ^{4}_{2}\text{He} + 2^{0}_{0}\gamma$
- Nuclear fission: [Eg] $^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{139}_{56}\text{Ba} + ^{94}_{36}\text{Kr} + 3^{1}_{0}\text{n}$
- Nuclear fusion: [Eg] $^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + ^{1}_{0}\text{n}$

DEFINITIONS

Proton (Atomic) Number: Number of protons in an atom

Nucleon (Mass) Number: Total number of neutrons and protons in the nucleus of an atom

Isotopes: Atoms of the same element that have the same number of protons but different number of neutrons

Nuclear Decay: Random process in which an unstable atomic nucleus loses energy by emission of electromagnetic radiation or particles.

Ionising radiation: Radiation with high energies that can knock off electrons from atoms to form ions.

Background radiation: Nuclear radiation in an environment where no radioactive source has been deliberately introduced.

Half-life of radioactive nuclide: time taken for half the nuclei of that nuclide in any sample to decay

Nuclear Fission: Process in which the nucleus of an atom splits and releases a huge amount of energy

Nuclear Fusion: Process in which two light atomic nuclei combine to form one heavier atomic nucleus and releases a huge amount of energy

CONSTANTS

• Size of typical atom • Radius of Earth	• 10^{-10} m • 10^{6} m
• g: gravitational acceleration/ acceleration due to gravity • g: gravitational field strength	• 10 m s^{-2} • 10 N kg^{-1}
Density of water, ρ	1000 kg m^{-3} or 1 g cm^{-3}
Atmospheric pressure, p_{atm}	1.0×10^{5} Pa / 1 atm (≈ 76 cm Hg)
Velocity of light in vacuum, c (Velocity of EM waves in vacuum)	3.0×10^{8} m s^{-1}
Velocity of sound (in air)	≈ 330 m s^{-1}
Refractive index of vacuum, n_{vacuum}	1
Refractive index of glass, n_{glass} Critical angle of glass, c_{glass}	1.5 ≈ 42°

PREFIXES

T	tera	10^{12}	d	deci	10^{-1}
G	giga	10^{9}	c	centi	10^{-2}
M	mega	10^{6}	m	milli	10^{-3}
k	kilo	10^{3}	μ	micro	10^{-6}
			n	nano	10^{-9}