Glossary

This glossary contains key words, equations and terms from the IB Physics Diploma course.

13 Relativity (Option A)

Standard level

This section takes words from Option A, sections A1, A2 and A3.

Dipole An object that is positively charged at one end and negatively charged at the other, or that has a magnetic north pole at one end and a magnetic south pole at the other. Magnets are always found as dipoles.

Electrical permittivity, ε The ability of different substances to transmit an electrical field. It is a measure of the amount of electrical flux (or electrical field) that is generated per unit of electrical charge in a given medium. The permittivity of free space is the permittivity of the vacuum.

Ether (or aether) A hypothetical substance, proposed as the medium through which electromagnetic waves travel. Theoretically the Earth should move through this medium and in Newtonian physics the ether should provide the only reference frame in which the speed of light in a vacuum is measured at exactly c, so it should define a stationary reference frame for the universe.

Event A single point in spacetime; a specific location in space at a specific moment of time. In each reference frame an event must have specific coordinates of position and time.

Galilean transformation The Newtonian, non-relativistic method of mathematically relating observations from one reference frame to another.

Inertial frame A frame of reference in which bodies that have no unbalanced forces on them obey Newton's first law, i.e. they move in straight lines with constant speed. The postulates of special relativity are valid in an inertial frame.

Inertial observer An observer who is neither accelerating nor experiencing a gravitational field.

Inertial reference frame A reference frame, or coordinate system, that is neither accelerating nor experiencing a gravitational field.

Invariant, invariant quantity The same in all reference frames. A quantity that has a value that is the same in all reference frames. In relativity examples are: the speed of light in a vacuum, spacetime interval, proper time interval, proper length, rest mass and electrical charge.

Length contraction The contraction of a measured length of an object relative to the proper length of the object due to the relative motion of an observer.

Length contraction formula $L = L_0/\gamma$, where L represents the length, L_0 represents the proper length as measured by an observer who is stationary relative to the length being measured and γ represents the Lorentz factor.

Lightline A term used by some authors to describe the worldline through spacetime made by a photon. This is normally drawn at 45° to the horizontal and vertical axes.

Lorentz factor, γ A very useful scaling factor that describes the distortion of non-invariant quantities when moving between different relativistic reference frames:

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

where c is the speed of light in a vacuum and v is the relative speed of the second reference frame. The Lorentz factor ranges from close to one at classical speeds to infinity near the speed of light in a vacuum.

Lorentz transformation The mathematical formulae used to calculate the new position and time coordinates, or spatial and temporal intervals, when transferring from one relativistic reference frame to another.

Magnetic permeability, μ The ability of a substance to support a magnetic field within itself in response to an applied magnetic field. For a specific substance, permeability specifies the magnetic flux that is generated per unit current around each metre of current-carrying wire. The permeability of free space is the permeability of the vacuum.

Michelson–Morley experiment An experiment designed to measure the Earth's speed through the ether. The famous null result was the prime reason for the abandonment of the ether idea, which contributed to the development of special relativity.

Monopole A source of charge that is only positive or only negative. Magnets are never found as separate monopoles but are always found as north–south pairs called dipoles.

Muon A member of the electron family with the same charge as an electron but with 207 times the rest mass. It is therefore unstable, decaying with a half-life of 1.5×10^{-6} s, typically into an electron, a neutrino and an anti-neutrino.

Muon decay experiment A compelling experiment supporting both time dilation and length contraction. The experiment compares the levels of high-energy muons found in the atmosphere at around 10 km with those found at the Earth's surface, using the muon half-life as a means of measuring time. Classical physics predicts that the number of muons reaching the Earth's surface should be a tiny fraction of those that are formed. The measured result of around a fifth matches the predictions of relativity.

Postulates of classical or Newtonian physics A unit of time, space and mass is invariant throughout the universe. The laws of mechanics are true in all reference frames.

Postulates of special relativity The speed of light in a vacuum is the same for all inertial observers. The laws of physics are the same for all inertial observers.

Proper length The proper length of an object is the length measured by an observer who is at rest relative to the length being measured. Where the length is the distance between two events the observer must be at rest relative to a virtual object that connects the two events, so that the distance between the two events is independent of time. The proper length is always the longest length measureable by any observer; all other observers must measure a contracted length.

Proper time interval The time interval between two events as measured by an observer who records the two events occurring at the same point in space. It is the shortest time interval between events measured by any inertial observer.

Reference frame A coordinate system from which events in space and time are measured. The reference frame is commonly a set of objects that remain at rest relative to one another, from which spatial measurements can be taken, and a timing system consisting of a set of virtual clocks.

Relativistic Travelling at a significant fraction of the speed of light so that the Lorentz factor is no longer very close to 1.

Relativistic mechanics The rules that describe motion within Einstein's theory of relativity.

Rest frame The frame of reference in which a given particle or object is at rest.

Rest mass The mass of a particle (or object) at rest, or as measured by an observer who is at rest relative to the particle. According to the theory of relativity, because the energy of a particle depends on its speed, and mass and energy are equivalent, as a particle's speed increases its mass must also increase. $m = \gamma m_0$, where m_0 represents the rest mass, m represents total mass of a particle and γ is the Lorentz factor.

Scintillation An event that produces photons (light) due to the interaction of charged particles with certain materials.

Simultaneous events Events that occur at the same time in a specific reference frame, so that in this reference frame they have the same time coordinates. Events that are simultaneous in one frame may not be so in another frame.

Spacetime The combination in relativity of space and time into a single entity that is used to describe the fabric of the Universe. Fundamentally in relativity, time and space are not independent of each other and are observed differently depending on the relative motion of an observer.

Spacetime interval, Δs_2 The distance between two events across spacetime. Spacetime interval combines both the spatial and temporal elements of spacetime into a single value.

Spatial To do with the dimensions of space. A spatial interval is a length in space.

Special relativity The theory developed by Albert Einstein based on two postulates: that the laws of motion are the same for all inertial (non-accelerating) frames of reference and that the speed of light (in a vacuum) is the same for all inertial reference frames. The consequences lead to time dilation, length contraction and the equivalence of mass and energy

Synchronized Two clocks are said to be synchronized if according to an observer they are reading the same time.

Temporal To do with time. A temporal interval is an interval of time.

Thought experiment An experiment that is carried out theoretically, or in the mind, rather than actually being done normally, because it clarifies one aspect of a theory or because it is logistically impossible.

Time dilation Relative to an observer who sees the two events occurring in the same place, and so measures the proper time between the two events. All other observers measure a reduction in the time interval between two events due to the events occurring at greater spatial separations. The faster an observer is moving, relative to the observer measuring proper time, the greater the time dilation.

Time dilation formula $\Delta t = \gamma \Delta t_0$, where Δt_0 represents the proper time interval as measured by an observer who sees the first and second events occur in the same place, Δt represents that time interval between the same two events as measured by any other observer, and γ represents the Lorentz factor.

Time interval The difference between two events' time coordinates as measured from a single reference frame.

Twin paradox A paradox that appears to challenge special relativity, based on the impossibility that two twins should each find that they are older than the other. One twin remains on Earth while the other travels at high speed to a distant star and returns. Both twins claim that in their own reference frame they are stationary throughout while the other twin moves, so that the paradox appears to be symmetrical. However, the situation is not symmetrical because the travelling twin has not been in an inertial reference frame throughout and will be younger when returned to Earth than the Earth-bound twin.

Velocity addition (relativistic) If a object A has velocity u and object B has velocity v when viewed from the reference frame of object C, then the velocity u' of A with respect to B, is:

$$\frac{u+v}{1+\frac{uv}{c^2}}$$

Advanced higher level

This section takes words from Option A, sections A4 and A5.

Black hole An object of so much mass and density that spacetime becomes infinitely stretched, so that light, information and particles are unable to escape. The event horizon marks the limits of a black hole.

Equivalence principle The idea that the effects of an acceleration and of a gravitational field are completely indistinguishable. This has powerful implications and demands that physics that occurs in an accelerating reference frame must also occur in a gravitational reference frame, implying that, since spacetime is curved in an accelerating reference frame, gravitational fields and therefore mass must also distort spacetime.

Escape speed The minimum speed needed to escape to an infinitely great distance from a specific point within a gravitational field.

Event horizon An imaginary spherical surface around a black hole on which the escape speed is equal to the speed of light in a vacuum. This is used to define the dimensions of the black hole. Inside the event horizon the laws of physics become uncertain, although some predictions can be made.

General theory of relativity Einstein's generalization of special relativity to include all observers, not just observers in inertial reference frames. The main implications of the theory are to describe the distortions of spacetime in accelerating reference frames and the distortion of spacetime due to the presence of mass.

Gravitational lensing The bending of light due to the curving of spacetime around massive objects. This results in tiny shifts in the apparent positions of stars close to the Sun and in distorted or multiple images of stars as they are lensed by closer galaxies.

Gravitational mass The mass calculated by measuring the weight of an object and dividing this by the gravitational field strength.
Gravitational redshift General name for the shift in the frequency or wavelength of a photon that travels up or down in a gravitational field. The effect is a redshift if the photon travels upward, a blueshift if it travels downward.
Gravitational time dilation The slowing of time in regions of intense gravity.
Gravity (relativistic interpretation) In general relativity, gravity is explained as a consequence of the curvature of spacetime induced by the presence of a massive object.
Inertial mass The mass of an object as measured by comparing an unbalanced force on an object with the object's acceleration. Inertial mass is equal to the unbalanced force divided by the acceleration.
Kinetic energy (relativistic) The quantity $E_k = (\gamma - 1)m^0c^2$. The total energy minus the rest energy.
Momentum–energy equation The relation $E^2 = m_0{}^2c^4 + p^2c^2$ between total energy and momentum.
Relativistic momentum $p = \gamma p_0 = \gamma m_0 v$. Since mass is no longer invariant, this is just the classical momentum multiplied by the Lorentz factor.
Rest energy The minimum energy needed to create a particle, $E = m_0c^2$.
Schwarzschild radius, R_S The radius of the event horizon of a simple, uncharged, non-spinning black hole. The Schwarzschild radius defines a spherical surface where the escape velocity exactly equals the speed of light in a vacuum, which is used to specify the limits of a simple black hole.
Singularity A point at which the curvature of spacetime becomes infinite, causing the laws of physics to break down. During the formation of a black hole the surface of the star collapses inwards to a point. This point is an example of a singularity.
Solar mass A unit of mass based on the mass of the Sun. 1 solar mass = 1.99×10^{30} kg
Total energy (relativistic) The combination of potential energy and kinetic energy of an object. Normally this will be the sum of the rest energy and the kinetic energy. $E = \gamma m_0c^2$

14 Engineering physics (Option B)

Standard level

This section takes words from Option B, sections B1 and B2.

Adiabatic Occurring without thermal energy being transferred into or out of a system. $Q = 0$. An idealized situation, but approximated to by rapid changes to well-insulated systems. For an adiabatic change in an ideal monatomic gas $pV^{\frac{5}{3}}$ = constant.
Analogous Describes different systems or theories that have useful similarities.
Angular acceleration, α The rate of change of angular velocity with time, $\frac{\Delta\omega}{\Delta t}$. Unit: rad s^{-2}. $\alpha = \frac{\omega_f - \omega_i}{t}$. It is related to the linear acceleration of a point on the circumference by $\alpha = \frac{a}{r}$.
Angular momentum, L Moment of inertia multiplied by angular velocity: $L = I\omega$. Unit: kg m^2 s^{-1}
Angular velocity, ω The rate of change of angular displacement with time, $\frac{\Delta\theta}{\Delta t}$. Unit: rad s^{-1}. $\omega = \frac{2\pi}{T} = 2\pi f$.
Axis of rotation Line about which an object can rotate.
Carnot cycle The most efficient thermodynamic cycle. An isothermal expansion followed by an adiabatic expansion; the gas then returns to its original state by isothermal and adiabatic compressions.
Compression (of a gas) Decrease in volume. Compare with *expansion*.
Conservation of angular momentum The total resultant angular momentum of a system is constant provided that no resultant external torque is acting on it.
Couple Pair of equal-sized forces that have different lines of action, but which are parallel to each other and act in opposite directions, tending to cause rotation.
Cycle (thermodynamic) A series of thermodynamic processes that return a system to its original state (for example, the Carnot cycle).
Efficiency (thermodynamic), η Useful work done/energy input. For a Carnot cycle, maximum efficiency, $\eta_{\text{Carnot}} = 1 - \frac{T_{\text{cold}}}{T_{\text{hot}}}$.
Entropy A measure of the disorder of a thermodynamic system.
Entropy change When an amount of thermal energy, ΔQ, is added to, or removed from, a system at temperature T, the change in entropy, ΔS, can be calculated from the equation $\Delta S = \frac{\Delta Q}{T}$. The units of entropy are J K^{-1}.
Equations of rotational motion
$\theta = \omega_i t + \frac{1}{2}\alpha t^2$
$\omega_f{}^2 = \omega_i^2 + 2\alpha\theta$
Expansion (of a gas) Increase in volume. Compare with *compression*.
First law of thermodynamics If an amount of thermal energy, $+Q$, is transferred into a system, then the system will gain internal energy, $+\Delta U$, and/or the system will expand and do work on the surroundings, $+W$: $Q = \Delta U + W$. (This is an application of the principle of conservation of energy.)
Flywheel Dense, cylindrical (usually) mass with a high moment of inertia – added to the axes of rotating machinery to resist changes of motion and/or to store rotational kinetic energy.
Heat pump A machine designed to move thermal energy in the opposite direction from its spontaneous flow (from hotter to colder).
Inertia Property of an object that resists changes of motion (accelerations).
Internal energy of an ideal gas, U The sum of the random translational kinetic energies of all the molecules. $U = \frac{3}{2}nRT$
Irreversible process A process in which *entropy* increases; all real processes are irreversible.
Isobaric Occurring at constant pressure. $\Delta p = 0$
Isothermal Occurring at constant temperature. There is no change of internal energy: $\Delta U = 0$. pV = constant. An idealized situation, but can be approximated to by slow changes.
Isovolumetric Occurring at constant volume, so that no work is done: $W = 0$

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

Moment (of a force) Sometimes used as an alternative to *torque*, especially if rotation is incomplete.

Moment of inertia, I The resistance to a change of rotational motion of an object, which depends on the distribution of mass around the chosen axis of rotation. The moment of inertia of a point mass is given by $I = mr^2$. Unit: $kg\,m^2$. The moment of inertia of any real, extended mass can be determined by the addition of the individual moments of inertia of its particles. This is represented by $I = \Sigma mr^2$.

Newton's second law for angular motion $\Gamma = I\alpha$

Order and disorder (molecular) The way in which molecules are arranged, or energy is distributed, can be described (and measured) in terms of the extent of patterns and similarities (if they exist).

Piston A solid cylinder that fits tightly inside a hollow cylinder, trapping a gas (usually). Designed to move as a result of pressure differences.

Pivot Point of rotation for a lever.

Point particle A theoretical particle that does not occupy any space, such that its properties are not dependent on its shape or size.

Principle of moments If an object is in rotational equilibrium the sum of the clockwise moments equals the sum of the anticlockwise moments.

***pV* diagram** A graphical way of representing changes to the state of a gas during a thermodynamic process.

Reservoir (thermal) Part of the surroundings of a thermodynamic system that is kept at approximately constant temperature and is used to encourage the flow of thermal energy.

Rigid body An object that keeps the same shape.

Roll Rotation of an object along a surface in which the lowest point of the object is instantaneously stationary if the surface is horizontal. Requires friction. Compare with *slipping*.

Rotation Circular motion around a point or axis.

Rotational dynamics Branch of physics and engineering that deals with rotating objects.

Rotational equilibrium Describes an object that is rotating with constant angular velocity (or is stationary). Occurs when there is no resultant torque acting.

Rotational kinetic energy, $E_{K_{rot}}$ Kinetic energy due to rotation, rather than translation. $E_{K_{rot}} = \frac{1}{2}I\omega^2$

Second law of thermodynamics The overall entropy of the universe is always increasing. This implies that energy cannot spontaneously transfer from a place at low temperature to a place at high temperature. Or, in the Kelvin–Planck version: when extracting energy from a heat reservoir, it is impossible to convert it all into work.

Thermal energy, Q Non-mechanical energy transferred because of a temperature difference.

Torque, Γ Product of a force and the perpendicular distance from the axis of rotation to its line of action: $\Gamma = Fr \sin \theta$. Unit: N m

Work done when a gas changes state, W Work is done *by* a gas when it expands (W is positive). Work is done *on* a gas when it is compressed (W is negative). At constant pressure $W = p\Delta V$. If the pressure changes, the work done can be determined from the area under a pV diagram.

Working substance The substance (usually a gas) used in thermodynamic processes to do useful work.

Advanced higher level

This section takes words from Option B, sections B3 and B4.

Aerofoil The cross-sectional shape of an aircraft wing, which is designed to produce lift using the Bernoulli effect and the force from the air striking the wing. Similar shapes are used in reverse to produce down-force on cars and lift in hydrofoils (for use in water).

Archimedes's principle When an object is wholly or partially immersed in a fluid, it experiences an upthrust (buoyancy force) equal to the weight of the fluid displaced.

Atmospheric pressure p_0 Can be considered as being due to the weight of the air above an area of $1\,m^2$. Acts equally in all directions.

Bernoulli effect An application of the Bernoulli equation – when the speed of a fluid flowing past a surface increases, the fluid will exert less pressure.

Bernoulli equation Equation that represents the steady flow of an ideal fluid through any enclosed system. Derived by considering the conservation of energy when the fluid changes speed and/or height: $\frac{1}{2}\rho v^2 + \rho gz + p$ = constant.

Buoyancy Ability of a fluid to provide a vertical upwards force (*buoyancy force*, B) on an object placed in or on the fluid. Buoyancy force, $B = \rho_f V_f g$

Continuity equation The volume of an ideal fluid passing any point in a closed system every second must be constant: Av = constant (also called the *volume flow rate*).

Damping When resistive forces act on an oscillating system, dissipating energy and reducing amplitude. Damping may be described according to its degree: over-damping (resistive forces are so large that the amplitude reduces relatively slowly and oscillations do not occur), under-damping (many oscillations occur because resistive forces are relatively small), or *critical damping*.

Damping, critical When an oscillating system quickly returns to its equilibrium position without oscillating.

Energy of an oscillator Proportional to its amplitude squared.

Fluid Substance that can flow – usually a gas or a liquid.

Fluid dynamics The study of moving fluids.

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

Frequency, driving The frequency of an oscillating force (*periodic stimulus*) acting on a system from outside. Sometimes called *forcing frequency*.

Frequency, natural The frequency at which a system oscillates when it is disturbed and then left to oscillate on its own, without influence from outside.

Frequency response graph Graph used to show how the amplitude of a system's oscillations responds to different driving frequencies.

Hydraulic braking system Cars and other vehicles use oil in pipes and cylinders to exert large forces on the rotating wheels in order to provide braking.

Hydraulic machinery Machines that use enclosed fluids to transfer and magnify forces.
Hydrostatic equilibrium When a fluid is either at rest, or any parts of it that are moving have a constant velocity.
Hydrostatic pressure The pressure exerted at a point in a stationary fluid because of the weight of the fluid above that point. $p = \rho_f gd$. Hydrostatic pressure acts equally in all directions. If the fluid is underneath air the overall pressure can be determined from $p = p_0 + \rho_f gd$.
Hydrostatics The study of stationary fluids.
Ideal fluid A fluid that is incompressible, non-viscous and has a steady flow if moving.
Incompressible Volume cannot be decreased.
Laminar flow Idealized model of the flow of a fluid (at relatively low speeds) in which parallel layers of fluid are visualized as moving independently of each other. Sometimes called *streamlined flow*.
Pascal's principle A pressure exerted anywhere in an enclosed static liquid will be transferred equally to all other parts of the liquid.
Periodic stimulus See *resonance*
Pitot tube Used for measuring the flow speed of a fluid, or the speed of an object through a fluid. Relies on comparing the pressure in the direct flow of the fluid to somewhere else *not* in the direct flow.
Q (quality) factor A numerical representation of the degree of damping in a system. $Q = 2\pi \times$ (energy stored in oscillator/energy dissipated per cycle), or for a resonating system oscillating regularly, $Q = 2\pi \times$ resonant frequency × (energy stored in oscillator/power loss).
Resonance The increase in amplitude that occurs when a system is acted on by an external periodic force that has the same frequency as the natural frequency of the system. The driving force must be in phase with the natural oscillations of the system.
Reynold's number, *R* Number used to predict the conditions for turbulent flow. $R = \frac{vr\rho}{\eta}$ (no unit). Different Reynold's numbers apply to different situations, but as a guide if $R < 1000$ we can expect laminar flow.
Stokes's law Viscous drag acting on a smooth, spherical object undergoing streamlined flow. $F_D = 6\pi\eta rv$
Streamlined flow See *laminar flow*
Streamlines Lines that show the paths that (massless) objects would follow if they were placed in the flow of a fluid.
Terminal speed Highest speed of an object in translational equilibrium falling vertically through a fluid. Occurs when the weight of the object is equal to the viscous drag + upthrust.
Turbulent flow Non laminar flow of a fluid, which usually occurs at higher flow rates.
Upthrust Alternative name for buoyancy force.
Venturi tube Apparatus with a narrow tube in which the fluid pressure is reduced (Bernoulli effect).
Vibration Mechanical oscillation.
Viscosity Measure of a fluid's resistance to flow. Quantified by the coefficient of viscosity, η (unit Pa s).
Viscous drag, F_D Force opposing the motion of an object through a fluid because of viscosity. See *Stokes's law*.
Volume flow rate Volume of an ideal fluid passing any point in unit time. Unit $m^3 s^{-1}$
Wind tunnel Apparatus in which the flow of air past a stationary object is observed.

15 Imaging (Option C)

Standard level

This section takes words from Option C, sections C1, C2 and C3.

Aberration, chromatic Inability of a lens to bring light of different colours (coming from the same place) to the same point focus.
Aberration, spherical Inability of a lens, or mirror, with spherical surfaces to bring light (coming from the same place) to the same point focus.
Absorption (EM waves) Transfer of wave/photon energy to other forms within a medium, so that it is not transmitted or scattered.
Aerial Metallic conductor connected to an electronic circuit, which is designed to efficiently transmit or receive electromagnetic waves (usually radio waves or microwaves).
Antenna See *aerial*
Attenuation The gradual loss of intensity of a signal as it passes through a material. Attenuation (dB) $= 10\log\left(\frac{I}{I_0}\right) = 10\log\left(\frac{P}{P_0}\right)$. The intensity in an optic cable is considered to vary exponentially with distance and the attenuation is usually quoted in $dB\,km^{-1}$. See *decibel scale*
Binary number Number in which each digit can only have one of two possible values (usually 0 or 1).
Centre of curvature Where mirrors and lenses are made with surfaces that are small parts of spheres, the centre of such a sphere is called the centre of curvature of the lens or mirror surface.
Cladding (of optic fibre) Layer of glass that surrounds the central core and protects it from damage. Cladding also prevents separate cores coming in contact with each other. The refractive index of the cladding must be lower than that of the core.
Co-axial cable Cable in which a central copper wire is surrounded by an insulator and then an outer copper mesh. The mesh screens the central wire from *electromagnetic noise* (interference).
Converging mirror Also known as a *concave* mirror. Rays parallel to the principal axis are converged to a real focus that is midway between the mirror and the *centre of curvature* of the mirror surface.
Critical angle, c The smallest angle of incidence that will result in total internal reflection. $n = \frac{1}{\sin c}$
Decibel (dB) scale Logarithmic scale used for comparing widely varying powers or intensities.
Digital communication Data are transferred as a signal containing only a very large number of pulses, each of which can only have one of two possible levels (0 or 1). See *binary number*.
Dioptre, D The unit of measurement of optical power. Power in dioptres $= \frac{1}{\text{focal length in metres}}$
Dispersion The spreading (in time and length) of a pulse as it travels an increasing distance. This also results in decreased amplitude. Dispersion limits the rate at which data can be transmitted. See *waveguide dispersion* and *material dispersion*.

Diverging mirror Also known as a *convex* mirror. Rays parallel to the principal axis are diverged from a virtual focus that is midway between the mirror and the *centre of curvature* of the mirror surface.

Eyepiece Lens in an optical instrument that is closest to the eye.

Far point Furthest point from the human eye that an object can be focused clearly; usually accepted to be at infinity for normal vision.

Focal length, *f* Defined as the distance between the centre of the lens (or mirror) and the focal point.

Focal point For a converging lens (or mirror) this is defined as the point through which all rays parallel to the principal axis converge after passing through the lens (or reflecting from the mirror). For a diverging lens (or mirror) the focal point is the point from which the rays appear to diverge after passing through the lens (or reflecting off the mirror).

Focus To cause radiation (especially light) to converge to, or appear to diverge from, a point, usually with the intention of forming an image.

Graded-index fibres Optic fibres that have a non-constant refractive index. The value of the refractive index is lowest at the circumference and progressively increases towards the centre. This has the effect of confining rays to curved paths close to the centre of the fibre and therefore reducing *waveguide dispersion*. See *step-index fibres*.

Image The representation of an object that our eyes and brain 'see'.

Image properties Position, magnification, whether it is upright or inverted and whether it is real or virtual.

Imaging Formation of images.

Instrumentation Scientific equipment for observing and measuring. Developments in imaging have been mainly dependent on improved instrumentation.

Interference (electronic) See *noise*

Lens Transparent material with regularly curved surfaces that can be used to form images. *Converging* (convex) lenses usually converge rays to a real image; *diverging* (concave) lenses diverge rays away from a virtual image.

Magnification, angular, M Defined as the angle subtended at the eye by the image/angle subtended at the eye by the object: $M = \theta_i/\theta_o$.

Magnification, linear, *m* Defined as height of image/height of object: $m = \frac{h_i}{h_o} = \frac{-v}{u}$ (no unit).

Magnifying glass (simple) Single converging lens used to produce a magnified, upright, virtual image of an object placed closer to the lens than the focal point. If the image is formed at the near point the angular magnification is highest: $M_{\text{near point}} = \frac{D}{f} + 1$. Alternatively the eye can be more relaxed when the image is at infinity, then $M_{\text{infinity}} = \frac{D}{f}$.

Material dispersion Dispersion in an optic fibre that is a result of different wavelengths travelling at different speeds (and refractive indices). It can be overcome by using monochromatic radiation (e.g. radiation from an infrared LED).

Microscope, compound Two converging lenses used to produce a higher magnification of a close object than is possible with a simple magnifying glass. *Normal adjustment* means that the image is formed at the near point of the observer. Angular magnification is equal to the product of the linear magnification of the objective lens and the angular magnification of the eyepiece lens.

Microscope, electron Microscope that achieves high resolution by using electrons (which have a small wavelength) instead of light.

Near point Nearest point to the eye at which an object can be focused clearly (without straining). Usually accepted to be 25 cm from a normal eye. This distance is sometimes given the symbol *D*.

Noise (electromagnetic) Unwanted and irregular e.m.f.s induced in a conductor that is transmitting a signal. They are induced if oscillating electromagnetic waves from other sources pass through the conductor. Noise is often called *interference*, but this should not be confused with the superposition effect. If different wires within the same cable affect each other it may be described as *crosstalk*.

Object The term used to describe the place(s) from which rays/waves diverge before an optical system produces an image. Objects can either be *points* or, more realistically, *extended*.

Objective Lens or mirror in an optical instrument that receives light from the object. The quality and diameter of the objective are important factors in the quality of the final image produced by the instrument.

Opaque Describes a material through which light cannot be transmitted.

Optic fibre (communication) Fibre that transfers data using a large number of pulses of (usually) infrared radiation. Such fibres have much less attenuation than copper wires and are able to transfer much more data for similar dimensions.

Parabolic reflector Used to focus a parallel beam to a point, or to produce a parallel beam from a source placed at the focus.

Power (optical), *P* The power of a lens is the reciprocal of its focal length: $P = \frac{1}{f}$. If the focal length is measured in metres, the power is in dioptres, *D*. Refraction effects are bigger in more powerful lenses. When lenses are placed close together, their combined power is equal to the sum of their individual powers.

Principal axis Imaginary straight line passing through the centre of a lens, or curved mirror, that is perpendicular to the surfaces.

Radio-astronomy The study of the universe using radio waves.

Radio interferometry telescopes Two or more synchronized radio telescopes linked together, probably in a pattern (*array*). The combined signals form an interference pattern that provides higher resolution than from a single dish.

Ray diagram Scale drawing that shows the paths of rays from an object, through an optical system to an image. Usually the paths of three rays can be predicted and these can be used to determine the properties of the image.

Real image Image formed at a place where light rays/waves converge.

'Real is positive, virtual is negative' convention The focal lengths of diverging lenses and the distances to virtual images are given negative values, so that when using the equation $m = \frac{-v}{u}$, upright (virtual images) will always have positive magnifications, and inverted (real) images will always have negative magnifications.

Resolution The ability to see detail in an image. Measured in terms of the angle subtended by two points that can just be seen as separate. Rayleigh's criterion predicts that if the angle subtended by two points $> 1.22\lambda/b$, then the two points can be resolved.

Retina The surface at the back of the eye on which images are normally formed.

Scattering (EM waves) Various processes in which the directions of waves are changed as they are passing through a medium.

Signal Information transferred in a circuit or communications system.

Step-index fibres Optic fibres that have a constant refractive index, although there is a difference (step) between the refractive index of the core and the refractive index of the cladding.

Telescopes, Earth-based Telescopes situated on the Earth's surface. Also described as *terrestrial*.

Telescope, radio Telescope that forms images using the radio waves emitted from all parts of the universe. A parabolic dish aerial focuses the waves, but the resolution may be limited by the relatively long wavelengths of radio waves. See *radio interferometry telescope*.

Telescope, refracting Two lenses used to produce an angular magnification of a distant object. The image is inverted. In normal adjustment the final image is at infinity and the angular magnification, $M = \frac{f_o}{f_e}$.

Telescope, reflecting Telescope that uses a converging mirror instead of a converging lens as the objective. In a *Newtonian mounting* a plane mirror is then used to reflect rays to the eyepiece at the side. In a *Cassegrain mounting* a diverging mirror produces extra magnification and enables the observer to look in same direction as the source of light.

Telescope, satellite-borne A telescope placed on an orbiting satellite in order to overcome the effects of the Earth's atmosphere on incident radiation.

Thin lens equation Equation linking image distance, v, to object distance, u, and focal length, f: $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$. This equation is widely used, but is only valid for rays close to the principal axis of a thin lens.

Translucent A description of a medium through which electromagnetic waves are transmitted but scattering prevents the formation of images.

Transmission (EM waves) Sending waves from one place to another without absorption and/or scattering.

Transparent A description of a medium through which electromagnetic waves are transmitted without absorption and/or scattering. Images can be formed from light that has passed through transparent materials.

Twisted pair cabling Cables that carry one or more pairs of insulated wires twisted together. The twisting reduces the effects of electronic noise (interference).

Virtual image Image formed at a place from which light rays/waves appear to diverge.

Waveguide Structure designed to transfer waves along a particular route.

Waveguide dispersion Waves passing along an optic fibre can follow slightly different paths, which can have slightly different lengths. This can result in waves that started together becoming dispersed by the time they have travelled long distances. This problem can be improved by using *graded-index fibres*.

Advanced higher level

This section takes words from Option C, section C4.

A-scan Ultrasound scan that produces an amplitude (or intensity)–time graph showing reflections from the boundaries between different media in the body. A-scans enable accurate measurements of the locations and dimensions of different parts of the body.

Acoustic impedance, Z A measure of the opposition of a medium to the flow of sound through it. Calculated from $Z = \rho c$ (unit $\text{kg}\,\text{m}^{-2}\,\text{s}^{-1}$). The amount of reflection of ultrasound waves from boundaries between media depends on how their acoustic impedances compare – the bigger the difference in impedances, the higher the percentage of incident waves that are reflected.

Attenuation of X-rays Because of absorption and scattering, the intensity of a parallel beam decreases exponentially with distance, x, travelled through a medium and it can be represented by the equation $I = I_0 e^{-\mu x}$, where μ is a constant called the *linear attenuation coefficient*. Attenuation (dB) = $10 \log\left(\frac{I_1}{I_0}\right)$.

Attenuation coefficient, linear, μ Constant that represents the amount of attenuation of X-rays per unit length in a particular medium (for radiation of a specified wavelength). Usual unit: cm^{-1}. Linked to the *half-value thickness* by the equation $\mu x_{1/2} = \ln 2$.

Attenuation coefficient, mass Constant that represents the amount of attenuation of X-rays per unit mass. Mass attenuation coefficient = linear attenuation coefficient/density = μ/ρ. Usual unit: $\text{cm}^2\,\text{g}^{-1}$.

B-scan Ultrasound brightness scan that produces a two-dimensional real-time video image.

Charge-coupled device (CCD) Widely used component in digital imaging. Tiny CCDs record the arrival of incident electromagnetic radiation (photons) and convert it into digital data.

Collimate Create a parallel beam.

Computed tomography (CT) Computer-controlled use of X-rays rotating around a patient to obtain good resolution images (*scans*) of multiple sections of the body. Also known as CAT scans (computed axial tomography).

Contrast Difference in intensity.

Fluorescent material Material that emits visible light after some other kind of radiation has been absorbed.

Gel (ultrasound probe) Gel of suitable acoustic impedance that is applied between the probe and the skin in order to improve the transmission of ultrasound into the body.

Gradient fields As well as the very strong primary magnetic field used in NMR, a secondary variable (gradient) field that is also applied to the patient. This ensures that different planes of the body are in slightly different magnetic fields, resulting in different *Larmor frequencies*.

Half-value thickness, $x_{1/2}$ Defined as the thickness of a medium that will reduce the transmitted intensity of an X-ray beam to half of its previous value.

Intensifying screen Screen containing a *fluorescent material* that is used to intensify (increase the intensity of) an image formed from X-rays.

Larmor frequency Frequency of *precession* of protons around an externally applied magnetic field. Larmor frequencies occur within the radio wave section of the electromagnetic spectrum and are proportional to magnetic field strength.

Magnetic resonance imaging (MRI) Alternative name for the use of NMR in medicine.

Nuclear magnetic resonance (NMR) Medical imaging technique in which protons in hydrogen atoms are made to spin in a very strong magnetic field. Radio frequency (RF) electromagnetic radiation is then used to make the proton spins align (a resonance effect) so that they create a detectable magnetic field. When the RF radiation is turned off the changes produced enable the location of the protons to be determined.

Piezoelectric effect Certain materials acquire a potential difference across them when they are deformed. This can be used to convert mechanical oscillations into oscillating electrical signals, and oscillating electric currents into mechanical vibrations, such as in an ultrasound transducer.

Precession When a spinning object also rotates around another axis at a lower frequency.

Probe (ultrasound) Common name for an ultrasound transducer.

Pulse repetition frequency Frequency of pulses of ultrasound, which can be adjusted to allow time for the reflected wave to be received back at the probe before the next pulse is emitted.

Quality of X-rays Describes the penetrating power of an X-ray beam (which is determined by the voltage used across the X-ray tube). More penetrating X-rays are often described as 'hard'.

Relaxation (NMR) Time during which excited protons return to their previous state. This time depends on the type of tissue involved, and the information improves the image quality.

Resonance Effect in which a system (that can oscillate) absorbs energy from another external oscillating source, such that the amplitude increases as energy is transferred.

RF coils (NMR) Coils that emit and receive the radio waves involved in NMR.

Risk analysis Scientific and technological developments can have adverse effects, which may involve health risks (direct or indirect). Every effort should be made to anticipate such risks and to evaluate the advantages and disadvantages of any research, or the subsequent use of the technology.

Scan (medical) Obtain a visual representation of the interior of the body using electromagnetic waves or ultrasound.

Sharp images Images with distinct edges and high resolution.

Tomography Obtaining images of a three-dimensional object as a series of sections or 'slices'. See *computed tomography*.

Transducer Device that converts a signal from one form of energy to another; typically to or from electricity. See *probe*.

Ultrasound Sound waves that have frequencies higher than those that can be heard by humans (≈ 20 kHz).

Ultrasound scan Medical imaging that is especially useful for identifying slight density changes between different soft tissues. Safe, mobile and inexpensive, but the resolution is disappointing.

Ultrasound scan frequency Higher frequencies (shorter wavelengths) produce better image resolution, but the attenuation is greater.

16 Astrophysics (Option D)

Standard level

This section takes words from Option D, sections D1, D2 and D3.

Accelerating universe The recession speed of distant galaxies (as determined from the redshift of Type Ia supernovae) provides evidence that the rate of expansion of the universe is increasing.

Apparent brightness, *b* Intensity (power/area) of radiation received on Earth from a star unit: $\mathrm{W\,m^{-2}}$. Related to luminosity by: $b = \frac{L}{4\pi d^2}$

Arc-second (arcsec) $\frac{1}{3600}$ of a degree.

Astronomical unit (AU) Unit of distance used by astronomers; equal to an agreed average distance between the Sun and the Earth.

Big Bang model Currently accepted model of the universe, in which matter, space and time began at a point 13.7 billion years ago and the universe has expanded ever since. Sometimes called the *Hot* Big Bang model because early temperatures of the universe were exceptionally high.

Binary star system Two relatively close stars orbiting their common centre of mass.

Black hole After a supernova, the remaining core of a red supergiant, which is too massive to form a neutron star, will become a black hole with forces of gravity so large that light cannot escape.

Blue-shift The spectra of radiation received from stars and (the relatively few) galaxies that are moving towards Earth are shifted towards shorter wavelengths.

Cepheid variable star Type of star that is very useful in determining the distance to galaxies. The luminosity of a Cepheid variable changes in a predictable way and can be estimated from a measurement of its time period. See *period–luminosity relationship*.

Chandrasekhar limit Maximum mass of a stable white star supported against gravity by electron degeneracy pressure (= 1.4 × solar mass). More massive stars will become neutron stars or black holes.

Cluster of galaxies Group of galaxies bound together by gravitational forces. See *super clusters*. (Should not be confused with a *galactic cluster*, which is a cluster of stars within a particular galaxy.)

Comet Relatively small object of ice, dust and rock that orbits the Sun, usually with a very elliptical orbit and long period. Some have 'tails' that are visible from Earth with the unaided eye when they are close to the Sun.

Constellation An area of the night sky defined and named by the pattern of visible stars it contains. The stars may appear relatively close together, but in practice they can be a long distance apart and unconnected. Compare with *stellar cluster*.

Cosmic microwave background (CMB) radiation Spectrum of electromagnetic radiation received almost equally from all directions (see *isotropic*) and characteristic of a temperature of 2.76 K. CMB radiation is evidence in support of the Hot Big Bang model.

Cosmic scale factor, *R* Used by astronomers to represent the size of the universe by comparing the distance between any two specified places (two galaxies, for example) at two different times, one of which is usually assumed to be the present. (So that the cosmic scale factor now is 1.) The distances, and the cosmic scale factor, increase with time because the universe is expanding. R is closely related to red-shift: $z = \frac{R}{R_0} - 1$.

Cosmology Study of the universe (cosmos).

Dark energy Unknown form of energy the existence of which has been postulated to explain the accelerating expansion of the universe. It is believed to account for about 68% of the total mass-energy in the universe.

Electron degeneracy pressure Process occurring within white dwarf stars that keeps them stable and stops them collapsing.

Elliptical In the shape of an ellipse (oval). An ellipse has two foci on its major axis.

Expansion of the universe We know that the universe has expanded since the Big Bang and that the rate of expansion is currently increasing. But past and future expansion rates are uncertain. Possibilities are often represented on a cosmic scale factor–time graph.

Galaxy A very large number of stars (and other matter) held together in a group by the forces of gravity.

Gravitational pressure (in a star) Pressure acting inwards in a star due to gravitational forces.

Hertzsprung–Russell (HR) diagram Diagram that displays order in the apparent diversity of stars by plotting the luminosity of stars against their surface temperatures.

Hubble's law The current velocity of recession (the speed at which a galaxy appears to be moving directly away from Earth), v, of a galaxy is proportional to its distance away (from Earth), d. $v = H_0 d$, where H_0 is the Hubble constant, which can be used to estimate the age of the universe: $T \approx \frac{1}{H_0}$.

Instability strip A region of the HR diagram contain pulsating, variable stars, such as Cepheid variables.

Interstellar matter Matter between the stars – mainly gases (mostly hydrogen and helium) and dust.

Isotropic Equal in all directions

Light year, ly Unit of distance used by astronomers equal to the distance travelled by light in a vacuum in 1 year.

Luminosity, *L* Total power radiated by a star (unit: W). From Chapter 8: $L = e\sigma AT^4$. (Emissivity, e, of stars is usually assumed to be 1.)

Main sequence The band of stable stars that runs from top left to bottom right on the *Hertzsprung–Russell diagram*. Most stars are located in the main sequence.

Mass–luminosity relationship More massive *main sequence* stars have high temperatures and fast fusion rates. This means that they have shorter lifetimes. The equation that indicates the approximate relationship between mass and luminosity is $L \propto M^{3.5}$.

Milky Way The galaxy in which our solar system is located.

Moons Massive objects that orbit planets.

Nebula (plural: nebulae) Diffuse 'cloud' of *interstellar matter*; mainly gases (mostly hydrogen and helium) and dust.

Neutron stars *Main sequence* stars that have a mass greater than 8 solar masses become red supergiants at the end of their time on the main sequence. Those that have an original mass less than about 40 solar masses will become very dense neutron stars after a *supernova*. They do not collapse further because of *neutron degeneracy pressure*.

Neutron degeneracy pressure Process occurring within neutron stars that keeps them stable and stops them collapsing.

Newton's model of the universe An infinite, uniform and static universe.

Nuclear fusion Process in which light nuclei join to make a heavier nucleus, with the release of energy. Nuclear fusion is the main energy source of stars.

Occam's razor If you need to choose between two or more possible theories, select the one with the fewest assumptions.

Oppenheimer–Volkoff limit Maximum mass of a stable neutron star supported against gravity by neutron degeneracy pressure (≈ 3 × solar mass). More massive stars will become black holes.

Parallax angle (stellar), *P* Half of the angle between imaginary lines from Earth to a nearby star's position (on the background of more distant stars) drawn 6 months apart.

Parsec, pc Unit of distance used by astronomers; equal to the distance to a star that has a parallax angle of one arc-second.

Period, *T* Time taken for one complete orbit (or other regularly repeating event).

Period–luminosity relationship Graph used with Cepheid variables to determine their luminosity from knowledge of the period of the oscillations of their luminosity. This enables their distance from Earth to be determined.

Planetary nebula Material emitted from the outer layers of a red giant star at the end of its lifetime. The core becomes a white dwarf star.

Planetary system A collection of (non-stellar) masses orbiting a single star.

Plasma State of matter containing a high proportion of separated charged particles (protons, ions and electrons).

Radiation pressure Pressure in a star due to radiation emitted.

Recession speed The speed with which a galaxy (or star) is moving away from Earth.

Red giant (and red supergiant) stars Relatively cool stars, so they are yellow/red in colour; their luminosity is high because of their large size. Most stars will become red giants (or red supergiants) at the end of their time on the *main sequence*.

Red-shift Displacement of a (line) spectrum towards lower frequencies. It occurs because the distance between the source and the observer is increasing. (Similar to the *Doppler effect*.) The red-shift of radiation received from distant galaxies is evidence that the universe is expanding. Quantified by the equation $z = \Delta\lambda/\lambda_0 \approx v/c$ (no unit).

Solar system The Sun and all the objects that orbit around it.

Standard candle Term used by astronomers to describe the fact that the distance to a galaxy can be estimated from a knowledge of the luminosity of a certain kind of star within it (such as a Cepheid variable or certain type of supernova).

Star Massive sphere of plasma held together by the forces of gravity. Because of the high temperatures, thermonuclear fusion occurs and radiation is emitted.

Star map Two-dimensional representation of the relative positions of stars as seen from Earth (usually either from the northern hemisphere or from the southern hemisphere).

Stellar cluster A group of stars formed from the same nebula that are relatively close together and move as a group because they are bound together by the forces of gravity. Compare with *constellation*. *Globular clusters* are approximately spherical (like a globe) because they contain many thousands of stars. *Open clusters* contain far fewer stars, so that the overall gravitational forces are less even and the cluster has an ill-defined shape.

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

Stellar parallax Method of determining the distance, d, to a nearby star from measurement of its *parallax angle*: d (parsec) $= 1/p$ (arc-second), where p is the parallax angle of the star.

Stellar evolutionary path Representation on the *HR diagram* of the changes to the temperature and luminosity of a star after it leaves the main sequence.

Stellar spectra The spectra that stars emit or absorb, which are used to determine the elements present.

Sun The object around which the Earth orbits. A *main sequence* star.

Super cluster (of galaxies) Group of clusters of galaxies. May be the largest 'structures' in the universe.

Supernova Sudden, unpredictable and very luminous stellar explosion. Type Ia supernovae have a known luminosity, which makes them very useful as *standard candles*.

Thermal gas pressure (in a star) Pressure in a star due to the motion of the particles within it.

Universe All existing space, matter and energy; also called the cosmos. There may be many universes.

Universe (observable) That part of our universe that we are theoretically able to observe from Earth at this time. What we can observe is limited by the age of the universe and the speed of light.

White dwarf stars Relatively hot stars, so that they are blue/white in colour, but their luminosity is low because of their small size. They are formed at the end of the main sequence lifetimes of stars of mass < 8 solar masses. The outer layers of the star are ejected as a *planetary nebula* and the inner core, which is initially extremely hot and luminous, cools and dims to become a white dwarf star.

Wien's (displacement) law Law that connects the wavelength at which the highest intensity is emitted from a star to its surface temperature (see Chapter 8): $\lambda_{max}T = 2.9 \times 10^{-3}\,\text{m K}$.

Advanced higher level

This section takes words from Option D, sections D4 and D5.

Anisotropic Varies with direction. Compare with *isotropic*.

Closed universe ($\rho > \rho_c$) A possible future in which the universe will stop expanding and then begin to contract, and eventually end as a 'Big Crunch'.

Cognitive bias When a person's judgement is incorrectly influenced by their own experiences and opinions.

COBE, Cosmic Background Explorer Satellite launched in 1989 that investigated cosmic microwave background radiation.

Cosmic microwave background radiation, fluctuations Tiny variations in the CMB (*anisotropies*), which provide evidence about the early universe.

Cosmological principle The universe is homogeneous and isotropic (on the large scale).

Cosmic scale factor–time graphs Useful way of representing possible futures of the universe, with and without *dark energy*.

Critical density (of the universe), ρ_c The theoretical density that would *just* stop the expansion of the universe after an infinite time. The equation $\rho_c = \frac{3H^2}{8\pi G}$ can be derived from classical physics theory.

Dark matter Matter that has not been detected directly because it neither emits nor absorbs radiation. The existence of dark matter is needed to explain the higher than expected rotational velocities of stars within galaxies.

Flat universe ($\rho = \rho_c$) A possible future in which the universe will approach a limiting size at infinite time.

Homogeneous All parts are similar.

Isotropic universe What we can observe is essentially the same in every direction. This implies that there is no edge and no centre to the universe.

Jeans criterion The conditions necessary for star formation – the collapse of an interstellar cloud to form a star can only begin if its mass $M > M_J$, where M_J is known as the Jeans mass.

Lifetime of a main sequence star Depends on its mass. Greater mass means a higher rate of fusion and shorter lifetime. $T \propto \frac{1}{M^{2.5}}$

MACHOs (massive astronomical compact halo objects) A general term for any kind of massive astronomical body, which might explain the apparent presence of dark matter in the universe.

Nuclear fusion of hydrogen The main source of energy in *main sequence* stars. There are three stages in the fusion of hydrogen into helium by the *proton–proton cycle*.

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.

Open universe ($\rho < \rho_c$) A possible future in which the universe will continue to expand for ever.

Planck Space Observatory Satellite launched in 2009 that had the primary aim of investigating variations in the CMB, with resolution improved on that achieved by earlier satellites.

Proton–proton cycle See *nuclear fusion of hydrogen*

r-process (rapid neutron capture) Relatively fast nucleosynthesis of heavier elements. Occurs in supernovae that have high temperatures and neutron densities, so neutron captures are more likely that beta decays.

Red-shift, cosmological Red-shift is due to the fact that the space between the source and the observer has expanded between the time when the radiation was emitted and the time when it was received. Evidence for the Big Bang model.

Red-shift, Doppler effect Red-shift due to the fact that the observer and the source are moving apart (in unchanging space).

Rotation curve Graph showing how the rotational velocity of stars varies with distance from the centre of a galaxy. Classical physics predicts that the speeds close to the centre of the galaxy are given by $v = \sqrt{\frac{4\pi G\rho}{3}}\,r$, and at longer distances $v \propto \sqrt{\frac{1}{r}}$. but theoretical curves do not agree with observations.

s-process (slow neutron capture) Relatively slow nucleosynthesis of heavy elements (but none heavier than Bi-209) in some red giants, in which neutron captures are less likely than beta decays.

Supernova, Type Ia Occurs when two stars in a binary system join together so that *electron degeneracy pressure* is no longer sufficient to prevent the collapse of the system. Because this only occurs when the system has acquired a certain (well-known) mass, the luminosities of Type Ia supernovae are always about the same and can be used as *standard candles*.

Supernova, Type II Occurs at the end of the lifetime of a red supergiant. Results in a *neutron star* or a *black hole*.

Temperature of the universe (average) Decreases as the universe expands and the cosmological scale factor increases: $T \propto \frac{1}{R}$.

WIMPs (weakly interacting massive particles) A general term for any currently undetected particles that might explain the apparent presence of dark matter in the universe.

WMAP (Wilkinson Microwave Anisotropy Probe) Satellite launched in 2001 that had the major aim of investigating variations in the CMB.