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GCE A-Level
H2 Physics

Volume I.

Definitions & Formulas

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H2 Physics (Syllabus 9749)

Physical quantities are measurable properties with a magnitude and a unit.

Base quantities are fundamental physical quantities defined and measured independently of other quantities.

Derived quantities are physical quantities calculated from base quantities using mathematical operations.

Scalar quantities are physical quantities that have only magnitude.

Vector quantities are physical quantities that have both magnitude and direction.

Systematic errors are measurement errors that consistently cause measured values to deviate from their true value by a fixed magnitude and in one direction.

Zero error is a type of systematic error that occurs when a measuring instrument does not start from exactly zero.

Parallax error is a type of systematic error that occurs due to incorrect eye positioning when reading the measuring scale.

Random errors are measurement errors where the measured values differ from the mean value with varying magnitudes and directions.

Precision refers to the degree of closeness between repeated measurements of the same quantity under consistent conditions.

Accuracy refers to the degree of closeness between a measured value and the true or accepted value of the quantity being measured.

Uncertainty, Δ refers to the range of possible values associated with a measured quantity due to limitations in the measurement process or instrument precision.

$$If\ Y = \frac{A^{\alpha} B^{\beta}}{C^{\gamma}},$$

$$\frac{\Delta Y}{Y} = \alpha \frac{\Delta A}{A} + \beta \frac{\Delta \mathrm{B}}{B} + \gamma \frac{\Delta \mathrm{C}}{C}$$

Homogeneity of physical equations refers to the principle that a valid physical equation must be dimensionally consistent, meaning all terms must have the same units or dimensions.

Dimensionless constants are constants with no units.

Distance, d is the total length covered by a moving object regardless of its direction of motion.

Displacement, s is the distance measured in a straight line from a fixed reference point.

$$s = ut + \frac{1}{2}at^2$$

Speed, $|v|$ is the rate of change of distance with respect to time.

$$|\mathrm{v}| = |u| + at$$

Velocity, v is the rate of change of displacement with respect to time.

$$v = u + at$$

$$v^2 - u^2 = 2as$$

$$Average\ Velocity = \frac{Total\ Displacement}{Total\ Time}$$

Acceleration, a is the rate of change of velocity with respect to time.

$$Average\ Acceleration = \frac{\Delta v}{\Delta t} = \frac{v - u}{t}$$

Uniform acceleration is a constant rate of change of velocity with respect to time.

Free fall is the motion of an object in a gravitational field where the only force acting on the object is the gravitational force.

Terminal velocity is the velocity at which a falling object experiences zero acceleration and travels at a constant speed. It occurs when the air resistance acting against the object equals its weight.

Rectilinear motion is the one-dimensional motion of an object along a straight line, where the path of the object does not change direction.

Newton's first law of motion states that a body will continue in its state of rest or uniform motion in a straight line unless an external resultant force acts on it.

Inertia of an object refers to the resistance of the object to change its state of rest or motion, due to its mass.

Newton's second law of motion states that the rate of change of momentum of a body with respect to time is directly proportional to the net force acting on it, and the change occurs in the same direction of the force.

$\sum F = \frac{dp}{dt} = \frac{d(mv)}{dt}$	
$\sum F = ma\ (if\ mass\ is\ constant)$	$\sum F = v\frac{dm}{dt}\ (if\ velocity\ is\ constant)$

Newton's third law of motion states that for every action, there is an equal and opposite reaction.

$$F_{AB} = -F_{BA}$$

Linear momentum is the product of the mass of an object moving in a straight line and its velocity

$$p = mv$$

Impulse, J is the product of the average force, F and duration of impact, Δt. It represents the change in momentum, Δp of the object as a result of this force.

$$J = F\Delta t = \Delta p$$

Principle of conservation of momentum states in a closed system, the total initial momentum of all objects before interaction is equal to the total final momentum after collision provided no resultant external force acts on the system.

$$\sum p_i = \sum p_f$$

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

(Perfectly) elastic collision is a type of collision in which both the total momentum and kinetic energy of the system are conserved after the collision.

$$\sum KE_i = \sum KE_f$$

$$\frac{1}{2}m_1 u_1 + \frac{1}{2}m_2 u_2 = \frac{1}{2}m_1 v_1 + \frac{1}{2}m_2 v_2$$

$$Relative\ speed\ of\ approach = Relative\ speed\ of\ separation$$

Inelastic collision is a type of collision in which the total momentum is conserved, but the total kinetic energy of the system is not conserved after the collision.

Perfectly inelastic collision is a type of collision where two objects stick together after the collision, resulting in the maximum possible loss of kinetic energy for the system.

Field of force is a region in space where a force can be experienced by objects with certain properties such as mass, charge, magnetism.

Stability of an object refers to its ability object to return to its equilibrium position after being displaced.

Terminal velocity is the constant maximum velocity reached by an object falling through a fluid when the downward gravitational force acting on the object is balanced by the upward drag force due to the fluid.

Static equilibrium is a state in which an object is at rest and the resultant force and resultant torque acting on it is zero.

Translational equilibrium is a state in which an object is moving with constant velocity in a straight line and the resultant force acting on it is zero.

Rotational equilibrium is a state in which an object does not rotate or is rotating with constant angular velocity and the resultant torque acting on it is zero.

Force is the rate of change of momentum of an object with respect to time.

Gravitational force, F_G is the pull exerted by Earth's gravity on any object.

Electrostatic force, F_E is the attractive or repulsive force between electric charges.

Magnetic force, F_M is the attractive or repulsive force between magnets.

Friction, f is the force that opposes or tends to oppose motion between surfaces in contact.

Viscous Force (drag force), f_{drag} is the resistive force due to the fluid's viscosity exerted by a fluid on an object moving through it.

Air resistance is the frictional force exerted by air that opposes the motion of moving objects.

Normal contact force, N is the push exerted by a surface on an object pressing on it. This push is always perpendicular to the surface.

Tension, T is the pull exerted by a stretched spring, string, or rope on an object attached to it.

Mass, m is a measure of the amount of matter in a body.

Weight W is the gravitational force acting on an object that has mass.

$$W = mg$$

Apparent weight is the perceived weight of an object that is influenced by the acceleration of the system that the object is placed in.

Component forces are individual forces that combine to produce a resultant force in a specific direction. These components are projections of a force vector along mutually perpendicular axes, typically represented as horizontal (x-axis) and vertical (y-axis) components in two-dimensional space.

$$F_x = F\cos\theta$$

$$F_y = F\sin\theta$$

Hooke's law states that the extension or compression of a spring, x is directly proportional to the force exerted by the spring, F provided the elastic limit is not exceeded.

$$F = kx$$

Spring constant is a measure of a spring's stiffness.

$$k_{series} = \left(\frac{1}{k_1} + \frac{1}{k_2}\right)^{-1}$$

$$k_{//} = k_1 + k_2$$

Centre of gravity of an object is an imaginary point where the entire weight of the object seems to act.

Moment of a force, M about a pivot, is the product of the force $\boldsymbol{F}$ and the perpendicular distance $\boldsymbol{d}_\perp$ from the pivot to the line of action of the force.

$$M = Fd_\perp$$

Torque of a couple, τ is the rotational effect produced by a pair of forces that are equal in magnitude but opposite in direction, whose lines of action do not intersect.

$$\tau = Fd_{\perp}$$

Principle of moments states that that when a body is in equilibrium, the sum of total clockwise moments, CW about a pivot is equal to the sum of total anticlockwise moments, ACW about the same pivot.

Taking moments about X,

$$CW = ACW$$

$$F_1 \times d_{1,\perp} = F_2 \times d_{2,\perp}$$

Stability of an object is a measure of its ability to return to its original position after it has been displaced from its initial position.

Density, ρ is the mass per unit volume.

$$\rho = \frac{m}{V}$$

Pressure, P is the force acting per unit area.

$$P = \frac{F}{A}$$

Hydrostatic pressure, P is the pressure exerted by a fluid at rest due to the force of gravity.

$$P = h\rho g$$

Upthrust (buoyant force), U is the upward force exerted by a fluid (liquid or gas) on an object that is wholly or partially submerged, due to the pressure difference, ΔP between the bottom and top surfaces of the object.

$$U = \Delta P \times A = (P_{bot} - P_{top}) \times A$$

Archimedes' principle states that an object wholly or partially submerged in a fluid experiences an upward buoyant force (upthrust), U that is equal to the weight of the displaced fluid, $V\rho g$.

$$U = V\rho g$$

Principle of floatation states that when an object floats in a fluid, the upthrust acting on the object must be equal to its weight.

$$U = W$$

Work done, W by a constant force on an object is the product of the force and the displacement in the direction of the force.

$$W = Fs$$

$$(Work\ done\ on\ or\ by\ a\ gas)\ W = p\Delta V$$

Energy is the ability to do work.

Principle of conservation of energy states that energy cannot be created or destroyed; it can only be transferred from form store to another. The total energy of an isolated system is constant.

$$KE_i + GPE_i = KE_f + GPE_f + WD_f$$

Kinetic energy, KE is the energy an object possesses due to its motion.

$$KE = \frac{1}{2}mv^2$$

Gravitational potential energy (near earth's surface), GPE is the energy an object possesses due to its position in a gravitational field. It is the work done to raise the object to a height, h from a reference level.

$$GPE = mgh$$

Electric potential energy is the energy a charged object possesses due to its position within an electric field.

Elastic potential energy, EPE is the energy stored in an elastic object when it is stretched or compressed from its equilibrium position.

$$EPE = \frac{1}{2}kx^2$$

Power, P is the work done per unit time.

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

$$P = Fv$$

Efficiency, η is the ratio of useful output energy (or power) to the total input energy (or power).

$$Efficiency, \eta = \frac{output\ power}{input\ power} \times 100\%$$

Angular displacement, θ is the angle subtended at the centre of a circle by an arc.

$$\theta = \frac{s}{r}$$

Angular velocity, ω is the rate of change of angular displacement with respect to time.

$$\omega = \frac{d\theta}{dt}$$

$$\omega = 2\pi f = \frac{2\pi}{T}$$

Period, T of an object in circular motion is the time taken for the object to complete one full revolution.

Frequency, f of an object in circular motion is the number of complete revolutions made by the object per unit time.

Linear speed, v in uniform circular motion is the constant speed at which an object moves along the circumference of a circle.

$$v = r\omega$$

Centripetal acceleration, a_c is the acceleration experienced by an object in uniform circular motion, directed towards the centre of the circle or axis of rotation.

$$a_c = \frac{v^2}{r}$$

$$a_c = r\omega^2$$

$$a_c = v\omega$$

Centripetal force, $\sum F_c$ is the net force experienced by an object in uniform circular motion, directed towards the centre of the circle or axis of rotation.

$$\sum F_c = \frac{mv^2}{r}$$

$$\sum F_c = mr\omega^2$$

Centrifugal force is an apparent force that arises due to inertia and pushes objects outward in a rotating reference frame.

Helical motion of an object is the combination of its rotational motion around a central axis and linear motion along the axis, resulting in a spiral path.

Newton's law of gravitation states that every particle in the universe attracts every other particle with a force, F_G that is directly proportional to the product of their masses, Mm and inversely proportional to the square of the distance between them, r^2.

$$F_G = \frac{GMm}{r^2}$$

$$F_G = -\frac{dU}{dr}$$

Gravitational field is a region in which a mass experiences a force due to gravitational attraction.

Gravitational field strength, g is defined as the gravitational force, F_G per unit mass acting on a mass, m placed at that point.

$$g = \frac{F_G}{m} = \frac{GMm}{r^2}$$

$$g = -\frac{d\phi}{dr}$$

Gravitational potential energy, U of a point mass in a gravitational field is the work done by an external force to bring a point mass from infinity to that point, without a change in kinetic energy.

$$U = -\frac{GMm}{r}$$

$$\Delta U = m\,\Delta\phi$$

Gravitational potential, ϕ at a point in a gravitational field is the work done per unit mass by an external force to bring the mass from infinity to that point, without a change in kinetic energy.

$$\phi = -\frac{GM}{r}$$

Geostationary orbit is an orbit around Earth where an object has an orbital period equal to the Earth's rotational period (24 hours) and orbits in the plane of the Earth's equator.

Escape velocity, v_e is the minimum speed an object must be projected from Earth's surface in order to break free from Earth's gravitational field.

$$v_e = \sqrt{\frac{2GM}{r}} = \sqrt{2gr}$$

Equipotential lines (or surfaces) are lines (or concentric spheres) in a gravitational field with equal gravitational potential.

Kepler's third law states that the square of a planet's orbital period, T^2 is proportional to the cube of the semi-major axis of its orbit, r^3.

$$T^2 \propto r^3$$

Kelvin, K is a unit S.I. for temperature. It is measured on an absolute scale starting at absolute zero (0 K), theoretically representing a state where particles have minimal motion.

$$T/K = \theta/°\mathrm{C} + 273.15$$

Thermal equilibrium describes a state in which two or more objects/regions have the same temperature and there is no net transfer of energy between them.

Ideal gas is a hypothetical gas that obeys the ideal gas law. Ideal gas particles have no intermolecular forces of attraction, occupy no volume, and collide perfect elastically with each other.

$pV = nRT = NkT$ $p = \frac{1}{3}\frac{Nm}{V} < c^2 > = \frac{1}{3}\rho < c^2 >$	$n N_A = N$ $k = \frac{R}{N_A}$
$c_{rms} = \sqrt{< c^2 >} = \sqrt{\frac{3RT}{N_A m}}$	

Assumptions of ideal gas are simplifications made to model the behaviour of gases, enabling the derivation of the ideal gas law and providing a useful approximation for gases under a wide range of conditions.

1. Gas particles are in constant random motion
2. Volume of particle is negligible compared to volume of gas
3. Intermolecular forces are negligible except during collisions
4. Intermolecular collisions are perfectly elastic
5. Duration of a collision is negligible compared to the time spent travelling between collisions

Mean translational KE of an ideal gas molecule, KE is the average kinetic energy due to the random motion of the molecules in the gas.

$$KE = \frac{1}{2} m < c^2 > = \frac{3}{2} kT$$

Boyles' law states that the pressure of a given amount of gas, p is inversely proportional to its volume, V at constant temperature.

$$p \propto \frac{1}{V}$$

Charles' law states that the volume of a given amount of gas, V is directly proportional to its temperature, T at constant pressure

$$V \propto T$$

Gay-Lussac's law states that the pressure of a given amount of gas, P is directly proportional to its temperature, T at constant volume

$$p \propto T$$

Internal energy, U is the sum of the total microscopic kinetic energy associated with the random motion of the molecules and the total microscopic potential energy due to intermolecular forces between the molecules in the system.

$$U = \sum microscopic\ KE + \sum microscopic\ PE\ , \qquad where\ |microscopic\ PE| \propto \frac{1}{r}$$

Zeroth law of thermodynamics states that if two systems are separately in thermal equilibrium with a third system, then the two systems will be in thermal equilibrium.

First law of thermodynamics states that the increase in internal energy of a system, ΔU is equal to the sum of the heat supplied to the system, Q_{in} and the work done on the system, W_{on}.

$$\Delta U = Q_{in} + W_{on}$$

$$\Delta U = \frac{3}{2} Nk\Delta T = \frac{3}{2} nR\Delta T\ (for\ ideal\ gases)$$

Conduction is the process of energy transfer where energy is transferred through the passing on of vibrational motion from one particle to another.

Convection is a process of energy transfer by means of convection currents of a fluid (liquid or gas), due to a difference in density.

Radiation is the process of energy transfer by electromagnetic waves. It does not require a medium.

Heat capacity, C of an object is the change in its internal energy per unit change in its temperature.

$$Q = C\Delta\theta$$

Specific heat capacity, c of a material is the change of its internal energy per unit mass for each unit change in its temperature.

$$Q = mc\Delta\theta$$

Latent heat of fusion, L_f is the amount of energy transferred to change a substance between the solid and liquid states, at constant temperature.

Specific latent heat of fusion, l_f is the amount of energy transferred per unit mass of a substance to change between the solid and liquid states, at constant temperature.

$$L_f = l_f m$$

Latent heat of vaporisation, L_v is the amount of energy transferred to change a substance between the liquid and gaseous states, at constant temperature.

Specific latent heat of vaporisation, l_v is the amount of energy transferred per unit mass of a substance to change it between the liquid and gaseous states, at constant temperature.

$$L_v = l_v m$$

Simple harmonic motion is a periodic motion of an object in which the acceleration, a of the object is directly proportional to its displacement, x from the equilibrium position, and is always opposite in direction to the displacement.

Displacement, x is the shortest distance of the oscillating object from its equilibrium position at any instant.

	$Max\ value$	$Variation\ with\ x$	$Variation\ with\ t$
x	x_0	-	$x = x_o \sin\,(\omega t + \phi)$
v	$v_0 = \omega x_o$	$v = \pm\omega\sqrt{x_o^2 - x^2}$	$v = \omega x_0 \cos\,(\omega t + \phi)$
a	$a_0 = -\omega^2 x_0$	$a = -\omega^2 x$	$a = -\omega^2 x_0 \sin(\omega t + \phi) = -\omega^2 x$

Velocity, v in a periodic motion is the rate of change of displacement with respect to time that is directed tangentially to the path of motion.

$$v_0 = \pm\omega x_o$$

Amplitude, A is the maximum displacement, x_0 of the oscillating object from its equilibrium position.

Period, T of a periodic motion is the time taken for one complete cycle of oscillation.

$$T = \frac{1}{f}$$

$$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{L}{g}}$$

Frequency, f of a periodic motion is the number of complete oscillations that occur per unit time.

$$f = \frac{1}{T}$$

Angular frequency, ω of a periodic motion is the rate of change of angular displacement, $\frac{d\theta}{dt}$ with respect to time.

$$\omega = 2\pi f = \frac{2\pi}{T}$$

Phase difference, $\Delta\phi$ is the difference in the positions of two oscillating bodies in their cycles

Natural frequency of a system is the frequency at which the system will oscillate freely without external influences.

Driving frequency is the frequency of an external periodic force applied to a system to sustain or influence its oscillation.

Resonance is a phenomenon which occurs for a system when the driving frequency of an external force on the system matches the natural frequency of the system, resulting in a significant increase in the amplitude of oscillation.

Free oscillation occurs when a system oscillates naturally without the influence of any external periodic force after being displaced from its equilibrium position.

Forced oscillation occurs when a system is made to oscillate by an external periodic force, typically at the driving frequency of that force.

Damping refers to the process by which energy is removed from the oscillating system and the amplitude of oscillations decreases over time.

Light damping occurs when the resistive forces are small, causing the system to oscillate with gradually decreasing amplitude over time.

Heavy damping occurs when the resistive forces are large enough to prevent oscillations, causing the system to slowly return to equilibrium over a prolonged period without oscillating.

Critical damping is a unique condition which occurs when the resistive forces are precisely sufficient to bring the system back to equilibrium in the shortest possible time without oscillating.

Wave is a type of oscillation that propagates through space, transferring energy with it but not matter.

Transverse waves are waves in which the direction of oscillations of wave particles is perpendicular to the direction of wave travel.

Longitudinal waves are waves in which the direction of oscillations is parallel to the direction of wave travel.

Compressions are regions in a longitudinal wave where the particles of the medium are close together, resulting in higher pressure.

Rarefactions are regions in a longitudinal wave where the particles of the medium are further apart, resulting in lower pressure.

Electromagnetic waves are transverse waves made up of oscillating electric and magnetic fields, which travel at $3.0 \times 10^8 \; m \, s^{-1}$ in a vacuum, without the need for a medium.

Displacement, x is the shortest distance moved by a particle of a wave from its equilibrium position.

Period, T of a wave is the time taken by each point on the wave to complete one oscillation.

$$T = \frac{1}{f}$$

Amplitude, A_0 of a wave is its maximum displacement from its equilibrium position.

Frequency, f of a wave is the number of oscillations each point completes per second.

$$f = \frac{1}{T}$$

Phase difference, $\Delta\phi$ between two particles or two waves is an indication of how much one wave (or particle) leads or lags behind the other.

$$\Delta\phi = \frac{2\pi\Delta x}{\lambda}$$

Wavelength, λ is the distance between two successive points on a wave that are in phase.

Wave speed, v is the distance travelled by a wave per unit time.

$$v = f\lambda$$

$$v = \frac{\lambda}{T}$$

Progressive waves are waves that transfer energy through medium or space without transporting matter.

Stationary (standing) waves are waves formed by the interference of two waves with the same frequency, amplitude, and speed traveling in opposite directions, resulting in fixed nodes and antinodes.

Intensity, I is the energy transferred per unit time per unit area, measured perpendicular to the direction of wave propagation.

$$I = \frac{P}{A} = \frac{E}{tA}$$

$$(in\ 2D)\ \ I = \frac{P}{2\pi r}$$

$$(in\ 3D)\ \ I = \frac{P}{4\pi r^2}$$

$$I \propto A^2$$

Plane polarisation is a process in which the oscillations of the wave are restricted to a single direction within a plane normal to the direction of propagation.

Malus' law states that when plane-polarised light is incident on an analyser, the intensity, I of the transmitted light is directly proportional to the square of the cosine of the angle, $\cos^2\theta$ between the transmission axes of the analyser and the polariser.

$$I = I_0 \cos^2\theta$$

Principle of superposition states that when 2 or more waves of the same kind are travelling in the same region simultaneously, the resultant displacement at any point is equal to the vector sum of the displacement of the individual waves at that point.

Acoustic resonance is the amplification of sound when an external frequency matches a system's natural frequency.

$(closed\ pipes)\ \lambda_i = \dfrac{4L}{2i-1}$	$f_i = \dfrac{v}{\lambda_i} = \dfrac{v(2i-1)}{4L}$
$(open\ pipes)\ \lambda_i = \dfrac{2L}{i}$	$f_i = \dfrac{v}{\lambda_i} = \dfrac{vi}{2L}$
$i\ \in \{1, 2, 3, \dots\}$	

Interference is the superposition of two or more coherent wave trains superpose to produce regions of maxima and minima in space.

Constructive Interference occurs when two or more waves arrive in phase with each other.

Destructive Interference occurs when two or more waves arrive $\pi\ rad$ out of phase with each other.

Coherent waves are waves that have a constant phase difference.

Monochromatic waves have only a single wavelength.

Path difference, Δx is the difference in distance travelled by two waves from their respective sources to a particular point in space.

$$(constructive)\ \Delta x = n\lambda$$

$$(destructive)\ \Delta x = \left(n + \frac{1}{2}\right)\lambda$$

Phase difference, $\Delta\phi$ is the difference in the phase angles of two waves at a given point in space, indicating how far one wave is ahead or behind the other in its oscillation cycle.

$$(constructive)\ \Delta\phi = 2\pi n$$

$$(destructive)\ \Delta\phi = 2\pi n + \pi$$

Diffraction is a phenomenon where waves spread out when passing through a narrow slit (of width b) or around an obstacle.

$$(single - slit)\ \ sin\ \theta = \frac{\lambda}{b}$$

$$(double - slit)\ \ \lambda = \frac{ax}{D}$$

Diffraction grating is an optical device consisting of an array of a large number of evenly spaced, parallel slits of the same width that diffract light into its constituent wavelengths that produce a spectrum.

$$d \sin\theta = n\lambda,\ \ for\ \ \theta \leq 90°$$

Rayleigh criterion is a standard used to determine the limit of resolution for optical systems. It states that the minimum resolvable detail between two sources occurs when the central of maximum of the diffraction pattern of one source coincides with the first minimum of the diffraction pattern of the other.

$$\theta = \frac{\lambda}{b}$$

Electric field is a region in which an electric charge experiences an electric force.

Permittivity of a medium, ε_0 is a measure of the medium's ability to permit the formation of an electric field within it.

Coulomb's law states that the electric force between two point charges, F_E is directly proportional to the product of their charges, $Q_1 Q_2$ and inversely proportional to the square of the distance between them, r^2.

$$F_E = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$$

$$F_E = -\frac{dU}{dr}$$

Electric field strength, E at a point in an electric field is the electric force, F_E per unit charge experienced by a small positive test charge placed at that point.

$$E = \frac{F_E}{q} = \frac{Q_1}{4\pi\varepsilon_0 r^2}$$

$$E = -\frac{dV}{dr}$$

$$(for\ parallel\ plates)\ \ E = \frac{\Delta V}{\Delta r}$$

Electric potential energy, U of a charge at a point in an electric field is the work done by an external force in bringing the charge from infinity to that point, without a change in kinetic energy.

$$U = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r}$$

$$U = qV$$

Electric potential, V at a point is the work done per unit charge by an external force in bringing a small positive test charge from infinity to that point, without a change in kinetic energy.

$$V = \frac{Q_1}{4\pi\varepsilon_0 r}$$

Electron volt, eV is a unit of energy that is equal to the energy gained or lost by an electron when it is accelerated through an electric potential difference of one volt.

$$1\ eV = 1.60 \times 10^{-19}\ J$$

Equipotential lines (or surfaces) are lines (or concentric spheres) in an electric field with equal electric potential.

Electric current, I is the rate of flow of electric charge with respect to time.

$$I = \frac{dQ}{dt}$$

$$I = nAvq$$

$$where\ n = \frac{No.of\ charges}{Volume}$$

Electromotive force, ε (e.m.f.) of an electrical source is the energy converted by the source from other forms of energy to electrical energy per unit charge delivered around a complete circuit.

$$\varepsilon = \frac{W}{Q}$$

Ampere, A is the unit for electric current. It is defined as the electric current that flows through a point in a conductor when one coulomb of charge passes through the point in one second.

Coulomb, C is the unit for electric charge. It is defined as the amount of charge which passes through a point in a conductor in one second when a constant current of one ampere flows through it.

Drift velocity, v is the average velocity of charge carriers (such as electrons) attained in a conductive material due to an externally applied electric field.

Volt, V is the unit for electric potential difference, electric potential or e.m.f. It is defined as the potential difference between two points in an electrical circuit when one joule of electrical energy is converted to other forms of energy to move one coulomb of charge between those points.

Potential difference, V (or potential drop) between two points in an electrical circuit is the electrical energy converted to other forms of energy per unit charge passing from one point to the other.

$$V = \frac{W}{Q}$$

Ohm's law states that the electric current flowing through a conductor, I is directly proportional to the potential difference across it, V provided temperature and other physical conditions remain constant.

Resistance, R of a component is the ratio of the potential difference V across it to the electrical current I flowing through it.

$$R = \frac{V}{I}$$

Internal resistance, r of a power source is the resistance of the materials within the battery that causes the charge circulating to dissipate some electrical energy from the power supply itself.

$$V_T = \varepsilon - Ir$$

Resistivity, ρ is an intrinsic property of a material that quantifies how strongly the given material opposes the flow of electric current.

$$R = \frac{\rho l}{A}$$

Ohm Ω is the unit of electrical resistance. A conductor has a resistance of one ohm when an electric current of one ampere flows through it when the potential difference across the conductor is one volt.

Power, P of an electrical component is the rate of change of electrical energy with respect to time to other forms of energy.

$P = IV$	$P = \frac{V^2}{R}$	$P = I^2R$

kilowatt-hour, kWh is a unit of energy equal to the amount of work done by a power of one kilowatt operating for one hour. It is commonly used to measure electrical energy consumption.

$$1\ kWh = 3.6\ MJ = 3{,}600{,}000\ J = 3.6 \times 10^6\ J$$

Effective resistance is the equivalent resistance of a network of resistors that produces the same total current when a voltage is applied, as if the network were replaced by a single resistor.

$$R_{series} = R_1 + R_2$$
$$R_{//} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1}$$

Negative temperature coefficient (NTC) thermistor is a type of thermistor whose resistance decreases as the temperature increases.

Light dependent resistor (LDR) is a type of resistor whose resistance decreases as light intensity increases.

Potential divider is a circuit consisting of two or more resistors connected in series across a voltage source that is used to divide the input voltage, V_T into smaller output voltages, V_1 based on the ratio of the resistances, $\frac{R_1}{R_1+R_2}$.

$$V_1 = \frac{R_1}{R_1 + R_2} V_T$$

Current divider rule is a circuit principle states that the current in any parallel branch of a circuit, I_1 is proportional to the ratio of the opposite branch resistance to the total resistance, $\frac{R_2}{R_1+R_2}$, multiplied by the total current, I_T.

$$I_1 = \frac{R_2}{R_1 + R_2} I_T$$

Node in an electrical circuit is a point where two or more circuit elements are connected together.

Kirchoff's current law (KCL) states that the total current entering a junction, $\sum I_{in}$is equal to the total current leaving the junction, $\sum I_{out}$.

$$\sum I_{in} = \sum I_{out}$$

Kirchoff's voltage law (KVL) states that the sum of all potential differences around any closed loop in a circuit is equal to zero.

$$\sum V = 0$$
$$\sum emf = \sum Voltage\ drops$$

Balanced potentials refer to a situation in an electrical circuit where the potential difference across two points is equal, resulting in no current flow between the two points.

$$V_{unknown} = \frac{l}{L}\varepsilon$$

Magnetic field is a region in which a current-carrying conductor or a moving charge experiences a magnetic force when placed within it.

Temporary magnets are magnets that retain their magnetism in the presence of an electric current or a permanent magnetic field.

Permanent magnets do not require the presence of an electric current or a permanent magnetic field to retain their magnetism.

Fleming's left hand rule (FLHR) is used to determine the direction of the force acting on a current-carrying conductor in a magnetic field.

$$F = BIL\ sin\ \theta$$

$$F = Bqv \sin \theta$$

$$r = \frac{mv}{Bq}$$

Magnetic flux density, B is the force acting per unit current per unit length on a current-carrying conductor placed at right angles to the uniform magnetic field.

$$B = \frac{F}{IL}$$

$$(at\ a\ distance\ r\ from\ the\ wire)\ B = \frac{\mu_0 I}{2\pi r}$$

$$(at\ a\ distance\ r\ from\ the\ centre\ of\ coil)\ \ B = \frac{\mu_0 NI}{2r}$$

$$(inside\ a\ solenoid)\ \ B = \ \mu_0 nI$$

Ampère's law states that the magnetic field, B created around a closed loop is directly proportional to the total electric current, I_1 passing through the loop. As a result, the force per unit length, $\frac{F}{l}$ between two parallel wires is directly proportional to the product of the currents, $I_1 I_2$ and inversely proportional to the distance between them, r.

$$\int B\ dl = \mu_0 I_1$$

$$(between\ 2\ parallel\ wires)\ \ \frac{F}{l} = \frac{\mu_0\ I_1 I_2}{2\pi r}$$

Tesla, T is a unit for magnetic flux density. It is defined as the magnetic flux density of a uniform magnetic field when a wire of length 1m, carrying a current of 1A, and experiences a force of 1N in a direction perpendicular to both the field and current.

Permeability of a medium, μ_0 is a measure of the medium's ability to support the formation of a magnetic field within it when exposed to an external magnetic field.

Velocity selector is a device that uses perpendicular electric and magnetic fields to allow only charged particles with a specific velocity, v to pass through.

$$v = \frac{E}{B} = \frac{V}{Bd}$$

Magnetic flux, ϕ through a plane surface is the product of the flux density normal to the surface and the area of the surface.

$$\phi = BA\cos\theta$$

Magnetic flux linkage, Φ through a solenoid is the sum of the fluxes through the individual turns of the coil in the solenoid.

$$\Phi = N\phi\cos\theta = NBA\cos\theta$$

Weber, Wb is a unit for magnetic flux. It is defined as the magnetic flux through a $1m^2$ surface when a magnetic field with a flux density of 1T passes through it perpendicularly.

Electromagnetic induction is the process through which an induced e.m.f. is produced in a conductor due to a changing magnetic field.

Faraday's law of electromagnetic induction states that any change in the magnetic flux linkage, $\Delta\Phi$ will cause an emf to be induced in a conductor and the magnitude of the induced emf, ε is directly proportional to the rate of change of magnetic flux linkage, $\frac{d\Phi}{dt}$.

$$\varepsilon = -\frac{d\Phi}{dt} = -\frac{\Delta\Phi}{\Delta t}$$

$$|\varepsilon| = \left|-\frac{\Delta\Phi}{\Delta t}\right| = \frac{\Delta NBA\cos\theta}{\Delta t}$$

Lenz's law states that the polarity or direction of an induced e.m.f., ε and hence the induced current, I in a closed circuit, is always such that its magnetic effect opposes the motion or change in flux producing it.

Fleming's right hand rule (FRHR) is used to determine the direction of the induced current in a conductor moving through a magnetic field.

Rectification is the process of converting an alternating current into direct current which only flows in one direction.

Root-mean-square value, of an alternating current, I_{rms} (or voltage, V_{rms}) is the equivalent value of a steady direct current, I_{DC} (or voltage, V_{DC}) that would produce the same average heat dissipation in a given resistor over a complete cycle.

$Full\ wave\ rectified$	$I_{rms} = \frac{I_0}{\sqrt{2}}$	$V_{rms} = \frac{V_0}{\sqrt{2}}$
$Half\ wave\ rectified$	$I_{rms} = \frac{I_0}{2}$	$V_{rms} = \frac{V_0}{2}$
$Square\ wave$	$I_{rms} = I_0$	$V_{rms} = V_0$
$Pulse\ train$	$I_{rms} = \sqrt{\frac{W}{T}}\ V_0$	$V_{rms} = \sqrt{\frac{W}{T}}\ V_0$

Mean power, $< P >$ is the average amount of power delivered by the source to the load over a complete cycle.

$$< P > = I_{rms}\, V_{rms} = I_{rms}^2\, R = \frac{V_{rms}^2}{R}$$

$$(for\ sinusoidal\ full - wave\ rectified) < P > = \frac{1}{2}\ P_0$$

Peak power, P_0 is the maximum instantaneous power delivered by the source to the load at any point during a cycle.

$$P_0 = I_0 V_0$$

Diode is a semiconductor device that allows electric current to flow in one direction only.

Alternating current (or voltage) is an electric current (or voltage) that periodically reverses its direction many times a second at regular intervals.

$$I = I_o \sin \omega t$$

$$V = V_o\ sin\ \omega t$$

Eddy currents are induced loops of electrical current within conductors due to a changing magnetic field in the conductor.

Transformer is a device that can change a high alternating voltage to a low alternating voltage, or vice versa.

$$(for\ ideal\ )\ \frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$$

$$(for\ non - ideal)\ \ \eta V_p\, I_p = V_s\, I_s$$

Photon is a discrete packet or quantum of energy, E of electromagnetic radiation with each packet having energy hf, where h is the Planck constant, and f is the frequency of radiation.

$$E = hf$$

Threshold frequency, f_0 is the minimum frequency of an incident electromagnetic radiation required for the emission of electrons from a metal surface.

Stopping potential, V_s is the minimum negative potential difference between the collector and emitter in a photoelectric experiment that is sufficient to stop the most energetic photoelectron from reaching the collector.

$$KE_{max} = \frac{1}{2} m{v_{max}}^2 = eV_s$$

Saturation current is the maximum current that can be measured when all emitted photoelectrons are collected by the collector.

Work function Φ of a metal is the minimum amount of energy required to remove an electron from the metal surface.

$$\Phi = hf_0$$

Photoelectric effect is a phenomenon used to demonstrate the particle-like property of light. It refers to the emission of photoelectrons from the surface of a clean, cold metal when electromagnetic radiation with a frequency greater than the metal's threshold frequency is incident on it

$$KE_{max} = hf - \Phi$$

Wave-particle duality is the concept that all matter exhibit both wave-like and particle-like properties.

de Broglie wavelength, λ is the wavelength associated with a particle which highlights the wave-particle duality of matter.

$$\lambda = \frac{h}{p}$$

Emission line spectra consist of discrete coloured lines of definite frequencies (or wavelengths) on a dark background. These lines correspond to specific frequencies (or wavelengths) of photons emitted by gas atoms or molecules when electrons are de-excited and transition to a lower energy level.

Absorption line spectra consist of discrete dark lines of definite frequencies on a coloured background. These lines correspond to specific frequencies (or wavelengths) of photons absorbed by gas atoms or molecules when electrons are excited and transition to a higher energy level.

$$hf = E_2 - E_1$$

Minimum cut-off wavelength, λ_{min} is the wavelength of the X-ray photon with the most energy in the continuous X-ray spectrum that is emitted when the incident high-speed electron loses all of its KE as it approaches the target atoms.

Continuous X-ray is a spectrum of X-rays emitted due to the deceleration of high-speed electrons when they approach target atoms, producing (braking) radiation with a continuous range of wavelengths.

Characteristics X-ray spectrum is a discrete spectrum of X-rays emitted when high-speed electrons knock out the inner shell electron of the target metal atoms, causing electrons from higher energy levels to transition into the vacancy, releasing photons with fixed energies corresponding to the differences between the energy levels.

Heisenberg position-momentum uncertainty principle is an inherent limitation in quantum physics which states that it is impossible to accurately and precisely measure both the position and momentum of a particle simultaneously. The more precisely one property is measured, the less precise, and thus more uncertain, the other measurement becomes.

$$\boxed{\Delta p \, \Delta x \gtrsim h}$$

Proton number (or atomic number) is the number of protons within the nucleus of an atom.

Nucleon number is the total number of neutrons and protons within the nucleus of an atom.

$$Nucleons = Neutrons + Protons$$

Isotopes are nuclides of the same element that have the same number of protons but different numbers of neutrons.

Mass defect, Δm of a nucleus is the difference between the total mass of a nucleus and the sum of the individual masses of its constituent protons and neutrons.

$$\Delta \mathrm{m} = \text{total mass of constituent protons \& neutrons} - \text{mass of nucleus}$$

Einstein's mass-energy equivalence is the principle that mass can be converted into energy and vice versa.

$$E = mc^2$$

Rest mass, m is the intrinsic mass of an object measured when it is at rest relative to an inertial frame of reference.

Unified atomic mass, u is equal to $\frac{1}{12}$ of the mass of one carbon-12 atom ${}^{12}_{6}C$.

Binding energy, BE is the energy required to completely separate a nucleus into its constituent protons and neutrons.

$$BE = \Delta m \times c^2$$

$$BE\ per\ nucleon = \frac{BE}{Total\ no.of\ protons + neutrons}$$

Nuclear fission is a process in which a high nucleon number nucleus disintegrates into smaller and more stable nuclei with higher binding energy per nucleon, releasing a large amount of energy mostly as kinetic energy of the products.

Nuclear fusion is a process in which low nucleon number nuclei combine to form a larger, heavier, and more stable nucleus with higher binding energy per nucleon, releasing a large amount of energy mostly as kinetic energy of the products.

Radioactive decay is a random and spontaneous process in which an unstable atomic nucleus loses its energy by emission of electromagnetic radiation and/or particle(s) and transforms into a more stable nucleus.

Half-life, $t_{\frac{1}{2}}$ of a radioactive nuclide is the time taken for activity of the radioactive nuclide to fall to half its initial value.

$$t_{\frac{1}{2}} = \frac{ln2}{\lambda}$$

Spontaneous decay describes a nuclear decay process that occurs naturally without any external influence. It cannot be sped up or slowed down by physical means such as pressure or temperature.

Random decay describes a nuclear decay process which happens unpredictably. It is impossible to predict which nucleus or when any particular nucleus will disintegrate.

Background radiation refers to nuclear radiation present in an environment that originates from natural and man-made sources, where no radioactive source has been deliberately introduced.

Activity, A is a measure of the rate at which a radioactive substance decays and is defined as the average number radioactive nuclei disintegrating per unit time.

$$A = \lambda N$$

$$A = A_0 e^{-\lambda t}$$

$$N = N_0 e^{-\lambda t}$$

Decay Law states that the rate of radioactive decay, $-\frac{dN}{dt}$ is directly proportional to the number of radioactive nuclei, N present.

$$-\frac{dN}{dt} \propto N$$

Decay constant, λ represents the probability of a radioactive nucleus decaying per unit time.

Becquerel, Bq is a unit of radioactivity. It is defined as one disintegration per second.

Ionising strength of an electromagnetic radiation or a particle refers to its ability to eject electrons from atoms to form ions.

Ionisation radiation is radiation with high energies that can knock off electrons from atoms to form ions.

Range of an electromagnetic radiation or a particle in a medium is the maximum distance travelled by the radiation/particle through the medium before being absorbed, scattered, or losing all its energy.

Data

Data		Applicable formulas
Speed of light in free space	$c = 3.00 \times 10^{8}\ m\ s^{-1}$	$E = mc^2$ $E = \frac{hc}{\lambda}$
Permeability of free space	$\mu_0 = 4\pi \times 10^{7}\ Hm^{-1}$	$B = \frac{\mu_0 I}{2\pi r}$ $B = \frac{\mu_0 NI}{2r}$ $B = \mu_0 nI$
Permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\ F\ m^{-1}$	$F_E = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$ $V = \frac{Q}{4\pi\varepsilon_0 r}$
Elementary charge	$e = 1.60 \times 10^{-19}\ C$	$U = eV$ $F = eE$ $I = nAve$
Planck's constant	$h = 6.63 \times 10^{-34}\ J\ s$	$E = \frac{hc}{\lambda}$ $\lambda = \frac{h}{p}$
Unified atomic mass constant	$u = 1.66 \times 10^{-27}\ kg$	-
Rest mass of electron	$m_e = 9.11 \times 10^{-31}\ kg$	-
Rest mass of proton	$m_p = 1.67 \times 10^{-27}\ kg$	-
Molar gas constant	$R = 8.31\ J\ K^{-1}\ mol^{-1}$	$pV = nRT$ $v_{rms} = \sqrt{< c >^2} = \sqrt{\frac{3RT}{M}}$
Avogadro constant	$N_A = 6.02 \times 10^{23}\ mol^{-1}$	$N = n \times N_A$
Boltzmann constant	$k = 1.38 \times 10^{-23}\ J\ K^{-1}$	$pV = NkT$ $KE = \frac{3}{2}kT$
Gravitational constant	$G = 6.67 \times 10^{-11}\ N\ m^2\ kg^{-2}$	$F_G = \frac{GMm}{r^2}$
Acceleration of free fall	$g = 9.81\ m\ s^{-1}$	$g = \frac{GM}{r^2}$