Glossary

Standard level

The glossary contains key words, equations and terms from the IB Physics Diploma course. This section takes words from Chapters 1–8.

A

Absolute temperature scale See *Kelvin scale of temperature*.

Absolute zero Temperature at which (almost) all molecular motion has stopped (0 K or −273 °C). The fixed lower point of the Kelvin temperature scale (absolute temperature).

Absorption Energy of particles or radiation is transferred to other forms within a material, so that it is not transmitted.

Absorption spectrum A series of dark lines across a continuous spectrum produced when light passes through a gas at low pressure.

Acceleration, *a* Rate of change of velocity with time, $a = \frac{\Delta v}{\Delta t}$ (unit: $m\,s^{-2}$). Acceleration is a vector quantity. Negative acceleration is commonly called *deceleration*.

Acceleration of free fall due to gravity Acceleration of a mass falling freely towards Earth. Numerically equal to the gravitational field strength on or near the Earth's surface, $g = 9.8 \approx 10\,m\,s^{-2}$.

Accuracy A single measurement is described as accurate if it is close to the correct result. A series of measurements of the same quantity can be described as accurate if their mean is close to the correct result. Accurate results have small systematic errors.

Activity of a radioactive source The number of decays every second.

Aerial A metallic conductor connected to an electronic circuit, which is designed to efficiently transmit or receive electromagnetic waves (usually radio waves or microwaves).

Aerodynamics The study of how objects move through air, or how air flow affects stationary objects.

Air resistance Resistive force opposing the motion of an object through air.

Albedo Defined as the total scattered or reflected power/total incident power (on part of a planet's surface). Albedo depends on the nature of the surface, cloud cover and inclination of the radiation to the surface. The Earth's annual mean albedo is approximately 30%.

Alpha particle A fast-moving helium-4 nucleus emitted by a radioactive nucleus, consisting of two protons and two neutrons tightly bound together.

Alternating current (ac) A flow of electric charge which changes direction periodically.

Ammeter An instrument which measures electric current.

Amount of a substance, *n* The number of defining particles in a substance. Usually measured in moles.

Ampere, A Fundamental SI unit of electric current. Commonly called an amp.

Amplitude, x_0 or A Defined as the maximum displacement of a wave or oscillation.

Analogue instrument Measuring instrument which has a pointer moving over a continuous scale. Compare with *digital instrument*.

Analogy Applying knowledge of one subject to a different subject using their similarities.

Angular momentum, *L* The angular momentum of an electron in a hydrogen atom is equal to its linear momentum multiplied by its orbital radius.

Annihilation (pair) When a particle and its antiparticle interact, they annihilate and their mass is converted to electromagnetic energy.

Anode An electrode into which (conventional) current flows from the circuit.

Antineutrino Low mass and very weakly interacting particle emitted during beta-negative decay. Antiparticle of a neutrino.

Antinodes The positions in a standing wave where the amplitude is greatest. See also *nodes*.

Antimatter Matter consisting of antiparticles.

Antiparticle Every particle has an antiparticle which has the same mass, but opposite charge and/or quantum numbers. (Some particles, for example photons, are their own antiparticles.)

Aperture A hole or gap. Usually applied to the control of light entering an optical instrument.

Atomic energy level One of a series of possible discrete energy levels of an electron within an atom.

Audible range Range of frequencies which can be heard by humans.

Avogadro's constant, N_A The number of particles in one mole of a substance (equal to the number of carbon atoms in 12 g of carbon-12).

B

Background radiation Ionizing radiation from radioactive materials in rocks, soil building materials and the environment, as well as cosmic radiation from outer space.

Banking The use of sloping surfaces to enable faster motion around curves.

Barometer An instrument for measuring atmospheric pressure.

Baryons Particles made from the combination of three quarks. For example, protons and neutrons.

Battery One or more electric cells.

Beta particle A high-speed electron which is released from a nucleus during *beta negative decay*, or a high-speed *positron* released during *beta positive decay*.

Bias A preference for one opinion, or one side of a discussion, often without fair consideration of others.

Binding energy, nuclear The energy released when a nucleus is formed from its constituent nucleons. Alternatively, it is equal to the work required to separate the nucleons completely. Binding energy is the energy equivalent of the mass defect.

Binding energy per nucleon (average) The binding energy of a nucleus divided by the number of nucleons it contains. It is a measure of the stability of a nucleus.

Black body An idealized object which absorbs all the electromagnetic radiation that falls upon it. A perfect black body also emits the maximum possible radiation.

Black-body radiation Radiation emitted from a 'perfect' emitter/black body. The characteristic ranges of different radiations emitted (spectra) at different temperatures are commonly shown in graphs of intensity against wavelength (or frequency).

Boil The change from a liquid to a gas at a well-defined temperature. This occurs throughout the liquid.

Boltzmann's constant, k_B Important constant which links microscopic molecular energies to macroscopic temperature measurements. Linked to the universal gas constant, R, by the equation: $k_B = \frac{R}{N_A}$.

Bosons A class of sub-atomic particle which includes gauge bosons, the Higgs boson and mesons.

Boundary (between media) A surface where waves may be reflected or transmitted (and maybe refracted).

Boundary conditions The conditions at the ends of a standing wave system. These conditions affect whether there are nodes or antinodes at the ends.

C

Calibrate To put numbered divisions on a scale.

Calorimeter An apparatus designed for experiments investigating thermal energy transfers. Such experiments are described as *calorimetric*.

Carbon dating A method of using the radioactive decay of carbon-14 to estimate the age of once-living biological material.

Cathode An electrode out of which (conventional) current flows around a circuit.

Cell (electric) A device which transfers chemical energy to the energy carried by an electric current. It is also called an electrochemical cell or a voltaic cell. See also *primary cell* and *secondary cell*.

Celsius A temperature scale based on the melting point (0 °C) and boiling point (100 °C) of water.

Centre of mass The average position of all the mass of an object. The mass of an object is distributed evenly either side of any plane through its centre of mass.

Centripetal acceleration and force Any object moving in a circular path has an acceleration towards the centre of the circle, called its centripetal acceleration. It can be calculated from the expression $a = \frac{v^2}{r}$. The force producing this acceleration is called a centripetal force, $F = \frac{mv^2}{r}$.

Chain reaction (nuclear) If, on average, one (or more) of the neutrons produced in a nuclear fission process causes further fission, the process will not stop and will become a self-sustaining nuclear chain reaction.

Charge The fundamental property of some sub-atomic particles which makes them experience electric forces when they interact with other charges. Charges may be *positive* or *negative*.

Charge a cell Reverse chemical reactions in a cell with an electric current so that the cell can be used again. It can also be called recharging.

Charge an object To add or remove electrons so that an object acquires an overall net charge.

Charge density, n The number of mobile charges in unit volume of a material.

Charging characteristic of a secondary cell P.d.–time graph for the length of charging process.

Chemical potential energy The energy related to the arrangement of electrons within the structure of atoms and molecules.

Circuit (electrical) A complete conducting path that enables an electric current to transfer energy continually from a source of potential difference (voltage) to various components.

Circuit breaker An electromagnetic device used to disconnect an electrical circuit in the event of a fault.

Classical physics Physics theories that pre-dated the paradigm shifts introduced by quantum physics and relativity.

Climate models Complex computerized modelling which attempts to predict the future climate of the planet, especially how it will be affected by global warming.

Coefficients of friction, μ Constants used to represent the amount of friction between different two surfaces: $F_f \leq \mu_s R$ (for static friction), $F_f = \mu_d R$ (for dynamic friction).

Coherent waves Waves that have the same frequency and a constant phase difference.

Collision Two (or more) objects coming together and exerting forces on each other for a short length of time. In an *elastic collision*, the total kinetic energy before and after the collision is the same. In an *inelastic collision*, the total kinetic energy is reduced after the collision. If the objects stick together it is described as a *totally inelastic collision*.

Compass A device for determining the direction to geographic north. A magnetic compass points to a magnetic south pole. Small plotting compasses are used to investigate the shapes of magnetic fields in the laboratory.

Components of a vector For convenience, a single vector quantity can be considered as having two parts

(components), usually perpendicular to each other. The combined effect of these components is exactly the same as the single vector. See also *resolve*.

Composite particles Particles that have internal structure because they contain other particles.

Compression (force) A force that tries to squash an object or material.

Compressions (in a longitudinal wave) Places where there are increases in the density and pressure of a medium as a wave passes through it.

Condensation The change from a gas (or vapour) to a liquid.

Conduction (thermal) The passage of thermal energy through substances as energy is transferred from particle to particle.

Conductor (electrical) A material through which an electric current can flow because it contains significant numbers of mobile charges (usually free electrons).

Confinement (quark) The term used to describe the fact that free individual quarks are never observed.

Conservation laws

Charge The total charge in any isolated system remains constant.

Energy The total energy in any isolated system remains constant. Energy cannot be created or destroyed.

Momentum The total momentum in any isolated system remains constant. The total (linear) momentum of a system is constant provided that no external forces are acting on it.

Quantum numbers In an equation describing a nuclear interaction, the total quantum numbers must be the same on both sides.

Contact (normal) forces Forces that occur between surfaces which are touching each other. Contact forces are perpendicular (normal) to the surfaces.

Control rods These are used to adjust the rate of fission reactions in nuclear reactors by absorbing more or fewer neutrons.

Controlled and uncontrolled nuclear fission In a nuclear power station the number of neutrons in the reactor core is carefully controlled in order to maintain the rate of the nuclear reactions. In nuclear weapons the number of neutrons is uncontrolled.

Convection The passage of thermal energy through liquids and gases due to the movement of the substance. This occurs because of differences in density.

Conventional current The direction of flow of a direct current is always shown as being from the positive terminal of the power source, around the circuit, to the negative terminal. The conventional current is opposite in direction to electron flow.

Correlation There is a correlation between data if they are interconnected in some way.

Coulomb, C The derived unit of measurement of electric charge. One coulomb of charge passes a point in one second if the current is one amp.

Coulomb constant, *k* The constant that occurs in the Coulomb's law equation: $k = \frac{1}{(4\pi\varepsilon_0)}$, where ε_0 is the electrical permittivity of free space.

Coulomb's law There is an electric force between two point charges, q_1 and q_2, given by $F = \frac{kq_1q_2}{r^2}$, where r is the distance between them and k is the Coulomb constant. The law may also be applied to charged spheres that are relatively far apart.

Count rate (radioactivity) Nuclear radiation is usually detected as a series of events which are 'counted'. A radiation 'counter' may display the count in a given time (per minute or per second). This is called the count rate.

Crest The highest part of a transverse mechanical wave.

Critical angle When a light ray meets a boundary with another medium with a lower refractive index, it will be totally internally reflected if the angle of incidence is greater than the critical angle.

Critical mass The minimum mass needed for a self-sustaining nuclear chain reaction.

Current (electric), *I* A flow of electric charge. Equal to the amount of charge passing a point in unit time: $I = \frac{\Delta q}{\Delta t}$. $1\,A = 1\,C\,s^{-1}$. Measured in amperes.

Cycle (oscillation) One complete oscillation.

D

Daughter product The resulting nuclide when a radioisotope decays.

Decay series (chain) A series of nuclides linked in a chain by radioactive decay. Each nuclide in the chain decays to the next until a stable nuclide is reached.

Deformation A change of shape.

Degraded energy Energy that has spread into the surroundings and cannot be recovered to do useful work.

Density, ρ Mass/volume. SI unit: $kg\,m^{-3}$.

Deplete To use up the supply of a resource.

Derived units Units of measurement that are defined in terms of other units.

Determinism The belief that future events are completely controlled by past events, so that full knowledge of the present can only lead to one outcome.

Diffraction The spreading of waves as they pass around obstacles or through apertures.

Diffusion The random movement of particles from a place of high concentration to places of lower concentration.

Digital communication Data are transferred as a signal containing only a very large number of digital pulses, each of which can only have one of two possible levels (0 or 1).

Digital instrument A measuring instrument that displays the measurement only as digits (numbers). Compare with *analogue instrument*.

Dipole Two close electric charges (or magnetic poles) of equal magnitude but of opposite sign (or polarity).

Direct current (dc) A flow of electric charge which is always in the same direction.

Discharge a battery/cell Use a cell to drive a current through a circuit, reducing the energy available for future use.

Discharge an object The flow of electrons to or from an object that reduces the overall (net) charge on it.

Discharge characteristic (of a battery/cell) P.d.–time graph for the duration of the battery/cell's use.

Discrete Individually separate.

Disperse (light) Separate, usually into different wavelengths/colours (e.g. to form a spectrum).

Displacement, angular, θ Defined as the angle through which a rigid body has been rotated from a reference position.

Displacement, linear, s Defined as the distance from a reference point in a specified direction. A vector quantity.

Dissipate To spread out so that it cannot be recovered.

Distance, s Length, a scalar quantity.

Drag The force(s) opposing motion through a fluid, sometimes called fluid resistance.

Drift speed The net speed of charges moving in an electric current.

Drift speed equation The equation relating drift speed to current: $I = nAvq$.

Dynamo A type of electric generator which produces direct current.

E

Earth (ground) connection A good conductor connected between a point on a piece of apparatus and the ground. This may be part of a safety measure, or to ensure that the point is kept at 0 V.

Echo A reflected sound which is heard distinctly from the original sound.

Efficiency Defined as the ratio of the useful energy (or power) output from a device to the total energy (or power) input; often expressed as a percentage.

Elastic behaviour A material shows elastic behaviour if it regains its original shape after a force causing deformation has been removed.

Elastic strain potential energy, E_P A form of energy that is stored in a material which has been deformed elastically. The energy is transferred when the material returns to its original shape: $E_P = \frac{1}{2}k\Delta x^2$.

Electric field A region of space where any charge would experience an electric force. It is represented in drawings by field lines.

Electric field strength, E Defined as the electric force per unit charge that would be experienced by a small test charge placed at that point: $E = \frac{F}{q}$ (unit: $N\,C^{-1}$).

Electric forces The fundamental forces that act across space between all charges. The forces between opposite charges are attractive. The forces between similar charges are repulsive. Reduces with an inverse square relationship with distance between point charges. See *Coulomb's law*.

Electric potential energy The energy stored due to the forces between charges.

Electrode A conductor used to make an electrical connection to a non-metallic part of a circuit.

Electrolysis The passage of an electric current through a substance in a liquid or molten state which causes chemical changes.

Electrolyte A solution that contains mobile ions.

Electromagnetic induction A process used by a generator to convert kinetic energy into electricity.

Electromagnetic spectrum Electromagnetic waves of all possible different frequencies, displayed in order. In order of increasing frequency: *radio waves*, *microwaves*, *infrared*, *visible light*, *ultraviolet*, *X-rays*, *gamma rays*. The visible spectrum in order of increasing frequency: red, orange, yellow, green, blue, indigo, violet.

Electromagnetic waves Linked electric and magnetic oscillations that can travel across vacuum at a speed of $3.0 \times 10^8\,m\,s^{-1}$. See *electromagnetic spectrum*.

Electromotive force (emf), ε Defined as the total energy transferred in a source of electrical energy per unit charge passing through it.

Electron A sub-atomic particle with a negative charge ($-1.6 \times 10^{-19}\,C$) and mass of $9.110 \times 10^{-31}\,kg$; present in all atoms and located outside the nucleus in discrete energy levels.

Electronvolt, eV Defined as the amount of energy transferred when an electron is accelerated by a p.d. of 1 V. $1\,eV = 1.6 \times 10^{-19}\,J$

Elementary particles Particles which have no internal structure. They are not composed of other particles. For example, electrons. They are sometimes called fundamental particles.

Elliptical In the shape of an ellipse (oval).

Emission spectrum The line spectrum associated with the emission of electromagnetic radiation by atoms, resulting from electron transitions from higher to lower energy levels.

Emissivity, e The power radiated by an object divided by the power radiated from a perfect black body of the same surface area and temperature.

Empirical Based on observation and/or experiment.

Endoscope A medical device which uses the total internal reflection of light to obtain images from inside the body.

Energy density The energy transferred from a unit volume of a source (units: $J\,m^{-3}$). Compare with *specific energy*.

Equation of state for an ideal gas $pV = nRT$ Describes the macroscopic physical behaviour of ideal gases.

Equations of motion Equations that can be used to make calculations about objects that are moving with uniform linear acceleration.

Equilibrium position The position in which there is no resultant force acting on an object.

Equilibrium (translational) An object is in translational equilibrium if there is no resultant force acting on it, so that it remains at rest or continues to move with a constant velocity.

Equivalence of mass and energy Any change of energy is equivalent to a certain change of mass, according to the equation $\Delta E = \Delta mc^2$.

Error When a measurement is not exactly the same as the correct value.

Error bars Vertical and horizontal lines drawn through each data point on a graph to represent the uncertainties in the two values.

Evaporation The change from a liquid to a gas occurring on the surface at a temperature below the boiling point.

Exchange particles Also known as gauge bosons. The exchange of these particles is used to explain fundamental forces (interactions). *Photons*, *gluons* and *bosons*.

Excitation The addition of energy to a system, usually changing it from its ground state to an excited state. Excitation of a nucleus, an atom or a molecule can result from absorption of photons or from inelastic collisions with other particles.

Expansion Increasing in size.

Explosion Sudden movement of masses from a central point in opposite directions (usually at high speeds).

Exponential change A change in which the rate of change of the quantity at any time is proportional to the actual quantity at that instant.

Extension Displacement of the end of an object which is being stretched.

F

Feedback When the past results of a continuing process are used to change future events in the same process. If results cause increased effects, it is described as positive feedback. If results cause reduced effects, it is called negative feedback.

Feynman diagrams A graphical means of representing particle interactions by the use of one or more vertices.

Field (gravitational, electric or magnetic) A field is a region of space in which a mass (or a charge or a current) experiences a force due to the presence of one or more other masses (charges or currents – moving charges).

Field lines and patterns Fields can be represented in drawings by a pattern of lines. Each line shows the direction of force on a mass (in a gravitational field), or on a positive charge (in an electric field), or of the north pole (in a magnetic field). A field is strongest where the lines are closest together. See also *uniform field* and *radial field*.

Filament lamp A lamp which emits light from a very hot metal wire. Also called an incandescent lamp.

Finite Limited.

Fissile Able to undergo nuclear fission.

Fission fragments The nuclei produced in a nuclear reaction.

Flavours (of quark) There are six different kinds of quark, which are called 'flavours' of quarks: *up*, *down*, *strange*, *charm*, *bottom*, *top*. The different types of lepton are also called flavours.

Fluid A liquid or gas.

Fluid resistance Force(s) opposing motion through a fluid, sometimes called drag.

Fluorescent lamp A lamp which produces light by passing electricity through mercury vapour at low pressure.

Force constant, *k* The ratio of force to extension for a stretched material or spring: $k = \frac{\Delta F}{\Delta x}$ (sometimes called the spring constant).

Force meter An instrument used to measure forces. It is sometimes called a newton meter or a spring balance.

Fossil fuels Naturally occurring fuels that have been produced by the effects of high pressure and temperature on dead organisms (in the absence of oxygen) over a period of millions of years. Coal, oil and natural gas are all fossil fuels used in power stations.

Frame of reference (for motion) A location to which observations and measurements of motion are compared. For example, the speed of a car may be $10\,m\,s^{-1}$ compared to the Earth's surface.

Free-body diagram A diagram showing all the forces acting on a single object, and no others.

Free electrons Electrons (most commonly in metals) that are not attached to individual atoms. They are also called delocalized electrons. They provide the mobile charges that are needed for an electric current to flow in solid conductors.

Free fall The motion through the air under the effects of gravity but without air resistance. In common use free fall can also mean falling towards Earth without an open parachute.

Free space A place where there is no air or other matter. Also called a vacuum.

Freeze The change from a liquid to a solid. Also called solidification.

Frequency, *f* Defined as the number of oscillations per unit time, or the number of waves passing a point per unit time (usually per second): $f = \frac{1}{T}$.

Friction Resistive forces opposing relative motion, particularly between solid surfaces (*solid friction*). Static friction prevents movement, whereas dynamic friction occurs when there is already motion.

Fuel A store of energy (chemical or nuclear) which can be transferred to do useful work (for example, generate electricity or power vehicles).

Fundamental Having no simpler explanation.

Fundamental forces (interactions) Strong nuclear, weak nuclear, electromagnetic, gravitational.

Fundamental units Units of measurement that are not defined as combinations of other units.

Fusion (thermal) Melting.

G

Gamma radiation, ray Electromagnetic radiation (photons) emitted during radioactive decay and having an extremely short wavelength.

Gas laws Laws of physics relating the temperature, pressure and volume of a fixed mass of an ideal gas: Boyle's law, Charles' law and the pressure law.

Gauge bosons See *exchange particles*.

Geiger–Muller tube An apparatus used to detect the radiation from a radioactive sample.

Generator (electrical) A device which converts kinetic energy into electricity.

Global warming The increasing average temperatures of the Earth's surface, atmosphere and oceans.

Gluon The exchange particle for the strong nuclear force.

Gravitational field strength, *g* Defined as the gravitational force per unit mass that would be experienced by a small test mass placed at that point: $g = \frac{F}{m}$ (unit: N kg^{-1}).

Gravitational forces Fundamental attractive forces that act across space between all masses. They reduce with an inverse square law with distance between point masses.

Gravitational potential energy, E_P Energy that masses have because of the gravitational forces between them. Changes in gravitational potential energy in a uniform field can be calculated from $\Delta E_P = mg\Delta h$.

Graviton The exchange particle for gravitational forces (to be confirmed).

Greenhouse effect The natural effect that a planet's atmosphere has on reducing the amount of radiation emitted into space, resulting in a warmer planet (warmer than it would be without an atmosphere).

Greenhouse effect (enhanced) The reduction in radiation emitted into space from Earth due to an increasing concentration of greenhouse gases in the atmosphere (especially carbon dioxide) caused by human activities; believed by most scientists to be the cause of global warming.

Greenhouse gases Gases which absorb and emit infrared radiation and thereby affect the temperature of the Earth. The principal greenhouse gases are water vapour, carbon dioxide, methane and nitrous oxide. Atmospheric concentrations of the last three of these have been increasing significantly in recent years.

Ground state The lowest energy state of an atom/electron.

H

Hadrons Particles made from the combination of quarks. For example, baryons and mesons.

Half-life (radioactive) The time taken for the activity or count rate from a source, or the number of radioactive atoms, to be reduced by half; the half-life is constant for a particular radioisotope.

Harmonics Different frequencies (modes) of vibration of an oscillating given system. They are mathematically related and numbered as *first harmonic*, second, third etc.

Heat engine A device that uses the flow of thermal energy to do useful work.

Heat exchanger Equipment designed to transfer thermal energy efficiently from one place to another.

Hertz, Hz The derived unit of measurement of frequency: 1 Hz = 1 oscillation per second.

Higgs boson The exchange of Higgs bosons in the *Higgs field iggs field* is responsible for giving particles the properties of mass.

Hooke's law The force needed to deform a spring is proportional to the extension (or compression).

Hydroelectric power (HEP) The generation of electrical power from falling water.

I

Ideal gas The kinetic model of an ideal gas makes the following assumptions: **i** The molecules are identical. **ii** The molecules are point masses with negligible size and volume. **iii** The molecules are in completely random motion. **iv** There are negligible forces between the molecules, except when they collide. **v** All collisions are elastic, that is, the total kinetic energy of the molecules remains constant.

Ideal meters Meters that have no effect on the electrical circuits in which they are used. An *ideal ammeter* has zero resistance and an *ideal voltmeter* has infinite resistance.

Imagination The formation of new ideas which is not related to direct sense perception or experimental results.

Immersion heater A heater placed inside a liquid or object.

Impact A collision involving relatively large forces over a short time. The effect of such an impact may be

different from the same impulse (Ft) delivered by a smaller force over a longer time.

Impulse Defined as the product of force and the time for which the force acts. It is equal to the change of momentum (unit: N s).

Incidence, angle The angle between an incident ray and the normal (or between the incident wave and the boundary).

Incident wave or ray A wave (or ray) arriving at a boundary.

Inclined plane A flat surface at an angle to the horizontal (but not perpendicular). A simple device which can be used to reduce the force needed to raise a load, sometimes called a ramp.

Infinite Without limits.

Inspiration Stimulation (usually to be creative).

Instantaneous value The value of a quantity at one particular instant (not an average value).

Insulator (electrical) A non-conductor. A material through which a (significant) electric current cannot flow, because it does not contain many mobile charges. Compare with *conductor*.

Insulator (thermal) A non-conductor. A material through which (significant) thermal energy cannot flow.

Intensity, *I* Defined as wave power/area: $I = \frac{P}{A}$. The intensity of a wave is proportional to its amplitude squared, $I \propto A^2$.

Interaction An event in which two or more objects exert forces on each other.

Interference A superposition effect that may be produced when similar waves meet. It is most important for waves of the same frequency and similar amplitude. Waves arriving in phase will interfere constructively because their path difference = $n\lambda$. Waves completely out of phase will interfere destructively because their path difference = $(n + \frac{1}{2})\lambda$.

Internal energy The total potential energy and random translational kinetic energy of the molecules of a substance.

Internal resistance, *r* Sources of electrical energy, for example batteries, are not perfect conductors. The materials inside them have resistance in themselves, which we call internal resistance. This results in energy dissipation in the battery and a reduction in the useful voltage supplied to the circuit. See also *lost volts*.

Intuition Immediate understanding, without reasoning.

Inverse square law For waves/energy/particles/fields spreading equally in all directions from a point source without absorption or scattering: the intensity is inversely proportional to the distance squared: $I \propto x^{-2}$.

Ionization The process by which an atom gains or loses one or more electrons, thereby becoming an ion. The required energy is called the ionization energy.

Ionizing radiation Radiation with enough energy to cause ionization in materials through which it passes.

Isochronous Describing events that take equal times.

Isotope Two or more atoms of the same element with different numbers of neutrons (and therefore different masses). A radioisotope is unstable and will emit ionizing radiation.

J

Jet engine An engine which achieves propulsion by emitting a fast-moving stream of gas or liquid in the opposite direction to the intended motion.

Joule, J Derived SI unit of work and energy: 1 J = 1 N m.

K

Kelvin scale of temperature Also known as the absolute temperature scale. A temperature scale based on absolute zero (0 K) and the melting point of water (273 K). The kelvin, K, is the fundamental SI unit of temperature: $\frac{T}{\text{K}} = \frac{\theta}{°\text{C}} + 273$. The kelvin (absolute) temperature is a measure of the mean random translation kinetic energy of one molecule of an ideal gas: $\bar{E}_\text{K} = \frac{3}{2}k_\text{B}T$. The total translational kinetic energy of one mole of an ideal gas = $\frac{3}{2}RT$.

Kilogram, kg SI unit of mass (fundamental).

Kilowatt hour, kWh The amount of electrical energy transferred by a 1 kW device in one hour.

Kinematics The study of moving objects.

Kinetic energy, E_K Energy of moving masses; translational KE is calculated from $\frac{1}{2}mv^2$.

Kinetic model of an ideal gas The idealized motions of the molecules in a gas used to predict the macroscopic behaviour of gases. See also *ideal gas*.

Kirchhoff's first circuit law $\Sigma I = 0$ (junction).

Kirchhoff's second circuit law $\Sigma V = 0$ (loop).

L

Lagging Thermal insulation.

Latent heat Thermal energy that is transferred at constant temperature during any change of physical phase. See also *specific latent heat*.

Left-hand rule (Fleming's) A rule for predicting the direction of the magnetic force on moving charges or a current in a wire.

Lens Curved transparent surface(s) used to refract waves to form a focus.

Leptons Elementary particles of low mass (*electrons*, *taus* and *muons* and their neutrinos).

Light dependent resistor (LDR) A resistor that has less resistance when placed in light of greater intensity.

Light emitting diodes (LEDs) Small semiconducting diodes that emit light of various colours at low voltage and power.

Linear relationship A relationship that produces a straight line graph.

Line of action (of a force) A line through the point of application of a force which shows the direction in which the force is applied.

Liquid crystal displays (LCD) Displays that use liquid crystal layers between polarizing filters. Voltages applied to the liquid crystal change its plane of polarization.

Longitudinal wave A wave in which the oscillations are parallel to the direction of transfer of energy, for example sound waves. Sometimes called a compression wave.

Lost volts A term sometimes used to describe the voltage drop that occurs when a source of electrical energy delivers a current to a circuit.

M

Macroscopic This describes an object that can be observed without the need for a microscope.

Magnetic field strength, *B* Defined as the force acting per unit length on unit current moving across the field at an angle θ: $B = \frac{F}{(IL\sin\theta)}$ (unit: tesla; $1\,T = 1\,N\,A^{-1}\,m^{-1}$).

Magnetic forces Fundamental forces that act across space between moving charges, currents and/or permanent magnets. The forces are perpendicular to the direction of the current.

Magnetic potential energy Energy associated with arrangements of magnets and currents.

Magnitude Size.

Mains electricity Electrical energy supplied to many different homes by cables from power stations.

Malus's law Used for calculating the intensity of light transmitted by a polarizing filter: $I = I_0\cos^2\theta$. I_0 is incident intensity and θ is the angle between the polarizer axis and the plane of polarization of the light.

Manometer A liquid in a U-tube used for measuring differences in gas pressure.

Mapping Representing the inter-relationships between ideas, knowledge or data by drawing (graphically).

Mass The property of matter which resists changes of motion.

Mass defect The difference in mass between a nucleus and the total masses of its constituent neutrons and protons when separated.

Mechanics The study of motion and the effects of forces on objects.

Medical scanners/imagers Equipment used in hospitals for obtaining images of the internal structure of the body.

Medium (of a wave) Material through which a wave is passing (plural: media).

Meltdown (thermo-nuclear) Common term for the damage to the core and reactor vessel which results from overheating following some kind of accident at a nuclear power station.

Mesons Particles which contain a quark and an antiquark.

Methodology An outline of the way in which a study, investigation or project is carried out.

Metre, m SI unit of length (fundamental).

Metric multiplier Prefix to a unit of measurement to indicate multiples or fractions of that unit. For example, kilo- indicates a multiple of 1000.

Microscopic This describes anything which is too small to be seen with the unaided eye.

Modelling A central theme of science: representing reality with simplified theories, drawings, equations, etc., in order to achieve a better understanding and make predictions.

Moderator A material used in a nuclear reactor to slow down neutrons to low energies.

Modes of vibration The different ways in which a standing wave may be set up in a given system. See also *harmonics*.

Molar mass Defined as the mass of a substance which contains one mole of its defining particles.

Mole, mol SI unit of amount of substance (fundamental). Defined as the amount of a substance that contains as many of its defining particles as there are atoms in exactly 12 g of carbon-12.

Momentum (linear), *p* Defined as mass times velocity: $p = mv$ (unit: $kg\,m\,s^{-1}$). A vector quantity.

Monochromatic Containing only one colour/frequency/wavelength (more realistically: a narrow range).

Motor effect The magnetic force on a current in a magnetic field, as utilized in electric motors.

N

Natural gas A naturally occurring mixture of gases (mainly methane) that can be used as a fuel. May be either a fossil fuel or produced by more recent biological processes.

Natural philosophy The name used to describe the (philosophical) study of nature and the universe before modern science.

Negligible Too small to be significant.

Neutral Uncharged, or zero net charge.

Neutrino A low mass and very weakly interacting particle emitted during beta-positive decay. Antiparticle of antineutrino.

Neutron A neutral sub-atomic particle with a mass of 1.675×10^{-27} kg. The number of neutrons in a nucleus is called the *neutron number* (N).

Neutron capture A nuclear reaction in which a neutron interacts with a nucleus to form a heavier nucleus.

Newton, N A derived SI unit of force: $1\,N = 1\,kg\,m\,s^{-2}$.

Newton's laws of motion

First law An object will remain at rest, or continue to move in a straight line at a constant speed, unless a resultant force acts on it.

Second law Acceleration is proportional to resultant force: $F = ma$ or $F = \frac{\Delta p}{\Delta t}$.

Third law Whenever one body exerts a force on another body, the second body exerts exactly the same force on the first body, but in the opposite direction.

Newton's universal law of gravitation There is a gravitational force between two point masses, M and m, given by $F = \frac{GMm}{r^2}$, where r is the distance between them and G is the universal gravitation constant. The law may also be applied to spherical masses which are relatively far apart.

Nodes The positions in a standing wave where the amplitude is zero. See also *antinodes*.

Non-renewable energy sources Energy sources that take a very long time to form and which are being rapidly 'used-up' (depleted).

Normal Perpendicular to a surface.

Nuclear equation An equation representing a nuclear reaction. The sum of nucleon numbers (A) on the left-hand side of the nuclear decay equation must equal the sum of the nucleon numbers on the right-hand side of the equation. This also applies to proton numbers (Z).

Nuclear fission A nuclear reaction in which a massive nucleus splits into smaller nuclei whose total binding energy is greater than the binding energy of the initial nucleus, with the simultaneous release of energy.

Nuclear fusion Nuclear reaction in which two light nuclei form a heavier nucleus whose binding energy is greater than the combined binding energies of the initial nuclei, thereby releasing energy.

Nuclear potential energy Energy associated with the arrangement of particles in the nucleus of an atom.

Nuclear waste Radioactive materials associated with the production of nuclear power that are no longer useful, and which must usually be stored safely for a long period of time.

Nucleon A particle in a nucleus, either a neutron or proton. The *nucleon number* (A) is the total number of protons and neutrons in the nucleus.

Nucleus The central part of an atom containing protons and neutrons. A nucleus is described by its atomic number and nucleon number. See *nuclide*.

Nuclide Term used to identify one particular species (type) of atom, as defined by the structure of its nucleus. A radionuclide is an unstable nuclide that will emit radiation.

O

Objective Free from bias and emotion. Compare with *subjective*.

Observer effect Occurs when the act of observation, or measurement, has an effect on the phenomenon being observed.

Ohm, Ω The derived unit of measurement of electric resistance: $1\,\Omega = \frac{1\,\text{v}}{1\text{A}}.1\,\text{V}$

Ohmic behaviour The electrical behaviour of an ohmic component is described by Ohm's law.

Ohm's law The current in a conductor is proportional to the potential difference across it, provided that the temperature is constant.

Optical fibre A thin flexible fibre of high quality glass which uses total internal reflection to transmit light along curved paths and/or over large distances.

Optically active substances Substances that rotate the plane of polarization of light which is passing through them.

Orbit The curved path (often assumed circular) of a mass, or charge, around a larger central mass or charge.

Order of magnitude When a value for a quantity is not known precisely, we can give an approximate value by quoting an order of magnitude. This is the estimated value rounded to the nearest power of ten. For example, 400 000 has an order of magnitude of 6 (10^6) because $\log_{10} 400\,000 = 5.602$, which is nearer to 6 than 5.

Oscillation Repetitive motion about a fixed point.

P

Pair production Conversion of photon energy into a particle and its antiparticle. The opposite of annihilation.

Parabolic In the shape of a parabola. The trajectory of a projectile if air resistance is negligible.

Paradigm (physics) A widely accepted model and way of thinking about a particular aspect of the physical world.

Parallax error An error of measurement that occurs when reading a scale from the wrong position.

Parallel connection Two or more components connected between the same two points, so that they have the same p.d. across them.

Particle accelerator An apparatus designed to produce particle beams of charged sub-atomic particles (or ions).

Particle beams Streams (flows) of very fast moving particles, most commonly charged particles (electrons, protons or ions), moving across a vacuum. Properties of the individual particles can be deduced by observing the behaviour of the beams in electric and/or magnetic fields.

Pascal, Pa The derived SI unit of pressure: $1\,\text{Pa} = 1\,\text{N}\,\text{m}^{-2}$.

Path difference The difference in distance of two sources of waves from a particular point. If the path difference between coherent waves is a whole number of wavelengths, constructive interference will occur.

Peer review The evaluation of scientific results and reports by other scientists with expertise in the same field of study, usually prior to publication.

Penetrating power Radiation continues to penetrate matter until it has lost nearly all of its energy. The greater the ionization per cm, the less penetrating power it will possess.

Period (time period), *T* The time taken for one complete oscillation, or the time taken for one complete wave to pass a point.

Permanent magnet A magnetized material which creates a significant and persistent magnetic field around itself. Permanent magnets are made from ferromagnetic materials, like certain kinds of steel. Soft iron cannot be magnetized permanently.

Permeability of a medium, μ A constant that represents the ability of a particular medium to transfer a magnetic force and field.

Permeability of free space (vacuum), μ_0 A fundamental constant that represents the ability of a vacuum to transfer a magnetic force and field.

Permittivity of a medium, ε A constant that represents the ability of a particular medium to transfer an electric force and field. Often expressed as relative permittivity: $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$ (no units), and also sometimes called *dielectric constant*.

Permittivity of free space, ε_0 A fundamental constant that represents the ability of a vacuum to transfer an electric force and field.

Phase (of matter) A system (substance) in which all the physical and chemical properties are uniform.

Phase (oscillations) Oscillations are in phase if they have the same frequency and their maxima occur at the same times.

Phase difference When oscillators which have the same frequency are out of phase with each other, the difference between them is defined by the angle (usually in radians) between the oscillations. Phase differences can be between 0 and 2π radians.

Photon A quantum ('packet') of electromagnetic radiation, with an energy $E = hf$. Exchange particle for the electromagnetic interaction.

Photosynthesis A chemical process that produces plant material (chemical energy) from carbon dioxide and water using the radiant energy from the Sun.

Photovoltaic cell Device which converts electromagnetic radiation (mainly light) into electrical energy. Also called a *solar cell*.

Planck relationship The frequency of electromagnetic radiation, f, emitted or absorbed when an electron undergoes a transition between two energy states is given by $\Delta E = hf$, where h represents Planck's constant and ΔE is the difference in energy levels.

Plane of polarization The plane in which all oscillations of a plane polarized wave are occurring.

Plane waves Waves with parallel wavefronts which can be represented by parallel rays.

Plasma A state of matter which is similar to a gas, but which contains a significant proportion of charged particles (ions).

Point particle, mass or charge A theoretical concept used to simplify the discussion of forces acting on objects (especially in gravitational and electric fields).

Polarity The separation of opposite electric charges or opposite magnetic poles which produces uneven effects in a system.

Polarization (plane) A property of some transverse electromagnetic waves in which the electric field (and magnetic field) oscillations are all in the same plane.

Polarizing filter A filter which transmits light which is polarized in one plane only. A filter used to produce polarized light from unpolarized light is called a *polarizer*. A polarizing filter which is rotated in order to analyse polarized light is called an *analyzer*. Crossed filters prevent all light from being transmitted.

Positron The antiparticle of the electron. It is released during beta positive decay.

Potential difference (electric), p.d. The electrical potential energy transferred (work done) as a unit charge moves between two points: $V = \frac{w}{q}$. Commonly referred to as voltage.

Potential divider Two resistors used in series with a fixed potential difference across them. When one resistance is changed, the p.d. across each resistor will change, and this can be used for controlling another part of the circuit.

Potential energy Energy which is stored. See *chemical potential energy*, *elastic strain potential energy*, *gravitational potential energy*, *electric and magnetic potential energies* and *nuclear potential energy*.

Potentiometer Variable resistor (with three terminals) used as a potential divider.

Power, *P* Defined as energy transferred/time taken ($P = \frac{\Delta E}{\Delta t}$) or, for mechanical energies: work done/time taken ($P = \frac{\Delta W}{\Delta t}$) (unit: watt; $1\,\text{W} = 1\,\text{J s}^{-1}$).

Power (electrical) The rate of dissipation of energy in a resistance: $P = VI = I^2R = \frac{V^2}{R}$.

Precautionary principle The idea that scientific research should not continue unless scientists are able to be absolutely sure that the research will not be harmful.

Precision A measurement can be described as being precise if a similar result would be obtained if the measurement was repeated. Precise measurements have small random errors.

Pressure, *P* Defined as force acting normally per unit area: pressure $= \frac{\text{force}}{\text{area}}$. The unit is the pascal, Pa. *Atmospheric pressure* is the pressure in the air due to molecular motions.

Pressure gauge An instrument for measuring gas pressure.
Primary cell An electric cell which cannot be used again after the chemical reactions have finished.
Primary energy source A natural source of energy that has not been converted to or from another form (for example, solar radiation, but not electricity or hydrogen).
Prism A regularly shaped piece of transparent material (such as glass) with flat surfaces which is used to refract and disperse light.
Projectile An object that has been projected through the air and which then moves only under the action of the forces of gravity and air resistance.
Propagation (of waves) The transfer of energy by waves.
Proton A sub-atomic particle with a positive charge ($+1.6 \times 10^{-19}$ C) and mass of 1.673×10^{-27} kg. The number of protons in a nucleus is called the *–proton number* (Z).
Pulse (wave) A travelling wave of short duration.
Pumped storage (HEP) Large quantities of water are pumped up to a higher location using excess electrical power. When needed, the water is allowed to fall down again so that electricity can be regenerated.

Q

Qualitative A description involving qualities, rather than quantities.
Quantitative A description involving quantities, measurements.
Quantized This describes something that can only exist in certain definite (discrete) numerical values.
Quantum The minimum amount of a physical quantity that is quantized.
Quantum number This is used to describe the quantized properties of particles which are conserved in interactions. (*Charge*, *baryon number*, *lepton number*, *strangeness*.)
Quantum physics (mechanics) The study of matter and energy at the sub-atomic scale. On this scale quantities are quantized.
Quarks Elementary particles. There are six kinds (flavours). They cannot exist as individual particles. They have a charge of $\pm\frac{1}{3}$e or $\pm\frac{2}{3}$e. Combinations of quarks are called hadrons.

R

Radial field A field that spreads out from a point equally in all directions.
Radian A unit of measurement of angle. There are 2π radians in 360°.
Radiation Particles or energy that radiate away from a source. Principally, various kinds of electromagnetic radiation and nuclear (ionizing) radiation.
Radiation sickness The condition associated with intense exposure to ionizing radiation.
Radioactive decay (radioactivity) The spontaneous transmutation of an unstable nucleus, accompanied by the emission of ionizing radiation in the form of alpha particles, beta particles or gamma rays.
Random Without pattern or predictability.
Random errors Measurements of any quantity may be bigger or smaller than the correct value and are scattered randomly around that value (for various reasons).
Range (of a projectile) The distance travelled before impact with the ground.
Rarefactions (in a longitudinal wave) Places in a medium where there are reductions in the density and pressure of a gas as a wave passes through it.
Raw data Measurements made during an investigation.
Ray A line showing the direction in which a wave is transferring energy. Rays are perpendicular to wavefronts.
Ray diagrams Drawings that represent the direction of waves or particles as they pass through a system.
Reaction force See also *Newton's third law*. Forces always occur in pairs and these forces are sometimes described as action and reaction. For example, the force of a bat hitting a ball can be described as an action force; at the same time the ball exerts an equal and opposite force on the bat, which can be described as a reaction force.
Reaction time The time delay between an event occurring and a response. For example, the delay that occurs when using a stopwatch.
Real gases Modelling of gas behaviour is idealized. Real gases will not behave exactly the same as the model of an ideal gas.
Reflection (waves) The change of direction that occurs when waves meet a boundary between two media, such that the waves return into the medium from which they came.
Reflection, law of The angle of incidence = angle of reflection (in the same plane).
Refraction The change of direction that can occur when a wave changes speed (most commonly when light passes through a boundary between two different media).
Refractive index, *n* Defined as the ratio of the speed of waves in vacuum (on air) to the speed of waves in a given medium. $n = \frac{v_{air}}{v_{medium}}$. Also $n = \frac{\text{sine of angle in air}}{\text{sine of angle in medium}}$.
Regenerative braking Decelerating a vehicle by transferring its kinetic energy into a form which can be of later use (rather than dissipating the energy into the surroundings). For example, by generating an electric current that charges a battery.
Renewable energy sources Sources that will continue to be available for our use for a very long time; they cannot be used up (depleted or 'run out'),

except over billions of years, when the Sun reaches the end of its lifetime. Compare with non-renewable energy sources, like oil.

Resistance (electrical) The ratio of p.d. across a conductor to the current flowing through it: $R = \frac{V}{I}$.

Resistive force Any force which opposes motion, for example, friction, air resistance, drag.

Resistivity, ρ The resistance of a specimen of a material which has length of 1 m and cross-sectional area of $1\,m^2$: $R = \frac{\rho L}{A}$.

Resistor A resistance constructed to have a specific value or range of values.

Resistors in parallel Resistors connected between the same two points so that they all have the same potential difference across them: $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$

Resistors in series Resistors connected one after another so that the same current passes through them all: $R_{total} = R_1 + R_2 + \ldots$

Resolve (a vector) To express a single vector as components (usually two which are perpendicular to each other).

Rest mass The mass of an isolated particle that is at rest relative to the observer.

Rest mass energy The rest mass expressed in the equivalent terms of energy.

Restoring force A force acting in the opposite direction to motion, returning an object to its equilibrium position.

Resultant The single vector which would have the same effect as the combination of two or more separate vectors.

Resultant force The vector sum of the forces acting on an object, sometimes called the 'unbalanced force' or 'net' force.

Rheostat A variable resistance used to control current.

Right-hand grip rule A rule for determining the direction of the magnetic field around a current.

Ripple tank A tank of water used for investigating wave properties.

Rocket engine Similar to a jet engine, but there is no air intake; instead an oxidant is carried on the vehicle, together with the fuel.

Rotational kinetic energy Kinetic energy because of rotation (spin).

Rutherford–Geiger–Marsden experiment The scattering of alpha particles by a thin sheet of gold foil which demonstrated that most particles passed through the foil completely undeflected, while a few were deflected at extremely large angles. This showed that atoms consist of mostly empty space with a very dense positively charged core (the nucleus).

S

Sankey (energy flow) diagram A diagram representing the flow of energy in a system. The widths of the arrows are proportional to the amounts of energy (or power). Degraded energy is directed downwards in the diagram.

Satellite An object which orbits a much larger mass. Satellites may be natural (like the Earth or the Moon) or artificial (as used for communication, for example).

Scalar A quantity which has only magnitude (no direction).

Scattering The irregular reflections of waves from their original path by interactions with matter.

Scientific notation Every number is expressed in the following form: $a = 10^b$, where a is a decimal number between 1 and 10 and b is an exponent (integer).

Second, s SI unit of time (fundamental).

Secondary cell An electric cell which can be recharged.

Secondary energy source A source which has been converted from a primary energy source; for example, electricity.

Self-sustaining nuclear chain reaction A reaction that occurs when enough of the neutrons created during fissions then go on to cause further fissions.

Semiconductor A material (such as silicon) with a resistivity between that of conductors and insulators. Such materials are essential to modern electronics.

Sense perception The five human senses, most commonly sight, are the most common way we have of receiving (becoming aware of, perceiving) scientific information.

Sensor An electrical component which responds to a change in a physical property with a corresponding change in an electrical property (usually resistance). Also called a transducer.

Serendipity Unplanned and unexpected good luck.

Series connection Two or more components connected such that there is only one path for the electrical current, which is the same through all the components.

Short circuit An unwanted (usually) electrical connection which provides a low resistance path for an electric current. It may result in damage to the circuit, unless the circuit is protected by a fuse or circuit breaker.

Simulation A simplified visualization (imitation) of a real physical system and how it changes with time. Usually part of a computer modelling process.

SI format for units For example, the SI unit for momentum is kilogram metre per second and should be written as $kg\,m\,s^{-1}$ (not kg m/s).

SI system of units International system of units of measurement (from the French 'Système International') which is widely used around the

world. It is based on seven fundamental units and the decimal system.

Signal generator A piece of electronic equipment used to supply low-power alternating currents of a wide range of different frequencies.

Significant figures (digits) All the digits used in data to carry meaning, whether they are before or after a decimal point.

Simple harmonic motion (SHM) Defined as oscillations in which the acceleration, a, is proportional to the displacement, x, and in the opposite direction, back towards the equilibrium position: $a \propto -x$.

Sinusoidal In the shape of a sine wave (often equivalent to a cosine wave).

Slow neutrons Low energy neutrons (typically less than 1 eV) that are needed to sustain a chain reaction. They are slowed down in a nuclear reactor by the use of a moderator. They are sometimes called thermal neutrons because they are in approximate thermal equilibrium with their surroundings.

Snell's law (of refraction) This connects the sines of the angles of incidence and refraction to the wave speeds in the two media (or the refractive indices): $\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$.

Soft iron A form of iron (pure or nearly pure) which is easily magnetized and demagnetized. Soft iron cores are used in a wide variety of electromagnetic devices.

Solar constant The intensity of the Sun's radiation arriving perpendicularly to the Earth's upper atmosphere.

Solar heating panel Devices for transferring radiated thermal energy from the Sun to internal energy in water.

Solenoid A long coil of wire with turns which do not overlap (helical). Solenoids are often used because of the strong uniform magnetic fields inside them.

Sound Longitudinal waves in air, or other media, that are audible (can be heard).

Specific energy The amount of energy which can be transferred from unit mass of an energy source (unit $\mathrm{J\,kg^{-1}}$).

Specific heat capacity, c Defined as the amount of energy needed to raise the temperature of 1 kg of a substance by 1 K: $c = \frac{Q}{m\Delta T}$.

Specific latent heat, L_f or L_v Defined as the amount of energy needed to melt (fusion) or vaporize (vaporization) 1 kg of a substance at constant temperature: $L = \frac{Q}{m}$ (unit: $\mathrm{J\,kg^{-1}}$).

Spectroscopy The analysis of spectra using instruments called spectroscopes or spectrometers.

Spectrum, continuous A spectrum in which a range of wavelengths are displayed in order. A continuous visible spectrum shows a smooth and uninterrupted change from one colour to another (plural: spectra).

Spectrum, line A spectrum of separate lines (rather than a continuous spectrum), each corresponding to a discrete wavelength and energy.

Speed, linear, v Average speed is defined as distance travelled/time taken, $v = \frac{\Delta s}{\Delta t}$. Instantaneous speed is determined over a very short time interval during which it is assumed that the speed does not change. It may also be determined from the gradient of a distance–time graph. Linear speed is a scalar quantity. Compare with velocity, a vector quantity (unit: $\mathrm{m\,s^{-1}}$).

Standard (particle) model A summary of the quarks, leptons and bosons that are believed to be the elementary particles of the universe.

Standing wave The kind of wave which may be formed by two similar travelling waves moving in opposite directions. The most important examples are formed when waves are reflected back upon themselves. The wave pattern does not move and the waves do not transfer energy.

State of a gas Specified by quoting the pressure, p, temperature, T, and volume, V, of a known amount, n, of gas.

Stefan–Boltzmann law A equation that can be used to calculate the total power radiated from a surface, $P = e\sigma AT^4$. σ is known as the Stefan–Boltzmann constant and e is the emissivity of the surface.

Stellar (hydrostatic) equilibrium Main sequence stars are in equilibrium under the effects of thermal gas pressure and radiation pressure acting outwards against gravitational pressure inwards.

Strain If a material has a strain, it has been deformed.

Strangeness A property of some quarks which was introduced to explain their unexpectedly long lifetimes. The quantum number of strangeness is conserved in some particle interactions.

Streamlined Describes a shape that reduces the resistive forces acting on an object which is moving through a fluid (gas or liquid).

Stress Tensile force/cross-sectional area.

Strong nuclear force A fundamental force acting on quarks. It is the force responsible for attracting nucleons together. It is a short range attractive force (the range is about 10^{-15} m), but for smaller distances it is repulsive, and hence it prevents the nucleus from collapsing. The exchange particle is the *gluon*.

Subjective Based on human feelings and opinions. Compare with *objective*.

Superconducting Without significant electrical resistance, which only occurs at very low temperatures.

Superposition (principle of) The resultant of two or more waves arriving at the same point can be

determined by the vector addition of their individual displacements.

Surroundings Everything apart from the system that is being considering; similar to the *environment*.

System The object(s) being considered.

Systematic errors A reading with a systematic error is always either bigger or smaller than the correct value by the same amount, for example, a zero-offset error.

T

Technology The application and use of scientific knowledge for practical purposes.

Temperature This determines the direction of thermal energy transfer. It is a measure of the average random translational kinetic energy of the molecules of a substance.

Tension (force) A force which tries to stretch an object or material.

Terminal potential difference The potential difference across the terminals of a battery (or other voltage supply) when it is supplying a current to a circuit. Typically it decreases (because of internal resistance) when the current rises.

Terminal speed (velocity) The greatest downwards speed of a falling object which is experiencing resistive forces (for example, air resistance). It occurs when the object's weight is equal in magnitude to the sum of resistive forces.

Tesla, *T* The SI unit of magnetic field strength: $1\,T = 1\,N\,A^{-1}\,m^{-1}$.

Test charge (or mass) An idealized model of a small charge (or mass) placed in a field in order to determine the properties of that field, but without affecting those properties.

Theory A term which can have many different interpretations. A scientific theory provides a fully tested and checked explanation of particular observations.

Thermal capacity Defined as the amount of energy needed to raise the temperature of something by one kelvin.

Thermal contact Objects can be considered to be in thermal contact if thermal energy (of any kind) can be transferred between them.

Thermal energy (heat) The (non-mechanical) transfer of energy between two or more bodies at different temperatures (from hotter to colder).

Thermal equilibrium A state in which all temperatures within a system are constant.

Thermistor (negative temperature coefficient) A resistor that has less resistance when its temperature increases. It is also called a temperature dependent resistor.

Thermodynamics A branch of physics involving transfers of thermal energy to do useful work.

Thermostat A component that is used with a heater or cooler to maintain a constant temperature.

Total internal reflection This occurs when a wave meets a boundary with another medium which has a lower refractive index (in which it would travel faster). The angle of incidence must be greater than the *critical angle*.

Tracer (radioactive) A radioisotope introduced into a system (for example, a human body) to track where it goes by detecting the radiation that it emits.

Trajectory The path followed by a projectile.

Transition (between energy levels) A photon is emitted when an electron makes a transition to a lower energy level. The energy of the photon is equal to the difference in energy of levels involved.

Translational This describes moving from place to place.

Translational equilibrium A state in which an object is remaining at rest or continuing to move with constant velocity.

Transmission The passage through a medium without absorption or scattering.

Transmit To send out (usually a signal carrying information).

Transmutation When a nuclide changes to form a different element during radioactive decay.

Transparent This describes a medium which transmits light without scattering.

Transverse wave A wave in which the oscillations are perpendicular to the direction of transfer of energy, for example light waves.

Trough The lowest point of a transverse mechanical wave.

Turbine A device which transfers the energy from a moving fluid (gas or liquid) to do mechanical work and cause (or maintain) rotation.

U

Ultrasonic Relating to frequencies of 'sound' above the range which can be heard by humans (approximately 20 kHz).

Uncertainty (random) The range, above and below a stated value, within which we would expect any repeated measurements to fall. Uncertainty may be expressed in *absolute*, *fractional* or *percentage* terms.

Unified atomic mass unit, *u* A unit of mass used to express the mass of atoms, sub-atomic particles and molecules. Equal to one-twelfth of the mass of the nucleus of a carbon-12 atom (at rest and in the ground state).

Uniform field A field of constant strength, represented by parallel field lines.

Universal gravitational constant, *G* The constant that occurs in Newton's universal law of gravitation.

Universal (molar) gas constant The constant, R, that appears in the equation of state for an ideal gas ($pV = nRT$).

Upthrust A force exerted vertically upwards on any object that is in a fluid.

Uranium enrichment Increasing the percentage of ^{235}U in uranium fuel in order to make it of use in a nuclear power station or for a nuclear weapon.

V

***V–I* characteristic** A graph of current–p.d. representing the basic behaviour of an electrical component.

Vaporization The change from a liquid to a vapour or gas by boiling or evaporation.

Vapour Gas which can be condensed by pressure to become a liquid.

Variable A quantity that may change during the course of an investigation. It may be measurable (quantitative) or just observable (qualitative). A quantity being deliberately changed is called the *independent* variable and the measured or observed result of those changes occurs in a *dependent* variable. Usually all other variables will be kept constant (as far as possible); they are called the *controlled* variables.

Variable resistor A resistor (usually with three terminals) which can be used to control currents and/or p.d.s in a circuit.

Vector Quantity which has both magnitude and direction. Compare with *scalar*.

Velocity, angular, ω Defined as rate of change of angular displacement with time: $\omega = \frac{\Delta\theta}{\Delta t}$ (unit: $\text{rad}\,\text{s}^{-1}$). For regular motion in a circle, $\omega = \frac{2\pi}{T} = 2\pi f$, and linear velocity = angular velocity × radius, $v = \omega r$.

Velocity, linear, *v* Defined as rate of change of linear displacement with time, $v = \frac{\Delta s}{\Delta t}$. Velocity is a vector quantity and can be considered as speed in a specified direction. If the velocity (speed) of an object changes during a period of time t, the initial velocity (speed) is given the symbol u and the final velocity (speed) is given the symbol v. Instantaneous velocity is determined over a very short time interval (unit: $\text{m}\,\text{s}^{-1}$) or from the gradient of a displacement-time graph.

Verify To show that something is true or accurate.

Vibration Mechanical oscillation.

Vibrational kinetic energy Kinetic energy due to vibration/oscillation.

Virtual particles Particles which are exchanged during fundamental interactions, but the speed of the exchange makes their lifetimes so short that they are impossible to observe.

Visualization Helping understanding by using images (mental or graphic).

Volt Derived unit of potential difference: $1\,\text{V} = 1\,\text{J}\,\text{C}^{-1}$.

Voltage See *potential difference*.

Voltmeter An instrument used to measure potential difference (voltage).

W

Watt, W Derived SI unit of power: $1\,\text{W} = 1\,\text{J}\,\text{s}^{-1}$.

Wave (mechanical) A wave transferring energy involving oscillating masses.

Wave (travelling) A wave which transfers energy away from a source. Sometimes called a progressive wave.

Wavefront A line connecting adjacent points moving in phase (for example, crests). Wavefronts are one wavelength apart and perpendicular to the rays that represent them.

Wavelength, λ Defined as the shortest distance between two points moving in phase (for example, the distance between adjacent crests).

Wave–particle duality Some properties of light need a wave theory to explain them, other properties can only be explained in terms of particles (photons).

Wave speed, *c* Defined as the speed at which energy is transferred by a wave: $c = f\lambda$.

Weak nuclear force Fundamental force acting between quarks and between leptons. It is involved with radioactive decay. Exchange particles are W or Z bosons.

Weigh Determine the weight of an object. In everyday use the word 'weighing' usually means quoting the result as the equivalent mass: 'my weight is 60 kg' actually means I have the weight of a 60 kg mass.

Weight, *W* Gravitational force acting on a mass: $W = mg$. Measured in newtons.

Wien's displacement law Relationship between absolute temperature and the wavelength emitted with maximum power by a black body at that temperature, $\lambda_{max} = \frac{2.90 \times 10^{-3}}{T}$.

Wind generator Device for transferring the kinetic energy of wind into electrical energy.

Work, *W* Work is the energy transfer that occurs when an object is moved with a force. More precisely, work done = force × displacement in the direction of the force: $W = Fs\cos\theta$, where θ is the angle between the direction of movement and the direction of the force.

Z

Zero offset error A measuring instrument has a zero offset error if it records a non-zero reading when it should be zero.

Higher level

The glossary contains key words, equations and terms from the IB Physics Diploma course. This section takes words from Chapters 9–12.

A

Acoustic Related to sound and hearing.

Alternator Ac generator.

Angular separation The angle subtended at the eye (or an optical device) by two points or distant objects.

Anti-reflection coating A very thin layer of a transparent material which is coated onto glass in order to increase the amount of light transmitted. The process involves destructive interference.

B

Beams of charged particles These are created and controlled by strong electric and magnetic fields. They are used to investigate the atomic and sub-atomic structure of matter.

Becquerel, Bq SI unit of (radio) activity, equal to one nuclear decay every second.

Beta particle spectra Beta particles emitted by nuclei of the same radioisotope have a range of different energies. This is evidence that a third particle (neutrino or antineutrino) is involved with the decays.

Bohr model A theory of atomic structure that explains the spectrum from hydrogen atoms. It assumes that the electrons orbiting around the nucleus can exist only in certain energy states at specific radii. In this model the electron could only have values of angular momentum (mvr) which fitted the equation $mvr = \frac{nh}{2\pi}$, where n is an integer, known as the principal quantum number.

Breakdown (electrical) The flow of current through an insulator when a fault occurs or if the voltage rises too high.

Bridge circuit A circuit in which two pairs of components are connected in parallel across a power source, with another component connected between their mid-points. Diode bridges are used for rectification. (Wheatstone and Wien bridge circuits are used for precise electrical measurements.)

C

Capacitance, C The ratio of the charge on a component (or other object) to the p.d. across it: $C = \frac{q}{V}$ (unit: farad, F).

Capacitor An electric circuit component designed to store small amounts of energy temporarily, usually consisting of two parallel metallic plates separated by a very thin insulator.

Capacitor discharge This occurs when the charge on a capacitor is allowed to flow around a circuit. Equations: $I = I_0 e^{-\frac{t}{t}}$, $q = q_0 e^{-\frac{t}{t}}$, $V = V_0 e^{-\frac{t}{t}}$.

Capacitor, energy storage Capacitors can store only relatively small amounts of energy, but they are able to transfer the energy quickly, and so they can deliver high power for a short time: $E = \frac{1}{2} CV^2$.

Capacitors in parallel Two or more capacitors connected so that they have the same potential difference: $C_{parallel} = C_1 + C_2 + \ldots$

Capacitors in series Two or more capacitors connected so that the same charge flows onto each of them: $\frac{1}{C_{series}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$

Combination of fields This requires vector addition to determine the resultant.

Combination of potentials This requires scalar addition to determine the resultant.

Conjugate quantities A pair of physical variables describing a quantum-mechanical system such that either of them, but not both, can be specified precisely at any given time. Also called linked variables. See *Heisenberg's uncertainty principle*.

D

Davisson–Germer experiment An experiment that verified the wave properties of matter by showing that a beam of electrons is diffracted by a crystal at an angle dependent upon the velocity of the electrons.

De Broglie's hypothesis All particles exhibit wave-like properties, with a de Broglie wavelength, $\lambda = \frac{h}{p}$, where p is the momentum of the particle.

Decay constant, λ This is defined as the probability of radioactive decay of a nucleus per unit time: $\lambda = -\frac{\left(\frac{\Delta N}{\Delta t}\right)}{N}$ (unit: s^{-1}). The decay constant is linked to the half-life of the nuclide by the equation: $T_{½} = \ln \frac{2}{\lambda}$.

Dielectric materials Insulators used between the plates of capacitors in order to increase their capacitance.

Diffraction grating A large number of very narrow parallel slits very close together. Used to disperse and analyse light. Angles for constructive interference are predicted by the equation: $n\lambda = d \sin\theta$.

Diode A semiconducting component that allows the passage of electric current only in one direction, when it is then described as *forward biased*.

Diode bridge Four diodes connected in a bridge circuit to provide full-wave rectification of an alternating current.

Dish aerial An aerial placed at the focus of a parabolic reflector, typically for receiving or transmitting radio waves.

Doppler effect When there is relative motion between a source of waves and an observer or detector, the emitted frequency and the received frequency are not the same. Sometimes called a *Doppler shift*. The frequency received from a moving source can be determined from the equation $f' = \frac{vf}{(v \pm u_s)}$; the frequency received by a moving observer can be determined from the equation $f' = \frac{(v \pm u_o)f}{v}$.

Doppler effect with light and other electromagnetic waves If the relative speed between the source and the observer, v, is significantly less than the speed of the wave, c, we can use the following approximation: $\frac{\Delta f}{f} = \frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$.

E

Eddy currents Circulating currents induced in solid pieces of metal when changing magnetic fields pass through them, for example in the iron core of a transformer.

Edge effects (uniform field) The electric field between parallel plates is assumed to be uniform except at the edges; these effects are not considered in any detail in this course.

Electromagnetic induction The production of an emf across a conductor which is experiencing a changing magnetic flux. This may be as a result of moving a conductor through a magnetic field, moving a magnetic field through a stationary conductor, or a time-changing magnetic flux passing from one circuit to another (without the need for any physical motion).

Electromagnetic induction in a straight conductor When a straight wire moves perpendicularly across a magnetic field, the induced emf can be determined from the equation: $\varepsilon = Bvl$ (or $\varepsilon = BvlN$ if there are N turns).

Electron scattering (by nuclei) High-energy electrons have a wavelength comparable to nuclear diameters, D, so that they will be diffracted in a similar way to light by narrow slits. The first diffraction minimum will occur at angle θ such that $\sin\theta \approx \frac{\lambda}{D}$. This equation can be used to determine nuclear diameters.

Electrostatic field An electric field that is constant, not changing.

Energy levels of hydrogen Because hydrogen is the atom with the simplest structure, scientists were very interested in determining the energy levels of the electron within the atom by examining hydrogen's line spectrum. They were able to show that the energy levels could be predicted by the empirical equation: $E = \frac{13.6(\text{eV})}{n^2}$. This equation was explained later by using the *Bohr model* of the hydrogen atom.

Equipotential line (or surface) Line (or surface) joining points of equal potential. Equipotential lines are always perpendicular to field lines.

Escape speed The minimum theoretical speed that an object must be given in order to move to an infinite distance away from a planet (or moon or star): $v_{\text{escape}} = \sqrt{\left(\frac{2GM}{R}\right)}$. This assumes that air resistance is not significant.

Expansion of universe The redshift of light (similar to the Doppler effect) from distant galaxies provides evidence of an expanding universe.

Exponential radioactive decay This is represented by the equation $N = N_0e^{-\lambda t}$. N_0 is the number of undecayed nuclei at the start of time t; N is the number remaining at the end of time t. Alternatively, equations of the same form can be used with activity, A, or the count rate. Activity is linked to the initial number of atoms by the equation: $A = \lambda N_0e^{-\lambda t}$.

F

Farad, F The derived unit of capacitance in the SI system. It is equal to the capacitance of a capacitor that has an equal and opposite charge of one coulomb on each plate when there is a potential difference of one volt between the plates. (μF and pF are also in common use.)

Faraday's law of electromagnetic induction The magnitude of an induced emf is equal to the rate of change of magnetic flux linkage: $\varepsilon = -N\frac{\Delta\Phi}{\Delta\tau}$. For an explanation of the negative sign, see *Lenz's law*.

Fermi radius, R_0 A constant in the equation for nuclear radius ($R = R_0A^{\frac{1}{3}}$). It is equal to the value of R for $A = 1$.

Ferromagnetic materials Materials containing iron which have excellent magnetic properties (high permeability).

Forced oscillations / vibrations Oscillations of a system produced by an external periodic force.

G

Galvanometer An ammeter that measures very small currents.

Generator (ac) A device containing coils that rotate in a magnetic field (or a field which rotates within coils), transferring kinetic energy to the energy carried by an alternating electric current.

Geostationary orbit A satellite is described as geostationary if it appears to remain above the same location on the Earth's surface. This can be very useful for communications. Geostationary satellites are in a type of geosynchronous orbit which must be in the same plane as the equator and with exactly the same period as the Earth's rotation on its axis (one day).

Geosynchronous orbit Any satellite orbit which has the same period as the Earth spinning on its axis. The orbit must have exactly the correct radius. Such orbits may, or may not, be geostationary.

Global positioning system (GPS) A navigation system which provides accurate information on the location of the GPS receiver by continually sending and receiving radio waves from several orbiting satellites.

H

Heisenberg's uncertainty principle A fundamental principle of quantum mechanics which states that it is impossible to measure simultaneously the momentum and the position of a particle with infinite precision: $\Delta x \Delta p \geq \frac{h}{4\pi}$. The principle also applies to measurements of energy and time: $\Delta E \Delta t \geq \frac{\lambda}{D}$.

Hollow charged sphere There is a constant potential within the sphere, which means that the electric field is zero. Faraday cages are a (non-spherical) example.

Hysteresis (magnetic) The changing magnetic properties of a ferromagnetic material depend on what has happened to it before and how quickly the changes take place. These effects are called hysteresis.

I

Insight (scientific) The ability to achieve a good understanding of a complex situation.

Iridescence The property of certain surfaces to produce variable coloured effects because of interference, depending on the angle at which they are viewed. (The feathers of some birds and insect wings are common examples.)

Iteration A repetitive mathematical procedure which calculates the changes which occur in small increments in order to determine an overall result.

J

Joule heating The transfer of electrical energy to thermal energy as a current passes through a resistance.

L

Laminations (iron core) Alternate layers of iron and insulation in a core of an electromagnetic device which are designed to limit energy dissipation due to eddy currents.

Law of radioactive decay The number of nuclei that decay per second, $\frac{\Delta N}{\Delta t}$, (= the activity, A, of the source) is proportional to the number of radioactive atoms still present that have not yet decayed, N: $= -\frac{\Delta N}{\Delta t} \lambda N$, where λ represents a constant, known as the *decay constant*.

Lenz's law (of electromagnetic induction) The direction of an induced emf is such that it will oppose the change that produced it. This is represented mathematically by the negative sign in the equation representing Faraday's law.

Lightning Discharge to the ground (or another cloud) of the net charge which has accumulated in a part of a cloud.

M

Magnetic flux, Φ Defined as the product of an area, A, and the component of the magnetic field strength perpendicular to that area, $B\cos\theta$: $\Phi = BA\cos\theta$ (unit: Weber, Wb).

Magnetic flux density, B The term commonly used at Higher Level for magnetic field strength.

Magnetic flux linkage, $N\Phi$ Defined as the product of magnetic flux and the number of turns in a circuit (unit: Wb).

Mass on a spring oscillator This can be used as a simplified visualization of many mechanical oscillators: $T = 2\pi\sqrt{\frac{m}{k}}$).

Mass spectrometer A device which can measure the masses and relative abundance of ions in a gas.

Matter waves Waves that represent the behaviour of an elementary particle, atom or molecule under certain conditions. See *de Broglie's hypothesis* and equation.

Modulation The act of changing the amplitude (or frequency) of a wave to represent variations in another signal (of lower frequency).

Multiple slits By increasing the number of parallel slits (of the same width) on which a light beam is incident, it is possible to improve the resolution of the fringes/spectra formed.

N

Neutron capture The process in which a nucleus absorbs one or more neutrons. This can result in the nucleosynthesis of heavier elements.

Neutron star A small and extremely dense star formed after a supernova. They consist almost entirely of closely packed neutrons.

Nuclear density Assuming that the nucleus is spherical, nuclear density may be determined from nuclear mass ($\approx Au$) divided by the volume of a sphere having the appropriate nuclear radius. All nuclear densities are similar in magnitude – which is extremely large.

Nuclear energy levels The emission of alpha particles and gamma rays with discrete energies during radioactivity indicates that nuclei have discrete energy levels.

Nuclear medicine The use of radioisotopes in the diagnosis and treatment of disease.

Nuclear radius, R R is proportional to the cube root of the nucleon number: $R = R_0 A^{\frac{1}{3}}$, where R_0 is called the *Fermi radius*.

Nuclear transition A change in nuclear energy level which results in the emission of a high-energy photon.

Nucleosynthesis The creation of the nuclei of chemical elements by fusion or *neutron capture* in stars. In

general, the collapse of main sequence stars of greater mass will result in higher temperatures, which means that the nuclei then have higher kinetic energies, so they can overcome the bigger electric repulsive forces involved in the fusion of heavier elements.

O

Orbital energy An orbiting satellite has both gravitational potential energy and kinetic energy: $E_P = -\frac{GMm}{R}$, $E_K = +\frac{\frac{1}{2}GMm}{R}$. Adding these together gives the total energy: $E_T = -\frac{\frac{1}{2}GMm}{R}$.

Orbital speed For a satellite in a circular orbit, its speed must have the correct value for the chosen radius: $v_{orbit} = \sqrt{\left(\frac{GM}{r}GM\right)}$.

Oscilloscope An instrument for displaying and measuring voltages which change with time.

P

Peak values (electrical) The maximum values of an alternating current, I_0, voltage, V_0, or power, P_0 (compare with *rms values*). $P_0 = I_0V_0$. Average power, $\overline{P} = \frac{1}{2}I_0V_0$.

Pendulum A weight suspended from a point so that it can oscillate freely. There are many designs. A *simple pendulum* consists of a small spherical mass on the end of a string ($T = 2\pi\sqrt{\frac{l}{g}}$).

Phase change Waves will undergo a phase change of π when they reflect off a boundary with a medium in which they would travel slower (greater refractive index).

Photoelectric effect The ejection of electrons from a substance by incident electromagnetic radiation, especially by ultraviolet radiation. It is sometimes called photoemission. The ejected electrons are called photoelectrons.

Photoelectric equation The maximum kinetic energy of an emitted photoelectron is the difference between the photon's energy and the *work function*: $KE_{max} = \frac{1}{2}mv_{max}^2 = hf - \Phi$.

Polar orbit A path of a low-orbit satellite which passes over the poles of the Earth and completes many orbits every day, passing over many different parts of the planet.

Polarized molecules Molecules with an uneven distribution of electrons.

Potential (gravitational and electric), *V* The potential at a point is equal to the work done per unit mass (or unit positive charge) in bringing a small test mass (or charge) from infinity to that point: $V_g = \frac{E_p}{m}$ and $V_e = \frac{E_p}{q}$ (units: $J\,kg^{-1}$ or $J\,C^{-1}$, which is more commonly called volts, V).

Potential barrier A graphical representation of the potential that a bound particle needs to overcome in order to escape from the forces which are confining it. Potential barriers may also be described as potential hills or potential wells.

Potential difference (gravitational and electric), *ΔV* The p.d. between two points is the work done when moving unit mass (or unit positive charge) between those points. The units are the same as for potential: $V_e = \frac{W}{q}$; $V_g = \frac{W}{m}$.

Potential energy in fields (gravitational and electric), E_P Work has to be done to move masses in gravitational fields or charges in electric fields. Potential energy is defined as the work done when bringing a mass (or charge) to its present position from infinity. Potential energy equals the area under a force–distance graph between the point and infinity.

Potential gradient (gravitational and electric), $\frac{\Delta V}{\Delta r}$ This equals the magnitude of the field strength: $g = -\frac{\Delta V_g}{\Delta r}$ and $E = -\frac{\Delta V_e}{\Delta r}$.

Primary and secondary coils (transformers) The coils to which the input and output of a transformer are connected.

Probability density, *P*(*r*) The probability of finding a particle in unit volume at a distance r from a reference point. Related to the wave function by the equation: $P(r) = |\psi|^2\Delta V$.

Q

Quantum tunnelling Because of uncertainty, there is a possibility that a particle can pass through a *potential barrier* and thereby create effects that would not be considered possible using the principles of classical physics.

R

Radar The use of the reflection of microwaves to locate the position and speed of planes and other vehicles.

Radial fields (electric equations) $F_e = \frac{kq_1q_2}{r^2}$; $E_p = \frac{kq_1q_2}{r}$; $E = \frac{kq}{r^2}$; $V_e = \frac{kq}{r}$.

Radial fields (gravitational equations) $F_g = \frac{GMm}{r^2}$; $E_p = -\frac{GMm}{r}$; $g = \frac{GM}{r^2}$; $V_g = -\frac{GM}{r}$.

Radio astronomy The study of space utilizing the detection of radio waves emitted by astronomical sources.

Rayleigh's criterion A guide to resolution: two point sources can just be resolved if the first minimum of the diffraction pattern of one occurs at the same angle as the central maximum of the other. This means that if the sources are observed through a narrow slit, they will just be resolved if they have an angular separation of $\theta = \frac{\lambda}{b}$. For a circular aperture, $\theta = 1.22\frac{\lambda}{b}$.

Rectification Change *alternating current* (ac) into *direct current* (dc). Rectification may be full wave or half wave.

Resistor–capacitor (RC) circuit A circuit with a resistor and a capacitance with values selected so that the capacitor charges or discharges at a required rate. See *time constant*.

Resolution The ability of an instrument (or an eye) to detect (resolve) separate details.

Resolvance, *R* A measure of the ability of a diffraction grating with N slits to resolve separate wavelengths: $R = \frac{\lambda}{\Delta\lambda} = mN$, where m is the diffraction order.

Retina The surface at the back of the eyeball where light is detected.

Reverse voltage A source of voltage connected in such a way as to oppose the usual direction of current flow. See *stopping potential*.

Root mean squared (rms) value The effective value of an alternating current (or voltage), also called its *rating*. It is equal to the value of the direct current (or voltage) which would dissipate power in a resistor at the same rate: $I_{rms} = \frac{I_0}{\sqrt{2}}$ and $V_{rms} = \frac{V_0}{\sqrt{2}}$, where I_0 and V_0 are the peak values.

Rutherford scattering Sometimes called Coulomb scattering. The scattering of alpha particles by nuclei which can be explained by the action of (only) an inverse square law of electric repulsion. For particles which are scattered through 180°, their initial kinetic energy can be equated to the electric potential energy when closest to the nucleus. This provides an estimate for the radius of the nucleus. When high-energy particles are used, they may enter the nucleus, so that strong nuclear forces may also be involved and then the scattering will no longer follow the same pattern.

S

Schrödinger wave equation An equation which represents the Schrödinger model of the hydrogen atom mathematically by describing electrons using *wave functions*. The square of the amplitude of the wave function indicates the probability of finding the electron at a particular point and time.

Secondary waves The propagation of waves in two or three dimensions can be explained by considering that each point on a wavefront is a source of secondary waves.

Simple harmonic motion (SHM) Defined by the equation: $a = -\omega^2 x$. Equations for displacement: $x = x_0 \sin \omega t$ (for oscillations which start with zero displacement at time $t = 0$); $x = x_0 \cos \omega t$ (for oscillations which start with displacement x_0 at time $t = 0$).

Simple harmonic motion (SHM), velocities Equations for velocity: $v = \omega x_0 \cos \omega t$ (for oscillations which start with zero displacement at time $t = 0$); $v = -\omega x_0 \sin \omega t$ (for oscillations which start with displacement x_0 at time $t = 0$). The velocity can also be determined from the displacement and amplitude: $v = \pm\omega\sqrt{(x_0^2 - x^2)}$.

Simple harmonic motion energy transfers All mechanical oscillators continually interchange energy between potential and kinetic forms:

$E_K = \frac{1}{2} m\omega^2(x_0^2 - x^2)$; $E_P = \frac{1}{2}m\omega^2x^2$; $E_T = \frac{1}{2}m\omega^2x_0^2$.

Single slit diffraction The simplest diffraction pattern is that produced by wavefronts interfering after they have passed through a narrow, rectangular slit. Minima occur at angles such that $\theta = \frac{n\lambda}{b}$.

Slip rings and brushes In an ac generator these are used for connecting the rotating coil to the external circuit.

Smoothing (capacitor) The use of a capacitor to make the output of a diode rectifier 'smoother' (less variable).

Stopping potential The minimum voltage required to reduce a photoelectric current to zero.

Synthesize To combine things together to make a useful whole.

T

Terminology The words and phrases used with a particular area of study.

Thin film interference The interference which occurs after a wavefront is split by reflection off two surfaces of a very thin transparent medium (film). Constructive interference occurs if $2dn = (m + \frac{1}{2})\lambda$. Destructive interference occurs if $2dn = m\lambda$.

Threshold frequency, f_0 The minimum frequency of a photon that can eject an electron from the surface of a metal.

Time constant, τ The value that characterizes the rate at which an RC circuit discharges (or charges): $\tau = RC$ (unit: s^{-1}). It is the time taken for the current (or charge, or p.d.) to fall to $\frac{1}{e}$, or 37% of the previous value.

Transducer A device which converts one form of energy to another. The word is most commonly used with devices that convert to or from changing electrical signals.

Transformer A device that transfers electrical energy from one circuit to another using electromagnetic induction between coils wound on an iron core. Transformers are used widely to transform one alternating voltage to another of different magnitude. *Step-up transformers* increase voltages; *step-down transformers* decrease voltages.

Transformer (ideal) An ideal transformer has no energy dissipation and is 100% efficient, so that $E_pI_p = E_sI_s$.

Transmission of electrical power Electrical power is sent (transmitted) from power stations to different places around a country along wires (cables) which are commonly called transmission (or power) lines. These lines are linked together in an overall system called the transmission grid.

Tuning fork Vibrating instrument of a simple shape used to produce a sound of a single precise frequency.

Tunnelling electron microscope Microscope which uses quantum tunnelling of electrons between a pointed electrode and the surface being scanned.

Tunnelling probability Probability that a particle can tunnel through a potential barrier.

Turns ratio (transformer) The ratio of turns in the primary and secondary coils of a transformer controls the output voltage. For an ideal transformer: $N_P/N_S = E_P/E_S$.

U

Uniform electric field Created between parallel charged plates: $E = \frac{V}{d}$ (unit: $V\,m^{-1}$).

W

Wave function, $\Psi(x,t)$ Mathematical function of space and time which describes the quantum state of a subatomic particle, such as an electron. It is a solution to the Schrödinger wave equation.

Weber, Wb Unit of magnetic flux: $1\,Wb = 1\,T\,m^2$.

Work function, Φ The minimum amount of energy required to free an electron from the attraction of the atoms in a metal's surface. Since the energy of the incident photons is equal to hf, $hf_0 = \Phi$, where f_0 represents the threshold frequency.

X

X-ray diffraction (crystallography) The investigation of the atomic and molecular structure of matter by detecting how X-rays are diffracted by crystalline materials. X-ray wavelengths are comparable to atomic dimensions.

Y

Young's double slits experiment A classic physics experiment which demonstrated the wave properties of light by producing an interference pattern.

Z

Zero of gravitational potential and potential energy This is chosen to be at an infinite distance away, where the gravitational forces are zero.