α-decay

is: the process in which a nucleus undergoes radioactive decay to form a less massive nucleus with the ejection of an α-particle, e.g. ${}^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$ (where ${}^{4}_{2}\mathrm{He}$ denotes the α-particle). [P9.2]

is a type: of radioactive decay. [P9.2]

α-particle

is: a helium nucleus with positive charge $2e$ and relative atomic mass 4.0026. [P8.1, P9.1, P9.2]

is ejected: in radioactive α-decay. [P9.2]

is denoted: α or ${}^4_2\mathrm{He}$ (or He^{2+} since it is a helium atom stripped of its two electrons). [P8.1, P9.1, P9.2]

aberration

is: distortion in an optical image produced by the optical system forming the image and composed of contributions arising from a number of well known causes that include spherical aberration, coma, and chromatic aberration. [P6.2, P6.4]

is also: those features of a lens or mirror which cause such distortions. [P6.4]

absolute error

is: the absolute value (i.e. modulus) of an error or uncertainty in a quantity. [P1.2]

has: the same dimensions as. the quantity itself. [P1.1]

absolute maximum

See global maximum.

absolute minimum

See global minimum.

absolute temperature

is: a temperature expressed in kelvin (K) on a temperature scale that starts at absolute zero. Such scales include the ideal gas absolute scale, the thermodynamic Kelvin temperature scale and the International Practical Temperature Scale 1990. [P7.2]

absolute value

See modulus.

absolute zero

is: the lowest possible temperature. [P7.2]

is defined: as 0 K (i.e. 0 kelvin). [P7.2]

corresponds: to −273.15 °C (i.e. −273.15 degrees Celsius). [P7.2]

absorbed dose

is: the amount of energy from ionizing radiation absorbed per unit mass by a body. [P9.3]

has as its SI unit: the gray (Gy), where $1\,\mathrm{Gy} = 1\,\mathrm{J\,kg^{-1}}$ (i.e. 1 joule per kilogram). [P9.3]

absorption

of: electromagnetic radiation

is: the outcome of any process whereby the energy carried by electromagnetic radiation is transformed and added to the internal energy of the medium through which the electromagnetic radiation is travelling.

should be contrasted: with emission, and reflection.

more generally is: the outcome of any process in which an entity or agency is partly or wholly assimilated into another.

absorption line spectrum

is: an absorption spectrum that exhibits absorption lines. [P8.2]

absorption lines

in: the absorption spectrum of a medium (especially a gas, vapour or plasma)

are: characteristic narrow ranges of frequency or wavelength (often treated as single frequencies or wavelengths) at which the spectral brightness is significantly less than the (average) spectral brightness in neighbouring parts of the relevant spectrum. [P8.2]

correspond individually: to a transition between two bound states of a particular kind of atom, molecule or ion (or to any other process) that causes the absorption of electromagnetic radiation at particular frequencies or wavelengths. [P8.2]

absorption spectrum

of: electromagnetic radiation, often produced from a continuous emission spectrum (e.g. a source of white light) which has been passed through a specified absorbing medium.

is: the distribution of (relative) spectral brightness with respect to frequency or wavelength. [P8.2]

may be displayed: as a graph of the (relative) spectral brightness plotted against wavelength or frequency, or (photographically) as a band of varying levels of brightness and darkness. [P8.2]

may exhibit: (especially for a gas, a vapour or a plasma) characteristic absorption lines, in which case it is often referred to as an absorption line spectrum, or (especially in the case of a solid or a liquid) smoothly varying absorption across a broad range of frequencies or wavelengths. [P8.2]

absorption transition

in: an atom, molecule or ion

is: a transition in which the atom, molecule or ion absorbs energy from incoming electromagnetic radiation and is thereby excited from one bound state to another bound state of higher energy. Each absorption transition gives rise to an absorption line in an appropriate absorption spectrum. [P8.2]

usually: involves the ground state as the lower energy state.

AC circuit, a.c. circuit

is: an electrical circuit in which an alternating current flows, or may be presumed to flow. [P5.4]

AC, a.c.

See alternating current.

acceleration

is: a vector quantity $\boldsymbol{a}$ which specifies the rate of change of velocity with time. [M2.1, M2.4, P2.1]

in one dimension is: $a_x = \dfrac{v_x - u_x}{t}$ for a particle moving in a straight line with uniform acceleration a_x along the x-axis, where u_x and v_x are the initial and final velocities respectively and t is the time taken for the change in velocity. [P2.1]

is defined generally: as $\boldsymbol{a} = d\boldsymbol{v}/dt$, the derivative of velocity with respect to time. [M4.1, M5.1]

is often specified: in terms of its scalar components, a_x, a_y, a_z by $\boldsymbol{a} = (a_x, a_y, a_z) = (dv_x/dt, dv_y/dt, dv_z/dt)$. [M4.1, M5.1]

has as its SI unit: $\mathrm{m\,s^{-2}}$ (i.e. metre per second squared). [M4.1]

is given graphically: at any particular time, by the gradient of the tangent to the velocity-time graph of the motion at that time. [M4.1, P2.1]

See also instantaneous acceleration.

acceleration due to gravity

is: the acceleration with which an object falls near to the surface of the Earth, due to the gravitational force that acts upon it. The magnitude of this acceleration is given the symbol, g and has the approximate value $9.8\,\mathrm{m\,s^{-2}}$. [P2.1]

is equal: to the gravitational field at the Earth's surface. [P3.2]

may be regarded: as the free fall acceleration of an object at the Earth's surface, or the surface gravity. [P3.2]

See magnitude of the acceleration due to gravity.

accommodated (eye)

is: an eye in which the ciliary muscles (which control the lens) are not fully relaxed. [P6.4]

is focused: somewhere closer than at its far point (usually infinity). [P6.4]

Contrast with unaccommodated (eye). [P6.4]

accuracy

of: a measurement or value

is: a measure of the extent to which the measurement (or value) differs from the true value. [P1.1]

is also: a measure of the extent to which the measurement (or value) is free of systematic error. [P1.1]

linguistically is: perverse. The greater the accuracy, the smaller is its numerical value. A clearer way of expressing it is to say that a quantity is 'accurate to within plus-or-minus so-much'. [P1.1]

Compare with precision.

achromatic doublet

is: a combination of two lenses (glued together), designed to minimize chromatic aberration at two predetermined wavelengths. [P6.4]

traditionally consists: of a converging lens of crown glass with low dispersion and a weaker diverging lens of flint glass with high dispersion. [P6.4]

acoustic energy

is: the energy transported by sound. [P5.7]

acoustic wave

See sound wave.

acoustics

is: the branch of physics concerned with the study of sound.

actinides

are: the fourteen chemical elements with atomic numbers in the range 89-102 inclusive (i.e. from actinium to nobelium). [P8.4]

are all: radioactive. [P9.3]

include: uranium and plutonium. [P8.4]

occur: in a part of the periodic table where the 5f subshell of atoms in their ground state is being progressively filled. [P8.4]

activity

is: the rate $R(t)$ at which the nuclei of a radioactive substance disintegrate due to radioactive decay. [P9.2]

is also: a measure of the rate of emission of α-particles, β-particles or γ-radiation from a radioactive isotope. [P9.2]

is related: to the number $N(t)$ of unstable nuclei of decay constant λ in a pure sample (containing only a single type of radionuclide) by
$R(t) = -dN/dt = \lambda N(t)$. [P9.2]

has as its SI unit: the becquerel (Bq). 1 Bq = 1 decay per second. The non-SI unit of activity, the curie (Ci, $1\,\text{Ci} = 3.70 \times 10^{10}\,\text{Bq}$) is also in common use. [P9.2]

See activity law.

activity law

is: the law which governs the activity $R(t)$ of a sample of a radioactive isotope, which will remain after a given time t has elapsed. The law is exponential: $R(t) = R_0\,e^{-\lambda t}$, where R_0 is the initial activity and λ is the decay constant. [P9.2]

See radioactive decay and radioactive decay law.

acute angle

is: an angle of less than 90°. [M2.1]

Contrast with obtuse angle and reflex angle.

addition (of vectors)

See vector addition.

addition formulae

are: a class of trigonometric identities. [M1.6]

See trigonometric functions in the Maths handbook.

addition identities

are: a class of hyperbolic function identities. [M4.6]

See hyperbolic functions in the Maths handbook.

adiabat

is: a path representing a quasistatic adiabatic process, usually on a *PVT*-surface (or some similar surface) or on one of its projections. [P7.4]

adiabatic

describes: a situation in which no heat enters or leaves a system, so that $\Delta Q = 0$. [P7.3]

adiabatic condition

for: a fixed quantity of ideal gas

states: that PV^{γ} = constant, where the constant is characteristic of the process, and γ the ratio of specific heats of the gas (C_P/C_V), is approximately constant for the gas. [P7.4]

characterizes: an adiabatic process. [P7.4]

adiabatic process

takes place: without heat entering or leaving the system, so $\Delta Q = 0$. [P7.3]

See adiabat and adiabatic condition.

adjacent side

of: a right-angled triangle

is: the side (not the hypotenuse) that is adjacent to any specified one of the acute angles. [M1.6]

See trigonometric functions in the Maths handbook.

air friction

is: air resistance. [P5.2]

air resistance

is: a force that opposes motion through air. [P2.3]

has magnitude: proportional to the square of the object's speed, for objects of moderate size and speed, moving through the Earth's atmosphere close to the Earth's surface. [P2.3, P5.2]

Airy disc

is: the central circular region of an Airy pattern, extending as far as the first minimum. [P6.4]

Airy pattern

is: the (angular) distribution of radiation diffracted by a circular aperture.
[P6.4]

alcohol-in-glass thermometer

is: a glass capillary with a bulb containing alcohol. Changes in temperature cause the glass and alcohol to expand (or contract) by different amounts, and the result is that the meniscus moves to different positions in the capillary. [P7.2]

can be calibrated: by marking meniscus positions corresponding to fixed points such as the boiling and freezing points of water, and then interpolating between them. [P7.2]

algebra

is: the branch of mathematics concerned with symbols and their manipulation according to defined rules.

algebraic

pertains: to algebra, the branch of mathematics concerned with symbols and their manipulation. [M1.1]

algebraic division

is: the application of division to an algebraic expression. [M1.4]

algebraic expression

is: an expression that contains algebraic symbols as well as numbers.

algebraic sum

is: a process of addition that respects a sign convention. [P2.7]

alkali metals

are: the metallic elements lithium, sodium, potassium, rubidium, caesium and francium. [P8.4]

are so named: because the metals dissolve in water to give solutions that contain significant concentrations of aqueous hydroxide (OH^-) ions. Materials generating such solutions are said to be alkalis (essentially the opposite of acids). [P8.4]

occur: in Group I of the periodic table. [P8.4]

alloy

is: a material with characteristically metallic properties, formed from a combination of elements, of which at least one major constituent is itself a metal. Although specified by a chemical formula, its constituents do not form molecules that correspond to the chemical formula.

alpha-particle

See α-particle.

alternate angles

See transversal.

alternating current, a.c.

is: an electric current which changes magnitude and direction in a regular periodic way. [P5.4, P5.5]

often is: sinusoidal, i.e. it may be described by the formula $I(t) = I_0 \sin(\omega t + \phi)$, where I_0 is the peak value or amplitude of the current, ω is the angular frequency, ϕ is the phase constant and $(\omega t + \phi)$ is called the phase of the current. [P5.4, P5.5]

may also be described: using complex quantities, so in the sinusoidal case $I(t) = \mathrm{Re}\,[\mathscr{I}_0 \exp(\omega t + \phi)]$. [P5.5]

more generally refers: to other associated electrical quantities whose direction varies with time, e.g. a.c. voltage. [P5.4]

is abbreviated: AC at the beginning of a sentence, and a.c. elsewhere. [P5.4]

alternator

is: a device that generates an induced voltage of changing polarity by rotating a coil within a magnetic field. [P4.4]

is also known: as an alternating current (a.c.) dynamo. [P4.4]

ammeter

is: an instrument for measuring electric current that is placed in series with other circuit components through which the current to be measured flows. [P4.1]

ideally has: zero resistance, so that it does not affect the circuit to which it is connected. [P4.1]

amount of substance

is: a measure of the quantity of substance in a sample, expressed in terms of the number of basic entities (atoms, molecules, etc.) of the substance that are present in the sample.

has as its SI unit: the mole (mol).

ampere, A

is: the SI unit of electric current (i.e. rate of flow of electric charge), one of the seven base units. [P4.1]

is defined: as that constant current which, if maintained in each of two infinitely long, straight, parallel wires of negligible cross section, placed 1 metre apart, in a vacuum, will cause each wire to experience a force of magnitude 2×10^{-7} newton per metre of its length. [P4.3]

is equivalent: to the transfer of one coulomb per second, so $1\ \mathrm{A} = 1\ \mathrm{C\ s^{-1}}$. [P4.1]

amplitude

of: an oscillation or a wave

is: the maximum magnitude of displacement from an equilibrium value. [P5.1, P5.5, P6.1]

is represented: by the constant A that appears in the general solution of the simple harmonic motion equation when written in the form
$y = A\sin(\omega t + \phi)$. [M5.1, P5.5, P5.6]

also appears: in similar equations such as that describing damped driven harmonic motion. [M6.3, M6.4]

is exemplified: by the maximum value of the pressure change caused by the passage of a sound wave. [P5.7]

angle

is: the inclination of one line with respect to another or, equivalently, the amount by which one line must be rotated about a point in order to align it with another line passing through the same point. [M1.6]

is commonly measured: in degrees or radians. [M1.6]

is also called: plane angle.

angle of contact

in: capillarity

is: the angle between a meniscus and a solid surface at their point of contact. [P7.6]

angle of deviation

in: geometrical optics and acoustics.

is: the angle through which a ray is turned, often by refraction on entering a different material or medium. [P6.3]

angle of dip

See angle of inclination.

angle of incidence

in: geometrical optics and acoustics.

is: the angle between the incident ray and the normal to the surface or interface at the point of incidence. [P5.7, P6.1, P6.2]

angle of inclination

is: the angle between the (local) Earth's magnetic field and the horizontal. [P4.2]

is also called: angle of dip. [P4.2]

angle of reflection

in: geometrical optics and acoustics.

is: the angle between the reflected ray and the normal to the surface or interface at the point of incidence. [P5.7, P6.1, P6.2]

is equal: to the angle of incidence, according to the law of reflection. [P5.7, P6.1, P6.2]

angle of refraction

in: geometrical optics and acoustics.

is: the angle between the refracted ray and the normal to the surface or interface at the point of incidence. [P5.7, P6.1, P6.2]

is related: to the angle of incidence via Snell's law (the law of refraction). [P5.7, P6.1, P6.2]

angular acceleration

is: the rate of change of angular velocity, either in magnitude or in direction or in both. [P2.7]

is defined: as $\boldsymbol{a}_\theta = d\boldsymbol{\omega}/dt$. [P2.7]

has as its SI unit: $\mathrm{rad\,s^{-2}}$ (i.e. radian per second squared. [P2.7]

can be represented: if the direction of the angular velocity does not change, by the scalar quantity $a_\theta = d\omega/dt$. [P2.7]

can be determined: if the angular acceleration a_θ is uniform, by $a_\theta = (\omega_2 - \omega_1)/t$, where ω_2 and ω_1 are the angular speeds at the end and beginning respectively of the time interval t. [P2.7]

angular frequency

of: oscillatory motion

is: a measure of the rate at which complete oscillations are executed. [M5.1, P5.5]

is related: to the frequency f of the oscillation by $\omega = 2\pi f$. [P5.1, P5.4, P5.5, P5.6]

is also related: to the period T of the oscillation by $T = 2\pi/\omega$. [P5.1, P5.5]

has as its SI unit: the hertz (Hz), where $1\,\mathrm{Hz} = 1\,\mathrm{s}^{-1}$ (i.e. per second). [P5.1, P5.4, P5.5]

is represented: by the parameter ω in the formula $y = A\sin(\omega t + \phi)$ that describes simple harmonic motion. [M6.3, M6.4, P5.1]

Compare with angular speed.

angular limit of resolution

See angular resolving power.

angular magnification

is: the ratio of the angle subtended at an observer's eye by an optical image, to the angle subtended by the object from which it is derived. [P6.4]

Compare with magnifying power.

angular momentum

of: a particle

about: a chosen origin O, from which the position of the particle is specified by the position vector $\boldsymbol{r}$,

is: $\boldsymbol{L} = \boldsymbol{r} \times \boldsymbol{p}$, where $\boldsymbol{p}$ is the momentum of the particle. [P2.8]

is also known as: the moment of momentum of the particle about O. [M2.7]

of: a collection of particles

about: a given point P

is: the (vector) sum of all the moments of momenta of each of the particles about P. [P2.8, P11.3]

of: a rigid body

with: angular velocity $\boldsymbol{\omega}$ about a single fixed axis of rotation, and moment of inertia I about that axis

is given by: $\boldsymbol{L} = I\boldsymbol{\omega}$. [P2.8]

has as its SI unit: $\mathrm{kg\,m^2\,s^{-1}}$ (i.e. kilogram metre squared per second).

See conservation of angular momentum.

angular position

of: a particle in a plane, with respect to a point O, taken to be the origin of Cartesian coordinates in the plane

is: the angle θ between the particle's position vector and the positive x-axis. [P2.7]

equivalently is: the polar angle of the point at which the particle is located, measured in a system of polar coordinates with origin at O.

angular probability density

in: Schrödinger's model of the hydrogen atom

is: the factor $|Y_{lm}(\theta, \phi)|^2$, that arises in calculating the probability density $|\Psi(r, \theta, \phi)|^2$, where $Y_{lm}(\theta, \phi)$ is the angular part of the wavefunction $\Psi(r, \theta, \phi)$. [P11.3]

angular resolving power

of: an optical system

is: a measure of the system's ability to produce or distinguish two separate images of two point-like objects which are, or appear to be, very close together. [P6.4]

is defined: as the minimum angular separation that the objects must have if their images are to satisfy the Rayleigh criterion. [P6.4]

is limited: by the 'diffraction limit' of the aperture of the optical system, which for a circular aperture of diameter d admitting light of wavelength λ is $(1.22\,\text{radian})\lambda/d$. [P6.4]

is also known: as the angular limit of resolution. [P6.4]

angular speed

of: a particle moving in a plane (taken to be the (x, y) plane) around a point O (taken to be the origin of the (x, y) plane) with an instantaneous angular position θ (measured between the particle's position vector $\boldsymbol{r}$ and the positive x-axis)

is: the magnitude of the rate of change of θ with respect to time. That is, $\omega = |\,d\theta/dt\,|$, where θ is normally measured in radians. [P2.6, P3.2]

has as its SI unit: $\mathrm{rad\,s^{-1}}$ (i.e. radian per second). [P2.7, P5.1]

is exemplified: in the case of uniform circular motion about O, at constant speed υ, by the relation $\omega = \upsilon/r$. [P2.6]

of: a rigid body in uni-axial rotation about a single axis of rotation that is fixed in relation to the body

is: the (positive) angle swept out per second by a line drawn from the axis of rotation to any point in the body that is not on the axis. [P2.7]

See also instantaneous angular speed.

angular velocity

of: a particle (or rigid body) in uni-axial rotation about a single fixed axis of rotation

is: a vector, usually represented by the symbol $\boldsymbol{\omega}$, whose magnitude is the angular speed ω, about that axis, and whose direction is along the axis, in the sense given by the right-hand grip rule (i.e. if the fingers of the right hand are curled in the direction of rotation of the body, then the extended thumb points in the direction of the angular velocity). [P2.7, P2.8]

satisfies: the relation $\boldsymbol{v} = \boldsymbol{\omega} \times \boldsymbol{r}$, where $\boldsymbol{v}$ is the velocity and $\boldsymbol{r}$ the position vector of the particle (or of any point in the rigid body) measured from an origin O on the axis of rotation. [P2.7]

has as its SI unit: $\mathrm{rad\,s^{-1}}$ (i.e. radian per second).

angular wavenumber

for: a periodic wave of wavelength λ

is defined: as $k = 2\pi/\lambda$. [M6.4, P5.6]

has as its SI unit: m^{-1} (i.e. per metre). [M6.4, P5.6]

is widely referred to: as the wavenumber, though this latter term is more properly reserved for $\sigma = 1/\lambda$, i.e. $k/2\pi$. [M6.4, P5.6]

See also angular wave vector and compare with angular frequency. [M6.4, P5.6]

angular wave vector

is: the generalization of the scalar angular wavenumber to a vector quantity which characterizes waves propagating in two or three dimensions. [P5.6]

is equal: in magnitude to $2\pi/\lambda$. [P5.6]

has direction: parallel to the direction of propagation of the wave. [P5.6]

usually is denoted: by the symbol $\boldsymbol{k}$. [P5.6]

more commonly is referred to: as the wave vector, or the propagation vector. [P5.6]

anharmonic oscillations

are: oscillations which are not simple harmonic. [P5.1, P5.3]

are characterized: by a restoring force which is not proportional to the displacement, and a period which depends on amplitude. [P5.1, P5.3]

anharmonic oscillator

is: an oscillator which displays anharmonic oscillations. [P5.3]

anion

is: a negatively charged ion. [P8.4]

annulus

is: a region of a plane lying between two concentric circles. [M2.1]

anode

is: an electrode connected to the positive terminal of a supply of electric current. (The term is used especially in the context of a discharge tube or a similar device.) [P8.1]

antidifferentiation

See inverse differentiation.

antilog

See antilogarithmic function.

antilogarithmic function

is: the function which undoes the effect of the log function $f(x) = \log_a(x)$, i.e. is the inverse function of $\log_a(x)$. [M1.5]

is given: by $g(x) = a^x$ (where $a > 0$), since $g\big(f(x)\big) = a^{\log_a(x)}$ which by definition is simply equal to x. [M1.5]

See also exponential function.

antinode

in: a standing (stationary) wave

is: one of the positions where the maximum displacement from equilibrium occurs. [P5.6]

antiparallel (vectors)

are: two vectors which point in exactly opposite directions. [M2.4, P2.2]

See also parallel (vectors)

antiparticle

is: a particle having the same rest mass as its partner particle but with its other attributes having the opposite sign. For example, the electron (a particle) and the positron (its antiparticle) have equal masses and opposite charges. [P9.2]

anti-phase

is: the condition in which two oscillations or waves of the same frequency have a phase difference of π (often referred to as π rad or 180°). The maxima of one disturbance then coincide with the minima of the other and vice versa, and the two oscillations or waves are totally out of step. [P6.1]

is equivalently: the condition of being totally out of phase. [P5.1]

anti-reflection coating

is: a thin transparent film applied to the surface of an optical component such as a lens in order to reduce (via interference) the amount of light which the surface reflects. [P6.1]

antisymmetric function

See odd function.

aperture

of: a lens or mirror

is: its effective size (usually expressed as a circular diameter).

more generally is: an opening or gap.

aperture stop

in: an optical system

is: the size of aperture which defines the amount of light entering the system. [P6.4]

apparatus

is: equipment used in a scientific experiment or investigation.

apparent depth

of: an object viewed by refraction at a plane surface

is: the depth below the surface at which the image appears to be. For near normal viewing the ratio of real depth to apparent depth is equal to the refractive index. [P6.2]

approximation

of: a number or quantity y by another number or quantity x

is obtained: when x and y have 'similar' values. The term 'similar' is not precisely defined but generally means that $|x - y| / |x|$ is much less than 1. Such a relationship is shown by writing $x \approx y$. [M1.2]

also refers: to approximation of a real situation by a model. [P1.1]

occurs: in 'orders', as in a crude 'first (order) approximation' or a more accurate 'second (order) approximation'. [P8.3, P8.4]

also occurs: in 'degrees', as in the approximation of a function by a polynomial (such as a Taylor polynomial of degree n). [M1.7, M4.5]

See also numerical integration and numerical procedures for information on the approximation of definite integrals and roots of equations.

aqueous humour

is: the clear, watery fluid between the cornea and the lens of the eye. [P6.4]

arbitrary constants

are: constants that arise (as constants of integration) in the solution of differential equations. The general solution of an n^{th}-order linear, ordinary differential equation contains n independent arbitrary constants (which are also known as essential constants). [P5.5]

arc

is: a part of a curve.

often specifically means: a part of the circumference of a circle, though this should more properly be called a circular arc. [M1.6, M2.1]

arc length

is: a length measured along an arc. [M1.6]

arccos, arcsin, arctan, arccosec, arcsec, arccot

See inverse trigonometric functions, and the Maths handbook.

arccosh, arcsinh, arctanh, arccosech, arcsech, arccoth

See inverse hyperbolic functions, and the Maths handbook.

Archimedes' principle

states: that an object immersed in a fluid will experience a force due to the fluid which acts upward through the object's centre of gravity, with a magnitude equal to the weight of the fluid which has been displaced by the object. [P7.6]

area

is: a measure of the amount of surface within given closed boundaries.

See Table 11 in Section 2 of the Maths handbook for the areas of particular shapes.

area between two graphs

of: the functions $f(x)$ and $g(x)$ which intersect at the points $x = a$ and $x = b$ (where $a < b$), and for which any other points of intersection lie between $x = a$ and $x = b$

is given: by the integral $\int_a^b |f(x) - g(x)|\, dx$.

area under a graph

of: the function $f(x)$ between a and b

is: a synonym, used in *FLAP*, for the definite integral of $f(x)$ from a to b, namely $\int_a^b f(x)\,dx$ where $b > a$. [M5.1, M5.2]

sometimes is referred to: as the signed area since, for $b > a$ it will be negative in any region where $f(x) < 0$. [M5.2]

can be identified: in graphical terms, with the physical area enclosed by the curve representing $f(x)$ the x-axis, and the lines $x = a$ and $x = b$ provided that $a < x < b$ for all x satisfying $a < x < b$ and the area is measured in the scale units that are appropriate to the graph in question. [M5.1, M5.2]

Argand diagram

is: a plane making use of Cartesian coordinates in which the x-axis represents the real part of a complex number and the y-axis represents the imaginary part. [M3.1, P5.5]

argument (of a function)

of: a function (e.g. $f(x)$)

is: the independent variable(s) e.g. x whose value(s) determines the value of the function. [M1.3]

argument (of a complex number)

of: a complex number in the polar form $z = r(\cos\theta + i\sin\theta)$, or the exponential form $z = r\,e^{i\theta}$

is: the value of θ. [M3.2, P5.5]

of: a complex number in the Cartesian form $z = a + ib$

may be: any value of θ that satisfies the equations

$$\sin\theta = \frac{b}{\sqrt{a^2 + b^2}}$$

$$\cos\theta = \frac{a}{\sqrt{a^2 + b^2}}$$ [M3.2, P5.5]

usually is: the particular value of θ (the principal value) that also satisfies the additional requirement $-\pi < \theta \le \pi$. [M3.2]

is denoted: by $\arg(z)$, though some authors use $\mathrm{Arg}(z)$ to indicate the principal value of $\arg(z)$. [M3.2]

arithmetic

pertains: to the branch of mathematics concerned with numbers and their manipulation. [M1.1]

arithmetic progression

is: a series of the form:

$$\sum_{k=0}^{n-1}(a+kh) = a+(a+h)+(a+2h)+\dots+[a+(n-1)h]$$

$$= na+\frac{(n-1)}{2}h$$

where the constant, *h* is known as the common difference. [M1.7]

arithmetic series

See arithmetic progression.

articulated body

is: a body of several defined, jointed parts, which otherwise can be treated as a rigid body. [P2.8]

aspheric lens

is: a lens whose surfaces are non-spherical. [P6.4]

aspheric surface

is: a non-spherical surface of a lens or mirror. [P6.4]

astronomical telescope

is: a telescope which produces a final image that is inverted. [P6.4]

asymptote

is: a straight line which a curve approaches but does not meet. [M1.3]

more precisely is: a straight line related to a curve in such a way that there is at least one direction of travel along the curve in which the shortest distance between them decreases progressively as the distance from the origin to the point becomes very large. [M4.4]

more formally is: a straight line which is the limit of the tangents to a curve as the point at which those tangents touch the curve tends to infinity. [M2.2, M2.3]

asymptotically

means: in the way that a curve approaches, but never meets, its asymptote.
[M1.3]

atmosphere, atm

is: a non-SI unit of pressure.

is defined: by $1\,\text{atm} = 1.013\,25 \times 10^5\,\text{N m}^{-2}$. [P7.2]

is more properly called: standard atmosphere.

more generally is: the layer of air above the Earth's surface which exerts atmospheric pressure.

atmospheric pressure

is: the pressure due to the weight of the atmosphere. [P7.2]

is not: a constant, but varies with time and position. [P7.2]

has a value: at the Earth's surface varying only by relatively small amounts. [P7.2]

has as a useful unit: the standard atmosphere (see atmosphere, atm) defined by $1\,\text{atm} = 1.013\,25 \times 10^5\,\text{N}\,\text{m}^{-2}$. [P7.2]

atom

is: the basic building block of all normal solid, liquid or gas matter. [P7.1]

is: the smallest part of a chemical element that retains the fundamental chemical and physical properties of that element. [P8.1]

extends: over a diameter of approximately 10^{-10} m. [P7.1, P8.1]

has: a dense, positively charged central nucleus with a diameter of order 10^{-14} m composed of neutrons and positively charged protons, surrounded by a cloud of negatively charged electrons equal in number to the number of protons, according to Rutherford's nuclear model and all 'realistic' models ever since. [P8.1]

has: zero electrical charge overall. [P8.1]

Contrast with ion.

atomic force microscope

is: an instrument that measures the vertical displacement of a probe tip, with a diameter of a few nanometers, as it is moved across the surface of a material in such a way that the force it experiences remains constant. [P7.1]

measures: the profile of the surface with an approximate resolution of $10^{-10}\,\mathrm{m}$. [P7.1]

can be used: to build a three-dimensional representation of the distribution of atoms on the surface of a material. [P7.1]

atomic mass unit, u

is: a non-SI unit of mass. [P8.1]

is defined: as one twelfth of the mass of one atom of the commonest carbon isotope ${}^{12}_{6}\mathrm{C}$, so the mass of one carbon-12 atom is exactly 12 u. According to current measurements, $1\,\mathrm{u} = 1.660\,54 \times 10^{-27}\,\mathrm{kg}$ (to six significant figures), or approximately $931\,\mathrm{MeV}/c^2$. [P8.1, P9.1]

atomic number

is: the number of protons within the nucleus of an atom, usually denoted by the symbol Z [P7.1, P9.1]

characterizes: each chemical element uniquely, since the nuclear charge of each atom of a chemical element with atomic number Z is simply Ze. [P7.1, P8.1]

also represents: the number of electrons required to balance the nuclear charge in an atom, and therefore determines the chemical behaviour of the atom. [P8.1]

attenuation coefficient

is: a quantity μ that measures the rate of exponential decrease in intensity, I, of γ-radiation with distance, x, travelled through a material. [P9.2]

is defined: by $I = I_0\,e^{-\mu x}$. [P9.2]

depends for its value: on the material and on the energy of the γ-radiation photons. [P9.2]

auxiliary equation

of: the differential equation

$$a\frac{d^2y}{dt^2}+b\frac{dy}{dt}+cy=0$$

is: the quadratic equation $ap^2 + bp + c = 0$. [M5.5, M6.3]

has the significance: that its roots, p_1 and p_2 appear in the general solution $B\exp(p_1t) + C\exp(p_2t)$ of the differential equation. [M5.5, M6.3]

may be generalized: (with changed significance) to other differential equations with constant coefficients.

average

means: typical or representative, often describing a condition which, if it persisted, would have the same effect over a specified range as that of which it is an average.

is often used; as a synonym for mean.

average a.c. power

of: an a.c. circuit, or a part of such a circuit,

is: the total energy dissipated in one period of oscillation divided by the duration of that period. [P5.4]

is given by: $\langle P \rangle = V_{\rm rms} I_{\rm rms} \cos\phi$, where $V_{\rm rms}$ and $I_{\rm rms}$ are the root-mean-square values of the current I and potential difference V and ϕ is the phase difference between I and V.

has as its SI unit: the watt (W). [P5.4]

average acceleration

over: a time interval Δt

of: a body moving in one dimension, along the *x*-axis

is given most simply: by the change of velocity Δv_x divided by the time interval Δt. That is, $\langle a_x \rangle = \Delta v_x/\Delta t$. [P2.1]

is given more specifically: for a body moving with velocity v_{x1} at time t_1 and velocity v_{x2} at time t_2, by

$$\langle a_x \rangle = \frac{v_{x2} - v_{x1}}{t_2 - t_1} \quad \text{[P2.1]}$$

average angular speed

over: a time interval Δt

of: a particle moving in a circle (whose centre is taken to be the origin)

is: the (positive) angle $\Delta\theta$ swept out by the position vector of the particle divided by the time interval Δt, i.e. $\langle \omega \rangle = \Delta\theta/\Delta t$. [P2.6]

average speed

of: the molecules in a gas with speed distribution $f(v)$

is obtained: by dividing the sum of the speeds of all the molecules by the total number of molecules. [P7.5]

is also obtained: by evaluating the integral $\langle v \rangle = \int_0^\infty v f(v)\, dv$. [P7.5]

See applications of integration in the Maths handbook.

average value of a function

over: the interval from a to b

is defined: as $f_{\rm av} = \dfrac{1}{(b-a)}\displaystyle\int_a^b f(x)\,dx$.   [M5.4]

average velocity

over: a time interval Δt

of: a body moving in one dimension, along the x-axis

is given most simply: by the change of position Δx divided by the time interval Δt, i.e. $\langle v_x \rangle = \Delta x/\Delta t$. [M4.1, P2.1]

is given more specifically: for a body with position x_1 at time t_1 and position x_2 at time t_2 by

$$\langle v_x \rangle = \frac{x_2 - x_1}{t_2 - t_1}$$ [M4.1, P2.1]

may be similarly expressed: in terms of the displacement s_x from a fixed point, rather than the position x. [P2.1]

of: a body moving in three dimensions

is given most simply: by the change of position $\Delta\boldsymbol{r}$ divided by the time interval Δt, i.e. $\langle \boldsymbol{v} \rangle = \Delta\boldsymbol{r}/\Delta t$. [P2.2]

is given more specifically: if the particle has position $\boldsymbol{r}_1$ at time t_1 and position $\boldsymbol{r}_2$ at time t_2, by

$$\langle \boldsymbol{v} \rangle = \frac{\boldsymbol{r}_2 - \boldsymbol{r}_1}{t_2 - t_1}$$

So, writing $\boldsymbol{r}_2 - \boldsymbol{r}_1 = \Delta\boldsymbol{r} = (\Delta x, \Delta y, \Delta z)$,

$$\langle \boldsymbol{v} \rangle = \left(\langle v_x \rangle, \langle v_y \rangle, \langle v_z \rangle\right) = \frac{\Delta\boldsymbol{r}}{\Delta t} = \left(\frac{\Delta x}{\Delta t}, \frac{\Delta y}{\Delta t}, \frac{\Delta z}{\Delta t}\right)$$ [P2.2]

Avogadro's constant

is: the physical constant N_A that represents the number of basic entities (atoms, molecules, ions etc.) per mole of any substance, [P7.1, P7.2]

has: the value $N_A = 6.0223 \times 10^{23}\,\mathrm{mol}^{-1}$ (to five significant figures). [P7.1, P7.2]

Compare with Avogadro's number (which has no units).

Avogadro's hypothesis

states: that equal volumes of all gases at the same temperature and pressure contain the same number of atoms or molecules. [P7.1]

Avogadro's number

is: the number of basic entities (atoms, molecules, ions, etc.) in one mole of any substance, namely 6.0223×10^{23} (to five significant figures). [P7.1, P7.2]

Compare with Avogadro's constant (which is defined per mole, and consequently has units mol^{-1}).

axes

are: straight lines at an angle to one another, along which and from which we can measure the coordinates of a point.   [P1.3]

usually are: Cartesian coordinate axes, which are at right angles to one another and which intersect at a common point called the origin.   [M1.3]

axis of rotation

of: a rotating rigid body

is: the straight line connecting all parts of the body which are at rest. [P2.8]

β-decay

is: the process in which a nucleus undergoes radioactive decay to form a less massive nucleus of a different element with the emission of a β-particle. [P9.2]

is classified: in two types: β^--decay and β^+-decay. [P9.2]

if β^--decay, is: radioactive decay with the ejection of an electron (a β^--particle) and an electron antineutrino, e.g. ${}^{15}_{6}\mathrm{C} \rightarrow {}^{15}_{7}\mathrm{N} + {}^{0}_{-1}\mathrm{e} + \overline{\nu}_\mathrm{e}$. A neutron in the original nucleus is transformed into a proton, an electron and an electron antineutrino: $\mathrm{n} \rightarrow \mathrm{p} + \mathrm{e}^- + \overline{\nu}_\mathrm{e}$. [P9.2]

if β^+-decay, is: radioactive decay with the ejection of a positron and an electron neutrino, e.g. ${}^{11}_{6}\mathrm{C} \rightarrow {}^{11}_{5}\mathrm{B} + {}^{0}_{+1}\mathrm{e} + \nu_\mathrm{e}$. A proton in the original nucleus is transformed into a neutron, a positron and an electron neutrino: $\mathrm{p} \rightarrow \mathrm{n} + \mathrm{e}^+ + \nu_\mathrm{e}$. [P9.2]

β-particle

is: a particle that is emitted in β-decay. [P9.2]

is classified: in two types: the β^--particle (an electron) which is emitted in β^--decay, and the β^+-particle (a positron) which is emitted in β^+-decay. [P9.2]

bac cab rule

is: a mnemonic reference to the vector identity
$\boldsymbol{a} \times (\boldsymbol{b} \times \boldsymbol{c}) = \boldsymbol{b}(\boldsymbol{a} \cdot \boldsymbol{c}) - \boldsymbol{c}(\boldsymbol{a} \cdot \boldsymbol{b})$. [M2.7]

balanced bridge

is: a bridge circuit whose electrical components are arranged so that there is no voltage between its output terminals. [P4.1]

balanced forces

are: two or more forces whose magnitudes and directions are such that their net force or resultant force is zero. [P2.3]

ballistic galvanometer

is usually: a type of moving-coil galvanometer. [P4.4]

is designed: with a weak restoring force and a weak damping force, so that a transient current produces an initial swing whose amplitude is proportional to the total charge passed.

is used: to measure quantities of electric charge, and (in conjunction with a search coil) magnetic fields. [P4.4]

Balmer series

is: the set of visible lines in the spectrum of atomic hydrogen, whose wavelengths are given by Balmer's formula. [P8.2]

Balmer's formula

is: the formula discovered by Johann Balmer (1825-1898) which gives, to a very high accuracy, the wavelengths of the visible spectral lines emitted by atomic hydrogen:

$$\lambda = 364.56\left\{\frac{n^2}{n^2-4}\right\}\text{nanometres.} \quad [\text{P8.2}]$$

back e.m.f.

See induced voltage.

band theory

is: the proposal that the energy levels of electrons in (crystalline) solids are distributed in energy bands. [P11.4]

is also: the theoretical study of energy bands and their consequences. [P11.4]

bar

is: a non-SI unit of pressure.

is defined: as 1 bar = 10^5 Pa (i.e. 10^5 N m^{-2}). [P7.2]

is slightly smaller: than another non-SI unit of pressure, the standard atmosphere; 1 atm = 1·013 25 bar. [P7.2]

barrier penetration

See quantum tunnelling.

base (of a number system)

of: a system for specifying numbers

is: a number that takes on the role that 10 plays in the specification of decimal numbers. A base *n* system uses *n* digits and is based on powers of *n*. [M1.2]

base (of a logarithm)

is defined: as the value of a in the identity $a^{\log_a(x)} = x$. [M1.5]

must be: positive. [M1.5]

is most commonly: e (the base of natural logarithms) or 10 (the base of common logarithms). [M1.5]

basic differentiation

is: an informal term used to denote a range of mathematical skills in the area of differentiation. [M4.2]

includes: the ability to differentiate 'standard' functions such as $\sin(kx)$, $\cos(kx)$, $\exp(kx)$ and $\log_e(kx)$, together with constant multiples, sums, products and quotients of such functions. [M4.2]

basic identities

are: a class of trigonometric identities. [M1.6]

See trigonometric functions in the Maths handbook for further details.

base units

are: seven SI units. [P1.1]

comprise: the metre, kilogram, second, ampere, kelvin, mole and candela. [P1.1]

battery

consists: of two or more electric cells connected together to act as a single current source. (Colloquially, a single cell is also called a battery.) [P4.5]

beam

is: a collection of waves or particles travelling along closely parallel paths.

is also: a bundle of closely parallel rays.

beat frequency

between: two oscillations or waves of similar frequency that are superposed

is: the frequency of the (modulated) amplitude of the superposed waves. [P5.1]

is equal: to the difference between the frequencies of the two oscillations or waves. [P5.1, P5.3, P5.7]

is also equal: to the reciprocal of the beat period. [P5.7]

beat period

is: the time interval between successive beats in situations where two waves (e.g. sound waves) of slightly different frequency are superposed. [P5.7]

is equal: to the reciprocal of the beat frequency. [P5.7]

beating

between: two oscillations or waves of similar frequency that are superposed

is: the periodic variation of the total amplitude that gives rise to beats. [P5.1]

occurs: at the beat frequency. [P5.1]

beats

are: periodic variations in intensity due to beating.   [P5.1, P5.7]

are produced: when two waves of nearly equal frequency and similar amplitude are superposed.   [P5.1, P5.7]

becquerel, Bq

is: the SI unit of activity.

is defined: as an activity of 1 decay per second.

is related: to a common non-SI unit, the curie (Ci), by $1\,\mathrm{Ci} = 3.70 \times 10^{10}\,\mathrm{Bq}$. [P9.2]

biconcave lens

is: a lens having two surfaces which curve inwards into the material. The centre is thinner than the edges. [P6.3]

often is called simply: a concave lens. [P6.3]

biconvex lens

is: a lens having two surfaces which curve outwards from the material. The centre is thicker than the edges. [P6.3]

often is called simply: a convex lens. [P6.3]

bimetallic strip

is: a thermally sensitive device consisting of two thin strips of different metals soldered, or otherwise attached, face to face. [P7.2]

bends: with any change in temperature, since the extent to which the two metals expand in response to a given change of temperature will generally differ. [P7.2]

can be used: to measure temperature or as a means of temperature-sensitive control. [P7.2]

binding energy (of a nucleus)

of: a nucleus

is: the minimum energy required to break a nucleus apart into its free constituent nucleons. [P9.1]

more generally is: the minimum energy required to separate any system into appropriately specified components.

binding energy (of an electron)

of: an electron

in: an atom

is: the minimum energy required to remove the electron from the atom. [P8.1]

binomial coefficient

is: any one of the coefficients, ${}^nC_r$, that arise in the binomial expansion. [M1.7]

is defined: as

$$
\begin{aligned}
{}^nC_r &= \frac{n!}{r!(n-r)!} \\
&= \frac{n(n-1)(n-2)\ldots(n-r+2)(n-r+1)}{r(r-1)(r-2)\ldots 2\times 1}
\end{aligned}
$$

where $n \geq r$.

(See factorial for the definition of n!) [M1.7]

See summations and series in the Maths handbook.

binomial expansion

is: a polynomial expression for $(a + b)^n$, where n is a positive integer:

$$(a+b)^n = \sum_{k=0}^{n} {}^nC_{n-k}\, a^{n-k} b^k$$

where ${}^nC_r$ is a binomial coefficient and $\sum$ is the summation symbol. [M1.7]

See binomial series, binomial theorem.

See also summations and series in the Maths handbook.

binomial series

is: an infinite series for $(1 + x)^r$, where r is any real number and $-1 < x < 1$:

$$(1+x)^r = 1 + \frac{rx}{1!} + \frac{r(r-1)x^2}{2!} + \frac{r(r-1)(r-2)x^3}{3!} + \dots \quad [\text{M1.7}]$$

is equivalent: to the corresponding binomial expansion when r is an integer.

See summations and series in the Maths handbook.

binomial theorem

is: an alternative expression for the binomial expansion or the binomial series. [M1.7]

bisection method

for: locating a root of an equation

works: by constructing a sequence of intervals of decreasing length, such that the associated function changes sign on each interval. [M1.4]

bisector

is: a line drawn in such a way that it cuts a specified angle into two equal parts. [M2.1]

black body

is: an idealized object that absorbs all the electromagnetic radiation that falls upon it. [P8.2, P10.1]

reflects: absolutely no radiation. [P8.2, P10.1]

is also: an ideal emitter of radiation. [P8.2, P10.1]

emits: black-body radiation - which has a spectrum that depends only on the temperature of the black body. [P8.2, P10.1]

has: spectral brightness which is given by Planck's function. [P7.3]

is approximated roughly: by a matt black surface. [P7.3]

is approximated well: by a cavity maintained at a well-defined temperature and connected to its environment by a small aperture. The spectrum of radiation inside such a cavity is described quite accurately by Planck's function, and the radiation emitted from the small hole closely approximates black-body radiation irrespective of the material of the container or the state of its inner surface. [P7.3, P8.2, P10.1]

black-body radiation

is: electromagnetic radiation emitted by a black-body. [P8.2, P10.1]

has: a characteristic spectrum whose spectral brightness at wavelength λ is given by Planck's function:

$$R_\lambda = \frac{2hc^2}{\lambda^5\left(\exp\left(hc/\lambda kT\right)-1\right)}$$

with an overall shape, a wavelength for peak emission, and a total radiated power per unit surface area all determined entirely by the temperature of the black-body. [P7.3, P8.2, P10.1]

is also found: within a cavity in thermodynamic equilibrium. [P8.2, P10.1]

therefore can be realized in practice: by using a cavity with a small aperture. [P8.2, P10.1]

black-body spectrum

See black-body radiation.

body

is: a collection of interacting particles which extends throughout a particular region of space.

Bohr model

of: the hydrogen atom

is: now supplanted but remains historically important as the first theoretical account of atomic structure to make use of quantum physics. [P8.2]

was formulated: by Niels Bohr (1885-1962) in 1913. [P8.2]

postulates: (1) that the negatively charged electron is held in a circular orbit around the positively charged nucleus by the Coulomb force between them;

(2) that the range of allowable orbits is restricted by the requirement that the angular momentum of the orbiting electron is quantized in units of $h/2\pi$, where h is Planck's constant;

(3) that, contrary to classical physics, the orbiting electron does not continuously lose energy through the emission of electromagnetic radiation;

(4) that electromagnetic radiation is emitted when the electron makes a transition from an initial orbit of energy $E_{\rm i}$ to a final orbit of energy $E_{\rm f}$ and that the frequency of that radiation is given by the Planck-Einstein formula as $f = (E_{\rm i} - E_{\rm f})/h$. [P8.2]

explains: many features of the spectrum of atomic hydrogen, including Balmer's formula. [P8.2, P11.3]

may be: extended to atoms other than hydrogen, but only with limited success.

See Bohr orbit, Bohr radius, Bohr's quantization, Bohr's quantum number.

Bohr orbit

in: the Bohr model of the hydrogen atom

is: one of the allowed orbits for the electron. An electron in such an orbit moves with a definite speed and has a constant energy; contrary to classical physics, it does not continuously emit electromagnetic radiation. [P8.2]

corresponds: to a definite energy level of the atom. [P8.2]

Bohr radius

in: the Bohr model of the hydrogen atom

is: the radius of the smallest Bohr orbit for the electron. [P8.2, P11.3]

is given: by $a_0 = \dfrac{\varepsilon_0 h^2}{\pi m_e e^2}$ where ε_0 is the permittivity of free space, m_e is the mass of the electron, e the charge on the proton, and h is Planck's constant. [P8.2]

therefore is: quantized by Bohr's quantum number n. [P8.2]

Bohr's quantization condition

in: the Bohr model of the hydrogen atom

states: that the magnitude L of the angular momentum of the electron as it orbits the nucleus must be a positive integer multiple of Planck's constant h divided by 2π. Thus:

$$L = \frac{nh}{2\pi} \text{ for } n = 1, 2, 3, \ldots$$

where n is called Bohr's quantum number. [P8.2]

Bohr's quantum number

in: the Bohr model of the hydrogen atom

is: an integer n that may take any positive value starting from 1, and which determines the (quantized) angular momentum magnitude L of the electron in the n^{th} Bohr orbit around the nucleus (see Bohr's quantization). [P8.2]

also determines: the radius of the n^{th} Bohr orbit and the associated energy level:

$$E_n = -(13.6\,\text{eV})/n^2 \text{ for } n = 1, 2, 3, \ldots$$ [P8.2]

boiling point

of: a liquid subjected to a specified external pressure (usually standard atmospheric pressure)

is: the temperature at which the saturated vapour pressure of the liquid is equal to the external pressure.

Boltzmann's constant

is: the physical constant k that has the value $k = 1.380 \times 10^{-23}\,\mathrm{J\,K^{-1}}$ (to four significant figures). [P7.5]

is expressible: in terms of two other physical constants, the molar gas constant R and Avogadro's constant N_{A}, by $k = R/N_{\mathrm{A}}$. From this, Boltzmann's constant is seen to act as the gas constant per molecule. [P7.5]

appears: in equations which relate microscopic properties to macroscopic parameters of physical systems; e.g. in an ideal gas at temperature T, the mean translational kinetic energy of a particle is $3kT/2$. [P7.5]

bond

between: atoms in a molecule or molecules in a solid (more particularly between specified states of those atoms or molecules)

is: a quantum physical phenomenon associated with a specific bonding energy that causes the atoms or molecules that have bonded to act as a single entity. [P11.4]

is fundamentally explained: by electromagnetic forces between the atoms or molecules. [P11.4]

may be classified: according to the number of electrons involved in maintaining the bond.

bonding electron

is: an electron involved in forming or maintaining a bond between atoms or molecules.

bonding energy

is: the minimum energy required to break a specific bond.

Born probability interpretation (hypothesis)

is: the association between the wavefunction of a particle and the probability of finding that particle in a given region of space at a particular time.

states: that if a particle moving in one dimension has the wavefunction $\Psi(x,t)$, then the probability of finding the particle in a small region Δx around x at time t is proportional to $|\Psi(x,t)|^2\,\Delta x$. If the wavefunction is normalized, then the probability is equal to $|\Psi(x,t)|^2\,\Delta x$. [P10.4, P11.1]

bound state

of: a quantum system

is: a state of a composite system in which a finite amount of energy is required to separate the components of the system.

is: in Schrödinger's model of the hydrogen atom, a state in which the probability that the electron will escape infinitely far from the proton, is zero.

is: in the Bohr model of the hydrogen atom, any one of an infinite number of possible states, corresponding to the allowed Bohr orbits for the electron, each with its own definite energy corresponding to one of the energy levels. [P8.2, P11.3]

boundary conditions

for: differential equations

are: conditions which specify the value of the dependent variable or its derivatives, for specific values of the independent variable. [M6.1, P11.1, P11.2]

can be used: to determine (or help to determine) any arbitrary constants that arise in the general solution of a differential equation. [P5.4, P5.5, P11.1, P11.2]

often arise as: conditions imposed on a wave at the boundary of a medium, usually involving the value of either the displacement of the medium or the derivative of the displacement with respect to position. [P5.6, P10.3]

Boyle's law

states: that at constant temperature, the pressure P and volume V of a fixed amount of ideal gas are related by $PV = \text{constant}$. [P7.2]

See ideal gas equation of state.

brackets

take the form: ( ), [ ], or { }. [M1.1]

have a hierarchy: {[( )]}. [M1.1]

are used: to separate one part of an expression from the rest. In a calculation, the part of an expression enclosed in brackets must be evaluated before being combined with other terms. [M1.1]

Bragg's law

for: diffraction of monochromatic electromagnetic radiation of wavelength λ

from: parallel planes of atoms separated by a distance d in an orderly array of atoms (such as a crystal)

determines: the values of the angle θ, (measured between the incident ray and the plane of atoms) at which local maxima of intensity are formed in the diffraction pattern by constructive interference of the reflected rays from adjacent planes of atoms. [P7.1]

is normally expressed: as $n\lambda = 2d \sin \theta$, where n is an integer. [P7.1]

branches

of: a hyperbola

refers: to the two separate parts of a hyperbola that are produced when a plane intersects a double cone. [M2.3]

breaking point

of: a given material

is: the point on the loading curve of the material at which the material breaks apart. [P7.6]

corresponds: to the maximum tensile stress that the material can sustain. [P7.6]

breeder reactor

is: a nuclear reactor whose reaction products include material that can be used as fuel for further reactions. [P9.3]

bremsstrahlung

is: the electromagnetic radiation emitted when an electrically charged particle is accelerated, in particular, when it is slowed down. For example, when high-energy electrons collide with a target, X-rays are produced with a continuous spectrum. [P8.3]

linguistically is: German for 'braking radiation'. [P8.3, P10.1]

bridge circuit

is: a circuit consisting of four electrical components (generally resistors) connecting four points (A, B, C, D, say) to form a closed loop. [P4.1]

produces: an output voltage between two non-adjacent points (A and C say) when a voltage source is connected across the other two points (B and D). [P4.1]

is used: to compare resistances. [P4.1]

is balanced: when the resistances are such that the output voltage is zero.

bridge circuit balance condition

is: the equation which relates the four resistances in a balanced bridge circuit. [P4.1]

brittleness

is: the property of a material which causes it to fracture without appreciable plasticity, before or soon after the elastic limit is reached. [P7.6]

Brownian motion

is: the microscopic random motion of pollen grains and other small particles suspended in gases or liquids. [P7.1, P8.1]

was first observed: by the botanist Robert Brown (1773-1858). [P7.1, P8.1]

was explained: as the result of numerous unseen molecular collisions, by Albert Einstein (1879-1955) in 1905. [P7.1, P8.1]

bulk modulus

of: a material (solid, liquid or gas)

is: an elastic modulus, conventionally denoted K. [P5.7, P7.6]

is defined: as the ratio of the applied volume stress $\sigma_{\rm vol}$ to the resulting volume strain $\varepsilon_{\rm vol}$:

$$K = \frac{\sigma_{\rm vol}}{\varepsilon_{\rm vol}} = \frac{-\text{pressure change}}{\text{fractional volume change}} \quad \text{(note the } - \text{ sign)} \quad [\text{P5.7}]$$

has as its SI unit: $\rm N\,m^{-2}$ or Pa (i.e. pascal). [P5.7, P7.6]

buoyancy

is: the phenomenon by which a fluid tends to reduce the apparent weight of a body through the buoyancy force. [P7.6]

buoyancy force

is: the vertical upward force exerted on a body by a static fluid in which it is submerged or floating. [P7.6]

is quantified: by Archimedes' principle. [P7.6]

is also called: the upthrust. [P7.6]

caesium atomic clock

is: a device that uses an atomic resonance in caesium of very narrow resonance absorption bandwidth and very high *Q*-factor, to provide a time or frequency standard. [P5.3]

is used: to establish the SI unit of time, the second. [P5.3]

calculation

is: a sequence of mathematical operations performed with the objective of determining the answer to a question.

calculus

is: a branch of mathematics which is concerned with the way in which (small) changes in one quantity determine or are determined by changes in related quantities. [M4.1, P2.1]

is more properly called: infinitesimal calculus. [M4.1, P2.1]

includes: differentiation and integration. [M4.1, P2.1]

calibration

is: the process of checking one measuring instrument against another, more accurate one. [P1.1]

calibration points

for: a thermometer

are: two or more fixed points which can be used to calibrate the scale of the thermometer. [P7.2]

are usually: triple points or boiling or freezing points. In the case of the Kelvin temperature scale one of the two points is the unattainable absolute zero, the other is the triple point of H_2O. [P7.2]

permit between or beyond them: interpolations or extrapolations, often using polynomial thermometric relations. [P7.2]

calorimeter

is: a container of known heat capacity used in calorimetry experiments. [P7.4]

calorimetry

is: the branch of physics concerned with the measurement of heat and its effects. [P7.4]

camera

is: a device for producing a record of an image, either on photographic film or via some other means (e.g. electronic). [P6.4]

See also pinhole camera. [P6.4]

cancelling

is: a term used to describe the mathematical process in which (a) a factor appearing on both sides of an equation is eliminated by dividing both sides of the equation by that factor; or (b) a factor appearing in both the numerator and denominator of a fraction (arithmetic or algebraic) is eliminated by dividing both the numerator and the denominator by that factor. [M1.1]

candela, cd

is: the SI unit of luminous intensity, one of the seven base units. (Not used in *FLAP*.)

capacitance

of: an isolated electrical conductor

is: the ratio of the charge q stored on the conductor, to the potential difference V between it and some selected reference point. [P4.5]

is given: by $C = q/V$. [P4.5, P5.5]

more generally is: the charge stored between two points per unit potential difference between those points.

is exemplified: by the capacitance between the terminals of a capacitor, which for parallel plates of area A separated by a dielectric with permittivity ε and thickness d is $C = \varepsilon A/d$. [P4.5]

has as its SI unit: the farad, (F), where $1\,\mathrm{F} = 1\,\mathrm{C\,V^{-1}}$. [P4.5, P5.5]

capacitive reactance

of: a capacitor with capacitance C, when passing alternating current of angular frequency ω

is: the ratio of the peak voltage to the peak current V_0/I_0. [P5.4, P5.5]

is given: by $X_C = 1/\omega C$. [P5.4, P5.5]

has as its SI unit: the ohm (Ω). [P5.4, P5.5]

See complex capacitive reactance, impedance, reactance.

capacitive time constant

is: the time for the current, charge or voltage across a capacitor to decay exponentially by a factor e. [P4.5]

is given: for a circuit in which a capacitor of capacitance C discharges through a resistance R, by $\tau = RC$. [P4.5]

capacitor

is: a device for storing electric charge. [P4.5, P5.5]

usually consists: of two parallel metal surfaces (not necessarily flat) separated by a dielectric. [P4.5]

generally has: in practical electronic circuits, a capacitance very much less than 1 farad (1 F) so its capacitance might well be expressed in microfarad (μF) or picofarad (pF).

capillarity

is: the elevation or depression of the surface of a liquid in contact with a solid due to the relative attraction of the liquid molecules for each other as compared to their attraction to those of the solid. [P7.6]

See meniscus.

capillary

is: a tube of narrow internal diameter. [P7.6]

See capillarity.

Carnot cycle

in: thermodynamics

is: a reversible closed cycle consisting of four steps, two isothermal processes linked by two adiabatic processes. [P7.4]

See Carnot engine.

Carnot engine

is: a reversible heat engine that utilizes the Carnot cycle. [P7.4]

has: efficiency $\eta = 1 - T_{\rm cold}/T_{\rm hot}$ when operating between temperatures $T_{\rm hot}$ and $T_{\rm cold}$. (Any reversible heat engine operating between those temperatures must have the same efficiency.) [P7.4]

is: the most efficient possible heat engine operating between two fixed temperatures. [P7.4]

Cartesian axes

See Cartesian coordinate system.

Cartesian component vectors

of: a vector $\boldsymbol{v}$, with respect to a given Cartesian coordinate system

are: the vectors $\boldsymbol{v}_x$, $\boldsymbol{v}_y$, $\boldsymbol{v}_z$ directed along the Cartesian axes such that $\boldsymbol{v}_x + \boldsymbol{v}_y + \boldsymbol{v}_z = \boldsymbol{v}$. [M2.5]

are therefore: individually proportional to the corresponding Cartesian unit vectors $\boldsymbol{i}, \boldsymbol{j}$ and $\boldsymbol{k}$. [M2.5]

should not be confused with: the Cartesian scalar components (v_x, v_y, v_z) of $\boldsymbol{v}$ which are individually the scalars by which a Cartesian unit vector must be scaled to produce the corresponding component vector (e.g. $\boldsymbol{v}_x = v_x\boldsymbol{i}$). [M2.5]

Cartesian coordinate system

is: a coordinate system that uses Cartesian coordinates, measured along mutually perpendicular axes from a point of common intersection called the origin. In three dimensions, the three axes are conventionally labelled as the *x*-axis, *y*-axis and *z*-axis, and it is conventional to perform the labelling so as to produce a right-handed coordinate system rather than a left-handed coordinate system.

can be generalized: to any number of dimensions.

Cartesian coordinates

are: coordinates measured from a common origin along axes that intersect (at the origin) at right angles. The horizontal axis normally is used to represent values of x. In two dimensions, the vertical axis is used to represent values of y. In three dimensions, the second horizontal axis is used to represent values of y, and the vertical axis to represent values of z. The convention is to refer to these as the x-axis, y-axis and z-axis. [M1.3, M2.2]

can be used: for any number of dimensions. [M1.3, M2.2]

Cartesian form (of a complex number)

represents: a complex number as $a + ib$ with a and b real. [M3.2]

Compare and contrast with exponential form and polar form, and see complex numbers in the Maths handbook for the relationship between these forms.

Cartesian form (of a vector)

is: the form in which a vector $\boldsymbol{v}$ is represented as a vector sum of Cartesian component vectors: $\boldsymbol{v} = \boldsymbol{v}_x + \boldsymbol{v}_y + \boldsymbol{v}_z$ or of scaled Cartesian unit vectors: $\boldsymbol{v} = v_x\boldsymbol{i} + v_y\boldsymbol{j} + v_z\boldsymbol{k}$ or, equivalently, as an ordered triple of Cartesian scalar components: $\boldsymbol{v} = (v_x, v_y, v_z)$. [M2.5]

See scalars and vectors in the Maths handbook.

Cartesian representation (of a complex number)

See Cartesian form.

Cartesian scalar components

of: a vector $\boldsymbol{v}$

are: the scalar quantities v_x, v_y and v_z which appear in the expression for $\boldsymbol{v}$ when given in the Cartesian form $v_x\boldsymbol{i} + v_y\boldsymbol{j} + v_z\boldsymbol{k}$. [M2.5]

are individually equal: to the projection of $\boldsymbol{v}$ onto the corresponding Cartesian unit vector, so $v_x = \boldsymbol{v} \cdot \boldsymbol{i}$, etc. [M2.6]

Cartesian sign convention

in: optics

is: a sign convention which takes the pole of a surface or the centre of a lens as the origin of a Cartesian coordinate system, ascribing positive signs to positions measured to the right or upwards, and negative signs to positions measured to the left or downwards of this origin. [P6.3]

Cartesian unit vectors

are: unit vectors in the mutually perpendicular directions of the Cartesian coordinate axes. Two such vectors are required in two dimensions, usually denoted by $\boldsymbol{i}$ and $\boldsymbol{j}$ in the directions of the x-axis and y-axis respectively. In three dimensions the three unit vectors are usually denoted $\boldsymbol{i}$, $\boldsymbol{j}$ and $\boldsymbol{k}$. [M2.5]

cathode

of: a discharge tube or a similar device

is: an electrode connected to the negative terminal of a supply of electric current. [P8.1]

cathode rays

are: the 'rays' emanating from the cathode of a discharge tube containing gas at a sufficiently low pressure. [P8.1]

are in fact: high-speed flows of electrons, as shown by J. J. Thomson (1856-1940). [P8.1]

cation

is: a positively charged ion. [P8.4]

caustic curve

is: the curve formed by the superposition of rays from a lens or mirror which suffers from spherical aberration. [P6.4]

Cavendish's experiment

is: an experiment to determine Newton's universal gravitational constant, *G*, first performed by Henry Cavendish (1731-1810) in 1798. [P3.2]

cell

See electric cell, and (in the context of crystals) unit cell.

Celsius temperature scale

is: a nearly centigrade temperature scale which tracks the Kelvin temperature scale precisely. [P7.2]

is defined: in terms of the Kelvin temperature scale by $T_C/°C = T/K - 273.15$, where T is an absolute temperature and T_C is the corresponding Celsius temperature. [P7.2]

is named: after Anders Celsius (1701-1744). [P7.2]

centigrade

is: the description given to a temperature which is measured on a centigrade temperature scale. [P7.2]

centigrade temperature scale

is: any temperature scale based on a thermometric property X that uses a thermometric relation of the form

$$T_{\rm cen} = \frac{X - X_0}{X_{100} - X_0} \times 100^\circ \text{centigrade.}$$ [P7.2]

will agree: with another centigrade scale at any fixed points (normally the freezing and boiling points of water) that are common to both scales, but will not necessarily agree at any other points because different physical properties X may vary differently with temperature. [P7.2]

central force

is: a force that is always directed towards a fixed point (sometimes called the force centre) and which has the property that its magnitude depends only on the distance from that point. [P2.4, P2.7, P2.8]

centre

of: a circle (or sphere)

is: the unique point that is at the same distance from every point on the circumference (or surface). [M2.1, M2.3]

is also: the unique point at which any two different diameters intersect. [M2.1]

is more generally: the mid-point of a body or system.

centre of gravity

of: a rigid body in a gravitational field

only exists: if the gravitational field is uniform, or if the body has a sufficiently high degree of symmetry.

is: the point (fixed with respect to the body, but not necessarily within the body) at which the entire mass of the body can be considered to be concentrated for the purpose of determining the effect of gravitational forces on the body. [P2.3, P2.7]

is therefore: the point about which the gravitational forces produce no resultant torque irrespective of the orientation of the body. [P2.7]

is determined: by the gravitational forces acting on the body as well as the distribution of mass within the body, but will always coincide with the centre of mass for a body in a uniform gravitational field.

centre of mass

of: a rigid body

is: the point (not necessarily within the body) at which the entire mass of the body can be considered to be concentrated for the purpose of determining the translational motion of the body under an applied force. If the body is entirely free to move and the line of action of the force passes through the centre of mass, that force will cause translation of the centre of mass but not rotation about the centre of mass. [P2.3, P2.7, P2.8]

is determined: by considering the body to consist of (infinitesimal) mass elements Δm_i at positions $\boldsymbol{r}_i$ and then finding the point specified by $\boldsymbol{r}_\mathrm{c}$, such that

$$\boldsymbol{r}_\mathrm{c} = \frac{\sum_i \Delta m_i \, \boldsymbol{r}_i}{\sum_i \Delta m_i} \quad [\mathrm{M5.4}]$$

should not be confused: with the centre of gravity.

centrifugal force

is: a fictitious force with no physical basis in fact, invented to allow Newton's laws of motion to be applied in a rotating frame of reference, which is a non-inertial frame of reference where Newton's laws are otherwise invalid. [P2.3]

centripetal acceleration

of: a particle in uniform circular motion

is: an acceleration directed towards the centre of the circle

has magnitude: $r\omega^2$, where r is the radius of the circle and ω is the particle's angular speed. [P2.6, P3.2]

centripetal force

on: a particle in uniform circular motion

is: the force which is necessary to maintain the uniform circular motion. [P2.3]

is directed: towards the centre of the circle. [P2.3]

has magnitude: $mr\omega^2$, where r is the radius of the circle, m is the mass of the particle and ω is its angular speed. [P2.6, P3.2]

chain rule

is: a rule used for differentiating a function of a function, such as $f(g(x))$. The rule states that if $u = g(x)$ and $y = f(u)$ so that $y = f(g(x))$ then

$$\frac{dy}{dx} = \frac{dy}{du} \times \frac{du}{dx} = f'(u) \times g'(x) \quad [\text{M4.3}]$$

See the chain rule and its uses in the Maths handbook.

change of phase

is: a process in which a substance changes from the solid phase, liquid phase or gaseous phase to one of the others. [P7.3]

changing the (dependent) variable

is: a technique used to transform a first-order differential equation into one that can be solved by a standard method such as separation of variables or use of an integrating factor. A new dependent variable is defined as an appropriate function of the old dependent variable and the independent variable. [M6.2]

chaos

is: a property exhibited by deterministic systems which are described by certain non-linear differential equations (or sets of non-linear equations).

occurs: when two systems governed by the same non-linear equation but with slightly different initial states subsequently develop in completely dissimilar ways. [M6.1]

characteristic emission spectrum

of: a chemical element

is: the emission spectrum from that chemical element and is unique to that chemical element. [P8.2]

often contains: prominent emission lines and is then referred to as the emission line spectrum of the chemical element. [P8.2]

characteristic X-ray spectrum

of: a heavy atom

is: the characteristic emission spectrum in the X-ray wavelength range from that atom and is unique to that kind of atom. [P8.3]

is produced: when an ejected inner shell (comparatively low energy) electron is replaced by an outer shell (comparatively high energy) electron, provided that the spacing between the energy levels is at least several thousand electronvolts. [P8.3]

charge

See electric charge.

charge carriers

are: mobile charged particles (e.g. electrons and ions) that can move within a material. [P4.1]

See hole.

charge sharing

is: the process by which a body can be charged by receiving some of the charge from another charged object with which it makes contact. [P3.3]

charge-to-mass ratio

for: a particle of charge q and mass m

is equal: to q/m. In the case of the electron the quantity e/m. is often referred to as the charge-to-mass ratio, even though the charge of the electron is actually $q = -e$. [P8.1]

Charles' law

states: that at constant pressure, the volume V and absolute temperature T of a fixed quantity of ideal gas are related by V/T = constant. [P7.2]

chemical bonding

is: the binding together of chemical elements by forces that are fundamentally electromagnetic. [P8.4]

See covalent bonding, ionic bonding, metallic bonding.

chemical compound

is: a substance that consists of more than one element, the atoms being bound together in a fixed ratio that is characteristic of the substance. [P8.1]

is also: a substance which can be broken down into more elementary substances by a process such as heating or the passing of an electric current. [P7.1]

chemical element

traditionally is: a substance which cannot be divided or separated by chemical means, including heating and passing of electrical current. [P8.1]

currently, is more appropriately defined: as matter consisting of atoms characterized by a single atomic number Z, which consequently contain a definite number of protons. (The atoms may be bound together to form molecules, as in the case of the diatomic oxygen molecule O_2.) [P7.1, P8.1]

chemical formula

is: a formula such as H_2O which uses chemical symbols to indicate the chemical elements involved in a chemical compound and subscripts to show the relative numbers of atoms of those chemical elements. [P8.1]

chemical reaction

is: a process in which bonds between atoms and molecules are made or broken with the result that materials are transformed.

chemical symbol

is: a symbol consisting of one or two letters that may be used to represent the name of a chemical element. The first letter is always upper case while the second, if there is one, is lower case. [P8.1]

is exemplified: by H for hydrogen, He for helium and Na for sodium. (See a copy of the periodic table for a complete list.) [P8.1]

chord

is: a straight line that cuts a curve at two points. [M2.1, M4.1, M4.2]

chromatic aberration

is: aberration caused by the variation of the focal length of a lens with wavelength, as a result of dispersion. [P6.4]

appears as: coloured fringes seen on images. [P6.4]

ciliary muscles

make up: the ring of muscles surrounding the lens of the human eye. The focal length of the lens is changed as these muscles contract or relax. [P6.4]

circle

of: radius R

centred: on a point P

is: the locus of all points in a plane that are located at a distance R from P.
[M2.1, M2.3, P3.2]

See equation of a circle.

circle of least confusion

is: the minimum but finite image size of a point object, which results from spherical aberration – in which the focal length of the lens varies with the radial distance of rays from the optical axis. [P6.4]

circuit

is: a continuous closed pathway, or network of pathways, along which electric charge may flow. [P4.1, P5.5]

circuit components

is: a general term for any of the many devices (e.g. capacitors, inductors, resistors) that might form part of a circuit.

circular

in: geometry

means: pertaining to a circle. [M2.1]

circumference (of a circle)

is (1): the distance $2\pi R$ around a circle of radius R. [M2.1]

is (2): the circle itself (as in 'a point on the circumference'). [M2.1]

See also perimeter.

classical mechanics

See Newtonian mechanics.

classical physics

is: that part of physics which includes and builds on Newtonian mechanics, Maxwell's theory of electromagnetism, the laws of thermodynamics and (usually) relativity, but which specifically excludes quantum physics. [M6.4, P10.2]

Clausius-Clapeyron equation

is: an equation that relates the slope (dP/dT) of the boundary curve between two phases on a $P\!-\!T$ diagram to the latent heat (ml) and change of volume (ΔV) involved in an isothermal crossing of that boundary at temperature T:

$$\frac{dP}{dT} = \frac{ml}{T\,\Delta V}$$ [P7.4]

closed cycle

is: any succession of processes (which may be reversible or irreversible) which restores a system to its initial state. [P7.4]

codomain (of a function)

of: a function

is: that set within which can be found the range of values of the dependent variable which are generated by the function over its domain. [M1.3]

coefficient

is: any one of the constants, a_0, a_1, a_2, … a_{n-1} and a_n, that appear in a polynomial expression of the form $a_0 + a_1x + a_2x^2 + \ldots + a_{n-1}x^{n-1} + a_nx^n$. [M1.3, M1.4]

is exemplified: by the coefficient of x^3 in $x^4 - 5x^3 - x^2 + 4x + 2$, which is -5.

coefficient of friction

See coefficient of sliding friction, coefficient of static friction.

coefficient of mutual inductance

of: a pair of coils (or circuits), or of a transformer,

is: the quantity M that relates the magnitude of the induced voltage in one coil to the rate of change of current, dI_2/dt, in the other coil, through the equation

$$V_1 = M\left|\frac{dI_2}{dt}\right|.$$ [P4.4]

has as its SI unit: the henry (H), where $1\ \mathrm{H} = 1\ \mathrm{V\ s\ A^{-1}}$. [P4.4]

often is abbreviated: to mutual inductance. [P4.4]

See also 'mutual induction'.

coefficient of self inductance

of: a coil (or circuit)

is: the quantity L that relates the magnitude of the self induced voltage V_{ind} in the coil to the rate of change of current dI/dt in the coil, through the equation

$$V_{\text{ind}} = L\left|\frac{dI}{dt}\right|. \quad [\text{P4.4, P4.5}]$$

has as its SI unit: the henry (H), where $1\,\text{H} = 1\,\text{V s A}^{-1}$. [P4.4, P4.5]

often is abbreviated: to self inductance or inductance. [P4.4, P4.5]

See also self-induction and inductance.

coefficient of sliding friction

for: an object sliding over a solid surface

is denoted: by μ_{slide}. [P2.3]

is: the ratio of the magnitude of the sliding frictional force on the object to the magnitude R of the reaction force on the object. [P2.3]

depends: on the surfaces involved and their state of lubrication. [P2.3]

is largely independent: of other factors, including the area of contact and the speed of the object. [P2.3]

usually is: smaller than the coefficient of static friction μ_{static}. [P2.3]

coefficient of static friction

for: an object on a solid surface, being prevented by friction from moving

is denoted: by μ_{static}. [P2.3, P2.6]

is: the ratio of the magnitude of the maximum frictional force on the object before it moves, to the magnitude R of the reaction force on the object. [P2.3, P2.6, P7.6]

depends: on the surfaces involved and their state of lubrication. [P2.3, P2.6]

is largely independent: of other factors, including the area of contact. [P2.3, P2.6]

usually is: larger than the coefficient of sliding friction μ_{slide}. [P2.3, P2.6]

coefficient of thermal conductivity

of: a substance (under strictly specified conditions of temperature and pressure)

is: the quantity κ that describes the relative ease with which heat is transferred through the material between points at different temperatures. [P11.4]

is defined: as κ in the relation (a special case of Fourier's law)

$$\frac{dQ}{dt} = -\kappa A \frac{T_2 - T_1}{l}$$

where, dQ/dt is the rate of flow of heat along a well insulated bar of length l and uniform cross-sectional area A from an end at temperature T_1 to an end at temperature T_2. [P11.4]

has as its SI unit: W m^{-1} K^{-1}.

See conduction (of heat) and Fourier's law.

coefficient of viscosity

is: the quantity η that describes the relative difficulty with which a fluid may flow. [P7.6]

is defined: by the relation (a special case of Newton's law of viscosity)

$$\sigma_x = -\eta \frac{dv_x}{dy}$$

where σ_x is the shear stress applied in a given direction, dv_x/dy is the velocity gradient in a perpendicular direction, and the minus sign indicates that the velocity decreases with distance from the plane over which the shear stress is applied. [P7.6]

is sometimes called: the viscosity of the fluid. [P7.6]

has as its SI unit: $\mathrm{kg\,m^{-1}\,s^{-1}}$, or equivalently $\mathrm{N\,s\,m^{-2}}$ or $\mathrm{Pa\,s}$.

coherence

between: waves

is: the property that enables phase differences known at one position or time to determine phase differences at other positions and times. [P5.3, P6.1]

coherent

describes: two waves related in such a way that knowing the phase of one at some particular time and position enables the phase of the other to be predicted at some position (if spatially coherent) or time (if temporally coherent) [P6.1]

may also be applied: in its temporal sense, to two oscillations. [P5.3]

coherent fibre bundle

is: an organized or stacked array of optical fibres, such that the relative position of each fibre in the fibre bundle is the same at either end of the bundle. [P6.2]

can be used: to transfer image information. [P6.2]

coil

is: a structure consisting of several loops (called turns) of wire wound in a similar sense to form a simple geometric shape, most typically a circular prism (cylinder) or a helix (solenoid), but possibly some other shape such as a rectangle.

coincident roots

of: an equation

are: repeated roots. (As, for example, the roots of the equation $(x - 1)^2 = 0$ are repeated and are therefore coincident at $x = 0$.) [M1.4]

colinear

means: acting along the same line. [P5.1]

collimator

is: a device used to produce a parallel beam of radiation from a lamp or other source. An optical collimator usually consists of a converging lens with an illuminated slit or circular aperture placed at its focus. [P6.4]

forms: the first stage of a spectrometer. [P8.2]

collision

is: a brief but strong interaction between two particles or bodies which come into close proximity. [P2.4, P2.5]

coma

in: an image

is: the aberration which appears as a comet-like flaring at the edge of an extended image. It is the result of the focal length for non-axial rays varying with their point of incidence on a lens.   [P6.4]

common denominator

of: two or more fractions

is: any number that is exactly divisible (without remainder) by the denominator of each of the fractions. [M1.1]

can be obtained: by multiplying together the denominators of each of the fractions (though the result will not necessarily be the lowest common denominator).

common difference

See arithmetic progression.

common factor

of: two of more numbers or algebraic expressions

is: any number or algebraic expression which is a factor of each. [M1.1]

common logarithm

is: a synonym for the logarithm to the base 10, i.e. $\log_{10}$.   [M1.5]

common ratio

See geometric progression.

common tangent

is: a straight line that is a tangent to two (or more) given curves. [M2.1]

commutator

is: a device used to periodically reverse the current in a rotating coil, in order to maintain the direction of a magnetic torque on the coil. [P4.3]

complementary angles

are: two angles whose sum is 90°. [M2.1]

complementary function

forms: part of the general solution to a second-order linear inhomogeneous differential equation with constant coefficients, of the form

$$a\frac{d^2y}{dt^2} + b\frac{dy}{dt} + cy = f(x).$$ [M6.3]

is: the general solution to the corresponding linear homogeneous differential equation

$$a\frac{d^2y}{dt^2} + b\frac{dy}{dt} + cy = 0.$$ [M6.3, P5.5]

completed square form

is: the form $y = a(x - p)^2 + q$ of a quadratic function, $y = ax^2 + bx + c$ that makes clear the location of the vertex at $(p, q) = \left(-b/(2a),\ \left[c - b^2/(4a)\right]\right)$.
[M1.3]

completely inelastic collision

is: a collision in which the maximum amount of kinetic energy is converted into other forms of energy, consistent with the principle of conservation of momentum. [P2.5]

completing the square

is: the procedure by which a quadratic function is expressed in completed square form. [M1.3, M1.4]

complex

means: pertaining to complex numbers.

complex capacitive reactance

of: a capacitor with capacitance C when passing alternating current of angular frequency ω

is given: by $z_C = -i/\omega C$.   [P5.5]

See complex impedance, capacitive reactance.

complex conjugate

of: a complex number, $z = x + iy$, (where x and y are real numbers)

is: $x - iy$. [M3.1, P5.5]

is denoted: by z^*. [M3.1, P5.5]

complex impedance

of: an electrical component or a network of such components subject to an alternating voltage of angular frequency ω

is: a complex quantity $\mathcal{Z}$ that determines the complex current $\mathcal{I}$ that flows in response to the complex voltage $\mathcal{V}$ through the relation $\mathcal{V} = \mathcal{Z}\mathcal{I}$. (It therefore determines the peak value and the phase lag of the sinusoidally varying current that flows in response to a sinusoidally varying voltage. [P5.5]

is given: for n (complex) impedances connected in series, by

$$\mathcal{Z} = \mathcal{Z}_1 + \mathcal{Z}_2 + \ldots + \mathcal{Z}_n$$ [P5.5]

is given: for n (complex) impedances connected in parallel, by

$$\frac{1}{\mathcal{Z}} = \frac{1}{\mathcal{Z}_1} + \frac{1}{\mathcal{Z}_2} + \ldots + \frac{1}{\mathcal{Z}_n}$$ [P5.5]

is given: for a single resistance by $\mathcal{Z} = R$; for a single inductance by $\mathcal{Z}_L = i\omega L$ and for a single capacitance by $\mathcal{Z}_C = -i/\omega C$. [P5.5]

See complex capacitive reactance and complex inductive reactance

complex inductive reactance

of: an inductor with inductance L when passing alternating current of angular frequency ω

is given: by $\mathcal{Z}_L = i\omega L$. [P5.5]

See complex impedance, inductive reactance.

complex number

is: an expression that may be written in the form $x + iy$, where x and y are real numbers and i is a symbol satisfying the algebraic rule $i^2 = -1$, i.e. $i = \sqrt{-1}$.
[M1.4, M3.1, P5.5, P10.3, P11.1]

complex plane

is: the set of all complex numbers or the representation of them on an Argand diagram. [M3.1]

complex variable

is: a variable that may take on complex values.

component vectors

of: a vector

are: a number of vectors (usually orthogonal) whose vector sum is the original vector. [M2.4, M2.5]

should not be confused with: (scalar) components of a vector.

components of a vector

are: *n* scalar quantities (v_x, v_y, v_z) that can be used to specify an *n*-dimensional vector in Cartesian form.

are sometimes referred to: as the scalar components, in order to emphasize their distinction from component vectors. [M2.4, P2.1, P2.2]

should not be confused with: component vectors.

See projection.

composite function

is: a function obtained through the combination of two or more functions. Given two functions $f(x)$ and $g(x)$, the composite function $f(g(x))$ is obtained by replacing each occurrence of x in $f(x)$ by $g(x)$. [M1.3, M4.3]

is also called: a function of a function. [M1.3, M4.3]

compound

See chemical compound.

compound microscope

is: a microscope which consists of an objective lens and an eyepiece lens, although each of these may consist of several component lenses. [P6.4]

compression

is: the process of making something smaller in size.

is also: the force within the body of a compressed elastic spring, acting along the axis of the spring in order to restore the spring's natural length. [P2.3]

also can mean: the externally applied force acting to compress such a spring. [P2.3]

also can mean: the difference in length between the uncompressed and the compressed spring. [P2.3]

also can mean: a region where pressure and hence density are higher than average. [P5.7]

Contrast with expansion and rarefaction.

Compton effect

is: the phenomenon involving the scattering of photons by an electron, which shows that each quantum of electromagnetic radiation has both energy and momentum. [P10.1]

Compton wavelength

for: a particle of mass m

is defined: as h/mc, where h is Planck's constant and c is the speed of light. [P10.1]

appears: in the theory of the Compton effect. [P10.1]

is of the same order of magnitude: as the change in wavelength of the scattered photons. [P10.1]

concave downwards

describes: a function whose second derivative is less than zero throughout an interval. [M4.4]

concave lens

is: a lens, shaped so that at least one of its surfaces curves inwards into the material. The centre is thinner than the edges. Usually the surfaces are spherical. [P6.3]

is also called: a diverging lens or a negative lens. [P6.3]

concave meniscus lens

is: a lens having two concave surfaces of different radii when viewed from one side and with the centre of the lens thinner than the edges. [P6.3]

concave mirror

is: a mirror shaped so that its reflecting surface curves inwards, away from the incoming light rays. [P6.3]

concave surface

is: a surface which bulges away from the object position, when viewed from that position. [P6.3]

concave upwards

describes: a function whose second derivative is greater than zero throughout an interval, i.e. a function where slope increases continually throughout the interval. [M4.4]

concentric

describes: any two objects which have the same centre, used especially of circles and spheres. [M2.1]

condensation

is: the process whereby a gas or vapour is converted into a liquid.

Contrast with evaporation.

conductance

of: a body of (electrical) resistance R

is: the reciprocal of the resistance, i.e. $1/R$.

conduction (of electricity)

is: the process whereby electric charge flows from one part of a material to another

takes place: at the atomic level, mainly through the movement of electrons from atom to atom.

therefore is: a transport process.

conduction (of heat)

is: one of three processes (the other two being convection and radiation) in which heat can be transferred. [P7.3]

is operative: only in materials (gases, liquids and solids), i.e. not in a vacuum. [P7.3]

takes place: at the atomic level, through energy being passed from atom to atom by vibration and/or collision. [P7.3]

is driven: at the macroscopic level, by a temperature gradient, with heat being transferred from high temperature to low temperature. [P7.3, P7.5]

therefore is: a transport process. [P7.5]

sometimes is quantified: by Fourier's law. [P7.3]

conduction band

in: the band theory of solids

is: the lowest energy band that would be completely unoccupied at absolute zero. [P11.4]

conduction electrons

in: the band theory of solids

are: those electrons that are relatively free to move through the solid and may therefore give rise to electrical conduction. [P11.4]

conductivity

of: a material

is: the reciprocal of the resistivity ρ of that material. [P4.1, P7.3]

has as its SI unit: $(\Omega\,\mathrm{m})^{-1}$, though $\mathrm{S\,m^{-1}}$ (i.e. siemens per metre) are also used. [P4.1, P7.3]

conductor (electrical)

See electrical conductor.

conductor (thermal)

is: a substance with a moderate to high coefficient of thermal conductivity, typically a metal, and usually also an electrical conductor.

cone

is: the shape formed by rotating a triangle about one of its sides. [M2.3]

cones

are: one of two types of light sensor present in the eye, the other type being rods. P6.4]

provide: colour vision, being mainly sensitive to either red, green or blue light but being ineffective at low light levels. [P6.4]

confinement

See plasma confinement.

congruent

describes: two geometric figures which are identical in shape and size. [M2.1]

conic section

is: the intersection of a cone with a plane. [M2.3, P3.2]

can be defined: as the locus of all points P, such that the ratio of the distance from P to a fixed point (the focus), to the distance from P to a fixed line (the directrix), is constant. The value of this constant is known as the eccentricity e.

The conic section is:

an ellipse if $e < 1$,

a parabola if $e = 1$,

an hyperbola if $e > 1$. [M2.3]

also can be defined: as the shape described by any second degree equation of the form:

$$ax^2 + 2hxy + by^2 + 2gx + 2fy + c = 0$$

The conic section is:

an ellipse if $h^2 < ab$

a parabola if $h^2 = ab$

an hyperbola if $h^2 > ab$. [M2.3]

See conic sections in the Maths handbook for further information.

conical pendulum

is: a mechanical system consisting of a mass, suspended from a point by a thread, undergoing uniform circular motion in a horizontal plane. [P2.3]

conics

See conic section.

conjugate equation

is: an equation which links object and image points for an optical element. [P6.3]

See conjugate equation for a single spherical surface and conjugate equation for a thin lens.

conjugate equation for a single spherical surface

is: an equation which links together the object distance and image distance and the radius of curvature of the spherical surface at which refraction occurs. [P6.3]

conjugate equation for a thin lens

is: an equation which links together the object distance and image distance and the radii of curvature of the lens surfaces at which refraction occurs. [P6.3]

conjugate planes

are: planes perpendicular to the optical axis, containing conjugate points.
[P6.3]

conjugate points

are: object and image points linked by a conjugate equation. [P6.3]

conservation of angular momentum

is a principle which states: that when no unbalanced external torque acts on a body or a system of bodies, the total angular momentum of that body or system stays constant. [P2.8]

conservation of charge

is a principle which states: that the total net charge in the Universe is constant. Charges can be created and destroyed but only if the amounts of positive and negative charge involved are identical so that the net change is zero. [P3.3]

conservation of energy

for: an isolated system (which is therefore not subjected to unbalanced external forces)

is a principle which states: that the total amount of energy in the system is always constant (i.e. energy cannot be created or destroyed), although some or all of the energy may be converted from one form into another. [P2.4, P2.5]

See conservation of relativistic energy.

conservation of mass

for: a system that does not exchange any matter with its environment

is a principle which states: that the mass of the system is constant and is unaffected by position, velocity, temperature or any other factor. [P2.3]

is approximately true: when the velocity of the system is much less than the velocity of light. [P2.3]

See conservation of relativistic energy.

conservation of mechanical energy

for: an isolated system in which only conservative forces act

is a principle which states: that the total mechanical energy (i.e. the sum of the kinetic and potential energies) stays constant. [P2.4]

conservation of momentum

for: an isolated system (which is therefore not subject to unbalanced external forces)

is a principle which states: that the total momentum of the system is constant. [P2.5]

implies: that the total momentum of the system of objects does not change due to mutual interactions between the objects within the system. [P2.5]

conservation of relativistic energy

is: simply the conservation of energy, but named in this way to emphasize that quantities such as kinetic energy should be specified in the form required by Einstein's special theory of relativity, and that contributions arising from mass energy should be included. [P9.1]

conservation principle (or law)

is: a law or principle which states that, at least under certain conditions, the value of a physical quantity remains fixed and does not vary in time. [P2.4, P9.1]

is exemplified: by conservation of mass, conservation of charge, conservation of energy, conservation of momentum and conservation of angular momentum. [P2.4, P9.1]

conservative force

is: a force which may be associated with a unique value of potential energy at each point in space and for which the work done between any two points is independent of the path chosen. As a result, the work done by the force around any closed path is zero. [P2.4, P11.2]

is exemplified by: gravitational forces, and electrostatic forces. [P2.4, P11.2]

conserved quantity

describes: any quantity that has the same value at the beginning and end of a wide class of processes, so that it might be made the subject of a suitably formulated conservation law. [P2.5]

constant

means: independent of time.

is also: a quantity whose value does not change in the course of a calculation. [M1.1, M1.3]

may be: a physical constant, e.g. Planck's constant or the speed of light in a vacuum.

may be: a mathematical constant, e.g. π or e.

Contrast with variable.

constant acceleration

See uniform acceleration.

constant acceleration equations

See uniform acceleration equations.

constant addition rule (for summation)

for: any constant a and any positive integer N

is: $\sum_{i=1}^{N}(x_i + a) = \sum_{i=1}^{N} x_i + Na$ [M1.7]

constant field

is: a field that does not change with time. [M2.6, P3.3]

constant multiple rule (for integration)

for: any constant a

is: $\int a\,f(x)\,dx = a\int f(x)\,dx$. [M5.2]

constant multiple rule (for summation)

for: any constant a and any positive integer N

is: $\sum_{i=1}^{N} ax_i = a\sum_{i=1}^{N} x_i$ [M1.7]

constant multiple rule (for differentiation)

for: any constant *a*

is: $\dfrac{d}{dx}\big(af(x)\big) = a\dfrac{d}{dx}\big(f(x)\big)$ [M4.2]

constant of integration

is: the arbitrary constant introduced by the process of indefinite integration. [M5.1, M5.2]

is exemplified: by the constant C in the equation $\int x\,dx = \dfrac{x^2}{2} + C$

constant of proportionality

between: two variables x and y which are proportional (i.e. $x \propto y$)

is: the constant k such that $x = ky$. [M1.1, P1.3]

does not depend: on the values of x and y though it may depend on the values of other variables that are independent of x and y. [M1.1, P1.3]

constant speed

See uniform speed.

constant velocity

See uniform velocity.

constant-volume gas thermometer

is: a thermally sensitive device in which the pressure of a gas, constrained to a constant volume, is used as a thermometric property. [P7.2]

is: not particularly convenient to use, but occupies a central role in defining precise scales for the measurement of temperature. [P7.2]

defines: a gas scale which is intimately related to the thermodynamic Kelvin scale, which is the most fundamental of all temperature scales because it is totally independent of the material (gas, liquid, or solid) and the thermometric property chosen. [P7.2]

construction line

is: an imaginary line added to a diagram to help in explanation, proof or problem solving. [P2.7]

constructive interference

is: the condition in which the superposition of two oscillations or waves produces a resultant with larger amplitude than either of the original oscillations or waves. When the two oscillations or waves are in phase, the amplitude of their resultant is the sum of their amplitudes. [P5.1, P5.6, P5.7, P6.1]

constructive superposition

See constructive interference.

continuous spectrum (emission or absorption)

of: electromagnetic radiation (usually from a specified source)

is: a spectrum that is (relatively) smooth and unbroken over a wide continuous range of wavelengths. [P8.2]

is typical: of the emission spectrum from a solid or liquid heated to a high temperature. [P8.2]

is exemplified: by white light, which can be dispersed by a diffraction grating or a prism into all the colours of the rainbow. [P8.2]

is also exemplified: by the black-body spectrum. [P8.2]

continuous flow method

is: a standard calorimetry procedure that can be used to measure specific heats of fluids. [P7.4]

involves: a fluid flowing at a constant known rate past a heater delivering a known power which produces a rise in temperature between the inlet and outlet. [P7.4]

continuous function

is: a function whose graph has no breaks. [M4.4]

continuous refraction

is: a phenomenon that can occur in a region of a medium where the refractive index varies smoothly with position. [P6.2]

can cause: an appropriately directed ray to change its direction continuously. [P6.2]

continuous variable

is: a variable that changes only in a smooth fashion (with no sudden jumps in its value). [M1.3]

continuous X-ray spectrum

is: the spectrum of X-rays that results when electrons are accelerated through a potential difference of several thousand volts and then strike a target. [P8.3]

is created: as the electrons come to rest. Because the energy of the electrons in the target ranges from zero to a maximum value, the energy of the X-rays emitted will also vary continuously from zero up to a maximum. [P8.3]

also known as: bremsstrahlung

Contrast with characteristic X-ray spectrum.

continuum

is: the continuous range of available energies for an electron moving under the influence of an atom or ion to which it is not bound. The electron is sometimes said to be in an unbound state of the atom or ion. [P8.2]

can be contrasted: with the discrete energy levels of the bound states of the atom which the electron might otherwise occupy. [P8.2]

is reached: by a bound electron which is given sufficient energy to exceed the ionization level of the atom or ion and therefore to escape from it. [P8.2]

continuum level

See ionization level.

contraction

is: the process of making something smaller is size.

control rod

is: a rod of a material that readily absorbs thermal neutrons. [P9.3]

is lowered: into a nuclear fission reactor to control or stop the nuclear chain reaction. [P9.3]

convection

is: one of three processes (the other two being conduction and radiation) in which heat can be transferred. [P7.3]

operates: only in fluids (i.e. gases and liquids), where the relative movement of parts of the fluid at different temperatures is the means by which heat is carried from hot regions to cold regions. [P7.3]

is classified: in two broad categories: 'forced convection', in which the fluid is being moved by external means (a breeze blowing across your face, or a coolant being pumped past a hot object), and 'free convection', in which the flow is induced by buoyancy caused by thermal expansion of hotter regions of the fluid relative to cooler regions (around fins designed to cool the electronics in your hi-fi amplifier, in central heating by electric convectors or, despite their common name, by water-filled radiators). [P7.3]

involves: a generally very complicated relationship between heat flow and temperature difference, depending on temperature difference in a non-linear way and on other factors including many thermal properties of the fluid and the geometry and orientation of the object exchanging heat with the fluid. There are many empirical formulae employed by engineers for situations commonly encountered, but when in doubt, or when information is lacking, the best one can do is to use Newton's law of cooling $\dfrac{dQ}{dt} = hA\Delta T$ where dQ/dt is the rate of heat flow between two surfaces of area A that differ in temperature by an amount ΔT, and h is an appropriately chosen convective heat transfer coefficient. [P7.3]

convective heat transfer coefficient

See convection.

converge

See convergent series and convergent sequence.

convergent integral

is: an improper integral with a finite value. [M5.2]

convergent sequence

is: a sequence, S_1, S_2, S_3, S_4, … all of whose members, beyond some particular member, are as close as we please to some particular number. This number is called the limit of the sequence. [M1.7]

convergent series

is: a series whose partial sums form a convergent sequence. The limit of a sequence of partial sums is known as the sum of the series. [M1.7]

converging lens

is: a lens which increases the convergence or reduces the divergence of light rays passing through it. [P6.3]

is also called: a convex lens or a positive lens. [P6.3]

conversion factor

is: a dimensionless factor, such as (10^3 m/km), which is actually equal to one, but which is expressed as a ratio of two quantities which have different units. [P1.1]

can be used: to convert a quantity expressed in terms of certain units into an equivalent quantity expressed in terms of other units. [P1.1]

convex lens

is: a lens, shaped so that at least one of its surfaces curves outwards, away from the centre of the material. The centre is thicker than the edges. Usually the surfaces are spherical. [P6.3]

is also called: a converging lens or a positive lens. [P6.3]

convex meniscus lens

is: a lens having two convex surfaces of different radius of curvature when viewed from one side, and with the centre of the lens thicker than the edges. [P6.3]

convex mirror

is: a mirror shaped so that its reflecting surface curves outwards, towards the incoming light rays. [P6.3]

convex surface

is: a surface which bulges towards the object position, when seen from that side. [P6.3]

coolant

in: a nuclear reactor

is: a fluid (liquid or gas) that keeps a reactor cool and transfers the energy released in the reactor so that it may be used to produce steam and hence drive electricity generators. [P9.3]

coordinate axes

See Cartesian coordinates.

coordinate system

is: a system for associating a set of values, called coordinates, with points in space so that each point may be uniquely identified and distinguished from every other point.

See Cartesian coordinates, polar coordinates and spherical polar coordinates.

coordinates

of: a point

are: the (unique) set of values associated with that point by a coordinate system that distinguish that point from other points.

are exemplified by: the x- and y-coordinates of a point on a graph. [P1.3]

Copenhagen interpretation

is: the most commonly accepted view of quantum physics. [P10.2]

holds that: the Universe operates according to probabilistic laws which tell us as much as can be known, even in principle, about future events. [P10.2]

was formulated: by a group of scientists (including Heisenberg) who worked in Copenhagen in the 1920s. [P10.2]

contrasts: with the many universe theory.

coplanar

means: in the same plane. [P2.7]

correspondence principle

states: that in the classical limit the predictions of quantum mechanics are in agreement with those of (non-relativistic) classical physics. [P11.2, P11.3]

corkscrew rule

is: a rule for working out the direction of a vector product such as $\boldsymbol{a} \times \boldsymbol{b}$.

states that: if the handle of a (right-handed) corkscrew is aligned with the vector $\boldsymbol{a}$ and oriented in such a way that its handle may be twisted into alignment with $\boldsymbol{b}$ by turning it through an angle less than 180°, then the direction of $\boldsymbol{a} \times \boldsymbol{b}$ is the direction in which the corkscrew would advance.

more briefly states: the direction of $\boldsymbol{a} \times \boldsymbol{b}$ is the direction of advance of a corkscrew as its handle is rotated from $\boldsymbol{a}$ to $\boldsymbol{b}$. [M2.7, P4.3]

Compare with the right-hand screw rule and the (preferred) right-hand rule.

cornea

is: the transparent protective outer covering to the eye. [P6.4]

is: the first surface at which refraction takes place for light entering the eye. [P6.4]

corresponding angles

See transversal.

cosecant, cosec

See trigonometric function.

cosech

See hyperbolic function.

cosh

See hyperbolic function.

cosine rule

states: that given a triangle with angles A, B and C opposite to sides a, b and c then $c^2 = a^2 + b^2 - 2ab\cos C$. Likewise $a^2 = b^2 + c^2 - 2bc\cos A$ and $b^2 = a^2 + c^2 - 2ac\cos B$. [M1.6]

reduces: to Pythagoras's theorem when the chosen angle is 90°.

See trigonometric functions in the Maths handbook for further details.

cosine, cos

See trigonometric function.

cosmic rays

are: high energy particles (mainly protons) which enter the Earth's upper atmosphere from space. They may collide with nuclei in the atmosphere, producing radioactive isotopes. [P9.3]

cotangent, cot

See trigonometric function.

coth

See hyperbolic function.

Coulomb force

See electrostatic force and Coulomb's law. [P3.3]

Coulomb's law

is: the law, first formulated by Charles Augustin de Coulomb (1736-1806), which describes the electrostatic force between charged particles. [P3.1]

states that: for two particles of charge q_1 and q_2 separated by a distance r, the force on particle 2 due to particle 1 is

$$\boldsymbol{F}_{\rm el} = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}\boldsymbol{\hat{r}}$$

where ε_0 is the permittivity of free space, q_1 and q_2 are signed quantities, and $\boldsymbol{\hat{r}}$ is a unit vector pointing from q_1 to q_2. The direction of the force is therefore along the line joining the charges, and like charges repel while unlike charges attract. [P3.3]

coulomb, C

is: the SI unit of charge.

is defined: as the amount of charge transferred when a current of 1 ampere flows for 1 second, so 1 C = 1 A s. [P3.3]

couple

is: a pair of forces of equal magnitude acting in opposite directions along different lines of action. [P2.7, P4.3]

may be characterized: by a non-zero torque about any point, the magnitude of which is equal to the magnitude of either one of the forces multiplied by the perpendicular distance between their lines of action. [P2.7]

causes: rotation but not translation, when applied to rigid body that is entirely free to move [P2.7]

coupled oscillators

are: two oscillators connected in such a way that the displacement of one oscillator affects the restoring force acting on the other. [P5.1, P5.3]

exhibit: normal modes. [P5.1, P5.3]

may be generalized: to a system of many oscillators.

covalent bond

is: a bond in which one or more electrons is shared between two (or more) atoms. [P11.4]

covalent bonding

is: a type of chemical bonding in which the chemical bonds are created by electron pairs shared between atoms. [P8.4]

has typical energy: of 1 to 5 eV. [P7.1]

is characterized: by an increased electron density between the nuclei of the atoms. [P11.4]

creep

is: the condition in which the strain in a material exhibits a slow time-dependence under constant stress in the region of plasticity. [P7.6]

critical

describes: the condition inside a nuclear reactor (or similar device) in which a nuclear chain reaction is just able to self-sustain at a steady rate, i.e. where, on average, exactly one neutron released in the fission of one nucleus goes on to produce fission in one further nucleus. [P9.3]

Contrast with subcritical, supercritical.

critical angle

for: light rays passing from a medium of given refractive index into a medium of lesser refractive index

is: the minimum angle of incidence that corresponds (via Snell's law) to an angle of refraction of 90°. A ray meeting the interface at a greater angle of incidence will suffer total internal reflection unless special steps are taken to frustrate the process. [P5.7, P6.2]

critical damping

is: the condition in which a damped oscillator just fails to oscillate and comes to rest in the shortest possible time following release from a given position. It is the intermediate condition between light damping (i.e. underdamping) and heavy damping (i.e. overdamping). [P5.2]

is accompanied by: no more than one overshoot of the equilibrium value before coming to rest.

is exemplified electrically: by a series a.c. circuit containing a capacitor of capacitance C, an inductor of inductance L, and a resistor of resistance R, wherein the damped oscillations of stored charge (or current) are critically damped when $R = 2\sqrt{L/C}$. [P5.4]

is exemplified mechanically: by a damped mechanical oscillator containing an oscillating body of mass m, a spring of spring constant k, and a linear damping force with damping coefficient b, wherein oscillations are critically damped when $b = 2\sqrt{km}$. [P5.4, P5.5]

is described by: $x(t) = (H + Jt)\,e^{-\gamma t/2}$ where $\gamma = b/m$ for a mechanical oscillator, and $\gamma = R/L$ for an electrical oscillator. H and J are constants determined by the initial conditions.

critical mass

is: the mass of a fissile material that is just capable of maintaining a nuclear chain reaction. [P9.3]

therefore is: the mass of a fissile material that is just capable of keeping a nuclear chain reaction at the critical condition. [P9.3]

critical opalescence

is: a phenomenon displayed by normally transparent fluids under the conditions that define the critical point. Illuminated by a beam of light, the substance takes on an intensely white, diffuse cloudy appearance. [P7.4]

critical point

of a substance

is: the unique point on a *PVT*-surface (or some similar surface), or on one of its projections, representing the state in which the liquid and vapour phases of a substance become indistinguishable. [P7.4]

See also critical opalescence.

critical pressure

is: the pressure of a substance at its critical point. [P7.4]

critical temperature

is: the temperature of a substance at its critical point.

is also: the maximum temperature at which a gas can be liquefied by an isothermal process. [P7.4]

critical volume

is: the volume of a substance at its critical point. [P7.4]

critically damped

See critical damping.

cross product

See vector product.

cross-sectional area

generally is: the area of intersection of a geometrical solid and a plane. Usually the plane is normal to an axis of symmetry, but could be some other specified direction. [M2.1]

See also prism.

crown glass

is: a glass of relatively low refractive index and thus low dispersive power. [P6.4]

is used as a component: in an achromatic doublet. [P6.4]

crystal

is: any material with a crystalline structure.

crystalline structure

is: a regular array of atoms in three-dimensional space that can be described by associating the same arrangement of one or more atoms with every point of a given three-dimensional lattice. [P11.4]

cubic equation

is: a polynomial equation of degree 3. [M1.4]

cubic function

is: a polynomial function of degree 3. [M1.3]

cuboid

is: any rectangular block. [M2.1]

current

See electric current.

current balance

is: a device designed to measure the force between two current-carrying coils or wires. [P4.3]

can be used: to measure currents accurately and hence to determine the current of magnitude one ampere. [P4.3]

current divider equations

are: a pair of equations which describe the way in which an electric current is divided between two resistors in parallel. [P4.1]

curve

is: a continuous set of points, often (though not necessarily) in a plane.

cut-off wavelength

of: a continuous X-ray spectrum.

is: the sharply defined wavelength, below which there is no continuous spectrum. [P8.3]

corresponds to: the situation in which the maximum kinetic energy of an incident electron is entirely radiated away as a single X-ray photon. [P8.3]

cycle

of: a periodic motion (or a more general oscillation)

is: the motion or behaviour which occupies exactly one period. [P5.1]

cyclotron

is: a device which can accelerate charged particles by applying a periodic electric field to the particle as it moves, constrained in a circular or spiral path, by an applied magnetic field. [P4.3]

cyclotron frequency

is: the frequency of the circular or helical motion of a charged particle in a uniform magnetic field. [P4.3]

is dependent: only on the particle's charge-to-mass ratio q/m and on the magnetic field strength B:

$$f_{\text{cyclotron}} = \frac{|q|B}{2\pi m}. \quad [\text{P4.3}]$$

cyclotron motion

of: a charged particle

in: a magnetic field

is: the periodic motion of the particle in the plane perpendicular to the magnetic field. [P4.3]

cyclotron period

is: the time to complete one period of cyclotron motion and the reciprocal of the cyclotron frequency. [P4.3]

d'Alembert ratio test

is: one of several tests for the convergence or divergence of a series. If a_n is the n^{th} term in the series, the test consists of calculating:

$$R = \lim_{n\to\infty}\left(\frac{a_{n+1}}{a_n}\right)$$

There are three possible outcomes:

$R < 1$ implying convergence,

$R > 1$ implying divergence,

$R = 1$ implying that the test is incapable of providing a definite answer.

[M1.7]

DC, d.c.

See direct current.

DC circuit, d.c. circuit

is: an electrical circuit in which a direct current flows, or may be presumed to flow. [P4.1]

DC isolation, d.c. isolation

of: two circuits

is: their separation such that they may have independent d.c. potentials but yet may be mutually influenced by each other's a.c. currents. [P4.4]

can be achieved: via the mutual inductance between the circuits, through a transformer or via a capacitor. [P4.1, P4.4, P5.4]

damped (electrical) oscillator

is: an electrical system in which a quantity such as charge or current exhibits oscillatory behaviour while energy is dissipated to the environment.

is exemplified: by a circuit in which an inductance L, capacitance C, and resistance R are connected in series, so that the charge q stored in the capacitor at time t obeys the differential equation:

$$L\frac{d^2q}{dt^2} = -\frac{1}{C}q - R\frac{dq}{dt}$$

and is consequently described, in the case of light damping ($R^2 < 4L/C$), by an oscillation with an exponentially decaying amplitude:

$$q(t) = q_0\,e^{-\gamma t/2}\cos(\omega t + \phi)$$

where $\gamma = R/L$, $\omega = \sqrt{\dfrac{1}{LC} - \dfrac{R^2}{4L^2}}$ and q_0 and ϕ are arbitrary constants. [P5.4, P5.5]

See critical damping. [P5.4, P5.5]

damped oscillator

See damped (electrical) oscillator, damped (mechanical) oscillator.

damped (mechanical) oscillator

is: a mechanical system in which a quantity such as displacement exhibits oscillatory behaviour while energy is dissipated to the environment.

is exemplified: by a particle of mass m on a spring of spring constant k, moving subject to a damping force with damping coefficient b so that its displacement from equilibrium, x, at time t satisfies the equation of motion:

$$m\frac{d^2x}{dt^2} = -kx - b\frac{dx}{dt}$$

and is consequently described in the case of light damping ($b^2 < 4mk$) by an oscillation with an exponentially decaying amplitude:

$$x(t) = x_0\,e^{-\gamma t/2}\cos(\omega t + \phi)$$

where $\gamma = b/m$, $\omega = \sqrt{\dfrac{k}{m} - \dfrac{b^2}{4m^2}}$ and x_0 and ϕ are arbitrary constants. [P5.2, P5.5]

See critical damping and heavy damping.

damped oscillation

See damped (electrical) oscillator, damped (mechanical) oscillator.

damping

is: any phenomenon involving dissipation (such as friction, viscosity or electrical resistance) that causes a system (particularly an oscillating system) to lose energy. [M6.3, P5.2, P5.4]

See damping force, damping constant.

damping coefficient

is: the constant b that appears in the equation for a linearly damped harmonic oscillator: $m\dfrac{d^2x}{dt^2} + b\dfrac{dx}{dt} + kx = 0$.

damping constant

for: an oscillating particle of mass m subject to a dissipative force of magnitude bv, where v, is the speed of the particle

is given: by $\gamma = b/m$. [P5.2]

is equal: to twice the decay constant α for the amplitude of the oscillation. [P5.2]

See damping force, damped mechanical oscillator.

damping force

in: a mechanical oscillator.

is: a dissipative force which opposes the motion and which therefore causes damping. [M6.3, P5.2, P5.4]

See damping constant.

data

is: recorded information, particularly numerical or statistical information that can be used in an analysis or calculation.

daughter isotope

See daughter nucleus.

daughter nucleus

is: an isotope produced in the radioactive decay of a parent nucleus. [P9.2]

de Broglie hypothesis

states: that the propagation of all matter is determined by an associated de Broglie wave, from which the diffraction and interference behaviours may be predicted. [P10.2]

de Broglie wave

is: a wave associated with the propagation of matter. [P10.2]

can be used: to predict the diffraction and interference behaviours of matter. [P10.2]

See de Broglie wavelength.

de Broglie wavelength

of: a particle or, more generally, of a free quantum

is given: by $\lambda_{\rm dB} = h/p$, where p is the magnitude of the momentum of the particle and h is Planck's constant. [P10.2, P11.1, P11.2]

determines: the diffraction when the quantum meets an obstacle. [P11.1, P11.2]

Debye model

is: a model of the specific heats of solids

postulates: that the solid behaves like an elastic body capable of exhibiting quantized oscillations characterized by a specific distribution of classical frequencies. [P11.4]

predicts: that near absolute zero the specific heat is proportional to T^3, where T is the absolute temperature. [P11.4]

decay

is: a general term describing the tendency to decrease with time.

See decay constant.

decay channels

are: the different ways in which a particular radioactive nucleus may decay. [P9.3]

decay constant

is: the constant of proportionality, α that relates the rate of radioactive decay, R to the number, N of unstable nuclei present: $R = \alpha N$. [P9.2]

is: a property of radionuclides, unaffected by the physical or chemical environment. [P9.2]

more generally is: the reciprocal of the time constant τ in any exponential decay process: $A(t) = A_0\,e^{-\alpha t} = A_0\,e^{-t/\tau}$. [P5.2]

deceleration

is: the slowing down of an object, and an associated reduction in speed. [M4.1, P2.1]

is commonly misconstrued: as negative acceleration. This may be, but is not necessarily, the case, since acceleration is a vector quantity and has an associated sign. [P2.1]

decibel, dB

is: a unit of (acoustic) intensity level. [P5.7]

permits representation: of intensity level in terms of a reference intensity level:

given a sound of intensity I (measured in $\mathrm{W\,m^{-2}}$), its intensity level is given by

$$\beta = 10 \times \log_{10}\left(\frac{I}{I_0}\right)\text{decibel}$$

where $I_0 = 1 \times 10^{-12}\,\mathrm{W\,m^{-2}}$. Audible, non-painful sounds usually have intensity levels in the range 0 to 120 dB. [P5.7]

decimal number

is: a number expressed in base ten notation, so that 345.6 means $3 \times 10^2 + 4 \times 10^1 + 5 \times 10^0 + 6 \times 10^{-1}$. [M1.2]

decimal places

describes: the number of digits which a decimal number has after the decimal point. [M1.2]

decreasing function

is: a function $f(x)$ for which $f(a) > f(b)$ for all $a < b$. [M4.4]

exists: on an interval if $f'(x)$ is negative at all points of the interval. [M4.4]

definite integral

of: a function $f(x)$ defined on an interval from $x = a$ to $x = b$

is denoted: $\int_a^b f(x)\,dx$

where the values a and b are known as the lower and upper limits of integration, $f(x)$ is called the integrand, and the symbol dx is the element of integration which shows that x is the integration variable with respect to which the integration is to be performed. [M5.1, M5.2, P2.4]

is defined: by the limit of a sum:

$$\int_a^b f(x)\,dx = \lim_{\Delta x \to 0}\left(\sum_{i=1}^{n} f(x_i)\,\Delta x_i\right) \quad \text{with } \Delta x_i = x_{i+1} - x_i$$

where the sequence of values $x_1, x_2, \dots x_{n+1}$ is such that $a = x_1 < x_2 < \dots < x_{n+1} = b$, and Δx is the largest of the Δx_i. [M5.1, M5.2, P2.4]

may be interpreted: for a given function between given limits, as the area under a graph of that function between the given limits, provided that due regard is paid to signs (areas of regions below the horizontal axis must be treated as negative quantities). [M5.1, M5.2, P2.4]

can be evaluated: according to the fundamental theorem of calculus using

$$\int_a^b f(x)\,dx = [F(x)]_a^b = F(b) - F(a)$$

where $F(x)$ is any indefinite integral of $f(x)$ (i.e. any function $F(x)$ that satisfies $dF/dx = f(x)$). [M5.1, M5.2, P2.4]

also can be evaluated: by means of numerical integration. [M5.1, M5.2, P2.4]

degeneracy

is: the phenomenon in which different quantum states of a system (e.g. the states of electrons in an atom) have the same characteristic energy and therefore belong to the same energy level of the system. [P8.3]

therefore is also: the existence of more than one independent wavefunction, characterized by different sets of quantum numbers, corresponding to the same energy level. [P10.3]

degenerate

describes: an energy level or a wavefunction, when degeneracy is present. [P10.3]

degree, °

is: the unit of plane angle corresponding to 1/360th of a circle, written as 1°. In other words, a rotation through 360° is a full rotation. [M1.6]

is equal: to 0.01745 radian, (to five decimal places). [M2.1]

degree Celsius, °C

is: a non-SI unit of temperature and temperature difference.

is defined: to be equal in size to the SI unit of absolute temperature, the kelvin (K), but the zeros of the thermodynamic Kelvin temperature scale and the Celsius temperature scale are different (0 °C = 273.15 K).

degree (of a differential equation)

is: the highest power to which the highest order of derivative in the differential equation is raised. [M6.1]

for: a linear differential equation is equal to 1. [M6.1]

degree (of a polynomial)

is: the integer n that appears in a polynomial expression of the form

$a_0 + a_1x + a_2x^2 + \dots + a_{n-1}x^{n-1} + a_nx^n = 0$, that is, the highest power of the variable in the polynomial expression. [M1.3, M1.4]

degrees of freedom

of: a system

are: the characteristics of a system's configuration that can be varied independently. [P5.1]

are exemplified: by the three position coordinates that determine the location of a particle in three-dimensional space.

correspond: to the independent variables required to describe the motion of the system fully. [P7.5]

are reduced: by constraints in the system which limit the possible motions. For instance, a system consisting of two independent particles has six degrees of freedom, but a 'dumb-bell' in which two particles are separated by a fixed distance has only five degrees of freedom (these can be thought of as three translational and two rotational degrees of freedom). [P7.5]

Demoivre's theorem

states: that for any real number, n

$$[\cos(\theta) + i\sin(\theta)]^n = \cos(n\theta) + i\sin(n\theta)$$ [M3.3, P5.5]

denominator

is: the number or expression at the bottom of a fraction. [M1.1]

density

of: a uniform body of mass M and volume V

is: the mass per unit volume of the body, M/V

is defined more generally: at a point in a (possibly non-uniform) body by

$$\rho = \lim_{\Delta V \to 0} \left(\frac{\Delta m}{\Delta V} \right)$$

where Δm is the mass of a small element of the body, of volume ΔV centred on the specified point.

dependent error

in: a measurement

when: the errors arising in the measurement are being analysed

is: any error whose size is determined, wholly or partly, by the size of another. [P1.2]

See uncertainty.

dependent variable

in: an experiment (or a calculation)

is: the quantity whose value is monitored by the experimenter (or by the person doing the calculation). [P1.3]

is controlled by: the value of the independent variable to which it is connected by a set of experimental observations (or by a mathematical function). [M1.3]

on graphs is plotted: conventionally along the vertical axis. [P1.3]

depth of field

is: the range of distances of an object from a lens, for which the image will appear to be sharp for a particular lens position. [P6.4]

increases: as the lens aperture is reduced in size. [P6.4]

Contrast with depth of focus.

depth of focus

is: the range of lens positions for which the image of an object will appear to be sharp for a particular distance of the object from the lens. [P6.4]

increases: as the lens aperture is reduced in size. [P6.4]

Contrast with depth of field.

derivative

of: a function $y = f(x)$

is: its rate of change with respect to x at any particular value of x

is given by:

$$f'(x) = \frac{dy}{dx} = \lim_{\Delta x \to 0}\left(\frac{\Delta y}{\Delta x}\right) = \lim_{\Delta x \to 0}\left[\frac{f(x + \Delta x) - f(h)}{\Delta x}\right]$$

where $f'(x)$ is known as the first derivative or derived function.

is defined: over any domain in which a unique limit exists for all values of x.
[M4.1, M4.2, P2.1]

derived function

See derivative.

derived units

are: SI units created by specified combinations of the base units. [P1.1]

See Table 2 in Section 0 of the Maths handbook for a detailed listing.

destructive interference

is: the condition in which the superposition of two oscillations or waves results in an oscillation or wave with smaller amplitude than either of the original oscillations or waves. When the two oscillations or waves are in anti-phase, the amplitude of their resultant is the difference of their amplitudes. [P5.1, P5.6, P5.7, P6.1]

also known as: destructive superposition.

destructive superposition

See destructive interference.

determinism

is: a belief that the Universe operates according to laws whose nature is such that the state of the Universe at one time completely determines its state at any later time. [P10.2]

deterministic system

is: a system for which a complete knowledge of the laws governing it and of its initial state allows its subsequent evolution in time to be predicted exactly.
[M6.1]

deuterium

is: the isotope of hydrogen that has mass number $A = 2$. [P9.3]

is also called: heavy hydrogen. [P9.3]

deuteron

is: a deuterium nucleus, ${}^{2}_{1}\mathrm{H}$. [P9.3]

is also represented: as D or sometimes d. [P9.3]

deviation

is: the difference between a particular measurement x_i (from a set of measurements) and the mean $\langle x \rangle$ of that set. The deviation of the i^{th} measurement is therefore $d_i = x_i - \langle x \rangle$.   [P1.2]

See also standard deviation.

diameter

of: a circle, sphere or ellipse.

is: a line segment passing through the centre of the circle, sphere or ellipse. [M2.1]

touches: the boundary at two 'diametrically opposite' points. [M2.1]

is also: the length of such a line segment, which will be twice the radius in the case of a circle or sphere, but will depend on orientation in the case of an ellipse. [M2.1]

diatomic ideal gas

is: an ideal gas in which the internal energy is a function of temperature T that (classically) rises from $3nRT/2$ at low temperature, to $5nRT/2$ at moderate temperature (due to the excitation of the rotational degrees of freedom), to $7nRT/2$ at high temperature (due to the excitation of vibrations). [P7.4]

can be used: to model the behaviour of a real gas with two atoms per molecule at low density. [P7.4]

dielectric

is: a term used to describe an insulator in situations where its dielectric constant is (or may be) of significance (e.g. between the plates of a capacitor). [P4.5]

dielectric constant

of: a medium

is: the ratio of the permittivity of the medium to the permittivity of free space, ε_0. [P4.5]

is synonymous: with relative permittivity, ε_r.

difference

See operation.

differential equation

is: an equation which involves the first derivative and/or higher derivatives of a quantity. [P5.3, P5.4, M6.1]

has as its order: the order of the highest derivative appearing in the equation. [M6.1, P5.3, P5.4]

has as its degree: the highest power of the derivative of highest order appearing in the equation. [M6.1, P5.3, P5.4]

has a general solution: which involves one or more arbitrary constants with values that have to be determined by boundary conditions which are characteristic of the problem being considered. [M6.1, P5.3, P5.4]

See differential equations in the Maths handbook for further details.

differential operator

is: an operator (i.e. a symbolic instruction to carry out a mathematical operation) that involves the process of differentiation. [M4.3]

usually acts: on whatever is immediately to its right. [M4.3]

is exemplified: by $\hat{\mathrm{p}}_x = -i\hbar\dfrac{d}{dx}$ which, in quantum mechanics, corresponds to the *x*-component of momentum. [P10.4]

is also exemplified: by $\hat{\mathrm{E}}_{\mathrm{kin}} = -\dfrac{\hbar^2}{2m}\dfrac{d^2}{dx^2}$ which, in quantum mechanics, corresponds to the kinetic energy of a particle moving in one dimension. [P10.4]

See also eigenfunction, eigenvalue and eigenvalue equation.

differentiation

is: the process of finding the derived function, or derivative, of a function.
[M4.1, M4.2]

diffraction

is: the ability of waves to bend around obstacles or to be spread by apertures. [P5.7, P6.1, P6.2]

depends for its amount: on the relationship between the wavelength of the wave and the size of the obstacle or aperture. [P5.7, P6.1, P6.2]

is negligible: when the wavelength is much less than the size of the obstacle or aperture. [P5.7, P6.1, P6.2]

is greatest: when the wavelength is about the same size as the obstacle or aperture. [P5.7, P6.1, P6.2]

diffraction grating

is: an optical device consisting of a flat plate with a series of equally spaced, parallel slits on its surface. The distance between the slits is usually a few wavelengths of the radiation involved, and is called the grating spacing. The plate may be transparent (a transmission grating) or reflecting (a reflection grating) and the slits may have been produced by ruling them with an appropriate machine (ruled grating), or by taking a cast of an existing ruled grating (replica grating). [P6.1]

produces: when illuminated by normally incident monochromatic light of wavelength λ an interference pattern which has primary intensity maxima at angles θ_n from the straight-through position given by

$$\sin\theta_n = \frac{n\lambda}{d}$$

where n is the order of diffraction and d is the grating spacing. [P5.5, P6.1]

diffraction pattern

is: an interference pattern from an identifiable obstruction, for example a circular aperture or slit, or a pair of slits (as in Young's experiment), or an array of slits (as in a diffraction grating). [P5.7, P6.1, P6.2]

See diffraction.

diffuse reflection

is: reflection from a rough surface, so that rays incident from the same direction are reflected in different directions by different parts of the surface. [P5.7]

diffusion

is: the process by which molecules spread from regions of high to low concentration. [P7.5]

therefore is: a transport process. [P7.5]

digit

is: a symbol used in the specification of a number 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 are the ten digits used to specify decimal numbers. [M1.2, P1.1]

dimension

of: a coordinate system (e.g. a system of Cartesian coordinates)

is: a 'direction' in which measurements may be made (usually) independently of measurements in other dimensions. In the case of Cartesian coordinates the directions of the *x*-axis, *y*-axis and *z*-axis each represent one of three independent dimensions. The number of dimensions (the dimensionality of the system) is therefore the minimum number of coordinates needed to uniquely identify any point in the region covered by the system of coordinates.

See also dimensional analysis and dimensions for a different meaning.

dimensional analysis

is: the process of assigning appropriate combinations of dimensions to physical quantities and using such assignments to test the plausibility of proposed relationships between physical quantities. [M1.3, P1.1]

dimensionless

refers: to a quantity with no overall dimensions, such as a pure number or a ratio of two quantities which have the same dimensions. [M1.2, P1.1]

dimensionless ratio

is: a ratio of two quantities which have the same dimensions. [M1.2]

dimensions

are: basic measurable quantities such as mass (M), length (L) and time (T). [M1.2]

can be used: singly or in appropriate combinations to characterize physical quantities. Speed, for example, can be measured in the same units as the ratio of a length to a time and is therefore said to have the same dimensions as length/time, a relationship shown by writing [speed] = [length/time] = $L\,T^{-1}$. Quantities with units that differ only by a dimensionless conversion factor are said to have the same dimensions. [M1.2, P1.1]

diminished

means: made smaller — as for an image formed by a lens or a mirror, when the image is smaller than the object. [P6.3]

dioptre

is: the unit of optical power of a lens, being the reciprocal of the focal length of the lens and expressed in m^{-1}. [P6.3]

dipole

See electric dipole, magnetic dipole.

dipole moment

See electric dipole moment, magnetic dipole moment.

direct current

is: an electric current whose direction does not vary with time. [P4.1]

more generally refers: to other associated electrical quantities whose direction or polarity does not vary with time, e.g. d.c. voltage. [P4.1]

is abbreviated: DC at the beginning of a sentence, and d.c. elsewhere. [P4.1]

direct integration

is: a method of solution which can be applied to differential equations of the form $\dfrac{dy}{dx} = f(x)$.   [M6.1, M6.2]

See inverse differentiation.

directed line segment

is: a line of finite length with an arrow head drawn on it. The length and orientation of such a line can be used to represent the magnitude and direction of a vector or a vector quantity in a diagram or illustration. [M2.4]

direction (of a vector)

is: a characteristic property of a vector which determines its orientation with respect to a system of coordinates. [P2.2]

usually is specified: in two dimensions relative to a two-dimensional Cartesian coordinate system, by quoting the angle (measured in the anticlockwise sense) from the positive *x*-axis to the vector. [P2.2]

may be more generally specified: by expressing the vector in terms of its components relative to a given Cartesian coordinate system.

See scalars and vectors in the Maths handbook.

direction (of propagation)

is: the direction of motion of a wave. [P5.6, P6.1]

See transverse wave and longitudinal wave.

direction cosines

of: a straight line relative to a three-dimensional system of Cartesian coordinates.

are: three numbers that represent the cosines of the angles between the line and the coordinate axes. [M2.2]

are: in the same ratio as the direction ratios of the line.

direction ratios

for: a straight line

in: three dimensions

are: the constants l, m, n in the equation for the straight line:
$\dfrac{x-a}{l} = \dfrac{y-b}{m} = \dfrac{z-c}{n}$, where (a, b, c) is a point on the line. [M2.2]

directly proportional

describes: two variables x and y, if their ratio x/y remains constant as x and y are varied. [M1.1]

is symbolized: by $x \propto y$. [M1.1]

generally is abbreviated: to 'proportional'. [M1.1]

See constant of proportionality.

Contrast with inversely proportional.

directrix

See conic section.

disc

is: a circle together with the points enclosed by its circumference. [M2.1]

discharge tube

is: a device used to investigate the conduction of electricity through a gas. [P8.1]

consists: in its simplest form, of a gas-filled glass tube containing an anode and a cathode, in which the pressure can be reduced by means of a pump. [P8.1]

discrete (variable)

is: a variable that only takes certain separated values and is therefore not a continuous variable. [M1.3]

discriminant

for: a quadratic equation $ax^2 + bx + c = 0$

is: the quantity $b^2 - 4ac$. [M1.3, M1.4]

determines: the number of times that the graph of the quadratic function will intersect the x-axis, i.e., the number of roots that the equation has. [M1.3, M1.4]

dispersion

is: the phenomenon in which a wave travels through a material with a phase speed that depends on its frequency. [P5.6, P6.1, P6.2, P6.3, P10.3]

arises from: variation of the refractive index of the material with the frequency of the wave, for an electromagnetic wave. [P5.6, P6.1, P6.2, P6.3, P10.3]

therefore causes: light of different frequencies to be refracted by different angles on entering the material, and hence enables light of different frequencies to be refracted in different directions. [P5.6, P6.1, P6.2, P6.3, P8.2, P10.3]

dispersion relation

of: a given type of wave in a specified medium

is: an expression which describes the variation of the wave's wavelength (or some related quantity such as wavenumber) with the frequency of the wave. [P10.3]

is exemplified: for an electromagnetic wave of wavelength λ travelling through a medium with a frequency-dependent refractive index $\mu(x)$, by $\lambda = c/f\mu(f)$ where c is the speed of light in a vacuum.

is also exemplified: by the dispersion relation for the de Broglie wave of a free particle $\omega = \dfrac{\hbar k^2}{2m}$, where ω is the angular frequency and k is the corresponding angular wavenumber.

dispersive power

is: the ability of an optical medium to produce dispersion for a given optical power or focal length. High or low dispersive power corresponds to high or low refractive index, respectively. [P6.4]

displacement

from: one point in space to another

is: the change in position from the first point to the second. [P2.1]

is represented: by a vector. The displacement $\boldsymbol{s}$ from a point with position vector $\boldsymbol{r}_1$ to a point with position vector $\boldsymbol{r}_2$ is given by $\boldsymbol{s} = \boldsymbol{r}_2 - \boldsymbol{r}_1$. [P2.2]

has magnitude: equal to the distance between the two points. [P2.2]

has direction: along the line from the first point to the second. [P2.2]

may be measured: from any selected reference point, unlike a position vector. [P2.2]

has as its SI unit: the metre (m). [M2.4]

in one dimension can be represented: by a single scalar component s_x. If the selected reference point is at the initial position of the particle, then the displacement of the particle at time t is $s_x = x(t) - x(0)$. [M4.1, P2.1]

in linear motion is given: for displacement of an object from its position at time t_1 to its position at time t_2 by the area under the corresponding velocity-time graph between t_1 and t_2. [M5.1]

displacement-time graph

for: a particle moving in one dimension

is: a graph of the displacement (from an agreed reference point) of the particle against time. The convention is to plot the displacement vertically and the time horizontally. The gradient of the displacement-time graph is the velocity in that dimension. [P2.1]

dissipation

is: the irreversible loss of energy by a system to its environment as a result of the action of dissipative forces.

dissipative forces

are: forces arising from friction, viscosity or similar effects that cause a reduction in relative motion, and are usually accompanied by the production of heat. [P5.2]

dissociation

is: the process of breaking a molecule (or part of a molecule) into its constituent atoms. [P8.2]

distance

from: one point to another

is: the magnitude of the displacement from the first point to the second. [M4.1]

therefore is: a positive quantity. [P2.1, P2.2]

has as its SI unit: the metre. [P2.2]

See basic coordinate geometry in the Maths handbook.

See also path length.

distance-time graph

is: a graph used in the analysis of one-dimensional linear motion, where the distance of an object from a reference point is plotted against the time. [P2.1]

distant-action force

is: a force that always exists between two particles without their being in contact and regardless of any intervening matter.

is exemplified: by the gravitational force. [P3.1]

distribution

of: values of a given physical quantity x

over: a number of particles or entities.

is: a function $f(x)$ which specifies the fraction of the total number of particles which have values of x lying within the small interval between x and $x + \Delta x$. [M5.4]

is defined: so that this fraction is equal to $f(x)\Delta x$. [M5.4]

divergent (integral)

is: an improper integral with no finite value. [M5.2]

divergent sequence

is: a sequence that does not converge. [M1.7]

divergent series

is: a series that does not converge. [M1.7]

diverging lens

is: a lens which increases the divergence or reduces the convergence of light rays passing through it. [P6.3]

is also called: a concave lens or a negative lens. [P6.3]

divisor

See operation.

domain (of a function)

of: a function

is: the range of values of the independent variable over which the function is defined. [M1.3]

Doppler effect

is: the effect in which the observed frequency of a wave (such as an acoustic wave or an electromagnetic wave) is changed when the source of the wave and the observer are moving with respect to each other. [P5.7]

causes: an increase in the observed frequency of the wave if the source and observer are moving closer together, and a decrease in the observed frequency of the wave if the source and observer are moving apart. [P5.7]

dose equivalent

is: a quantity that quantifies the biological hazard of ionizing radiation [P9.3]

is defined: as the product of the absorbed dose and the appropriate radiation weighting factor. [P9.3]

has as its SI unit: the sievert, Sv. [P9.3]

dot product

See scalar product.

dots (...)

See ellipsis.

double angle formulae

are: a class of trigonometric identities. [M1.6]

See trigonometric functions in the Maths handbook for details.

double bond

is: a chemical bond between two atoms, which is equivalent to two single bonds. [P8.4]

arises: in electronic theories of bonding, from the sharing of two pairs of electrons. [P8.4]

double cone

is: the surface produced by extending to infinity (in both directions) every straight line on the surface of a cone. [M2.3]

double-argument identities

are: members of a class of hyperbolic function identities. [M4.6]

See hyperbolic functions in the Maths handbook.

doublet

in: a line spectrum

consists: of two spectral lines whose wavelengths are almost equal. [P8.2]

arises: when two transitions have almost the same energy difference.

appears: if at all, in each order of diffraction from a diffraction grating (except in the zeroth order). [P8.2]

driven oscillations

describes: the behaviour exhibited by a driven oscillator. [P5.4, P5.5]

driven oscillator

is: an oscillating system that is supplied with energy (continuously or periodically) by an externally applied driving force.

is exemplified: by a mechanical oscillator consisting of a particle of mass m moving in one dimension along the x-axis subject to a restoring force $-kx$ a damping force $-bv_x$ and a driving force $F_0 \sin(\Omega t)$, so that its displacement from equilibrium, x at time t satisfies the equation of motion:

$$m\frac{d^2x}{dt^2} = -kx - b\frac{dx}{dt} + F_0\sin(\Omega t)$$

and consequently will eventually exhibit forced oscillations described by

$$x(t) = A_0 \sin(\Omega t + \phi)$$

where $A_0 = \dfrac{F_0/m}{\sqrt{(\omega_0^2 - \Omega^2)^2 + (\gamma\Omega)^2}}$ and $\phi = \arctan\left(\dfrac{-\gamma\Omega}{\omega_0^2 - \Omega^2}\right)$ with $\omega_0 = \sqrt{k/m}$ and $\gamma = b/m$. [P5.2, P5.3]

is also exemplified: by an electrical oscillator consisting of an inductance L in series with a capacitance C and a resistance R driven by an applied voltage $V_0 \sin(\Omega t)$. In such a system the charge q stored on the capacitor at time t is described by the same equations as the driven mechanical oscillator, subject to the replacement of m, k, b and F_0 by L, $(1/C)$, R and V_0, respectively. [P5.4]

has angular frequency: Ω which is completely independent of the natural frequency ω of the oscillating system in the absence of driving or damping forces. [P5.4]

displays amplitude: A_0, which is generally dependent on the angular frequency (Ω) of the driver and which may exhibit resonance at a particular driving frequency. [P5.4]

driving force

is: one of a trio of forces that determine the behaviour of a driven oscillator: restoring force, damping force and driving force. [P5.2, P5.3, P5.5]

ductile region

is: the part of the loading curve (the graph of stress against strain) of a material over which it exhibits plasticity.

is also called: the plastic region. [P7.6]

dummy variable

is: the variable of integration which is used in a definite integral. [M5.2]

is named: 'dummy' since it does not appear in the final answer, so its identity is unimportant. [M5.2]

more generally is: in a particular calculation, any variable that does not appear in the final result of that calculation.

dynamic equilibrium

is: a state of a multi-member system in which there is no time-dependence in the average properties of the system as a whole, but in which there are changes and fluctuations in the states of the individual members of the system. [P7.6]

dynamic friction

See sliding friction.

dynamics

is: the study of how forces give rise to changes in motion. [P2.3]

Compare with kinematics.

dynamo

is: a device that generates an induced voltage by rotating a coil within a magnetic field. [P4.4]

produces: depending on the arrangement of the connections to the external circuit, an output which may be either a.c. or d.c. An a.c. dynamo is also known as an alternator. [P4.4]

e

is: a numerical constant, whose value to eight decimal places is 2.718 281 83 [M1.5]

can be defined: by

$$e = \lim_{n \to \infty} (1 + 1/n)^n. \quad [M1.5]$$

equivalently can be defined: by

$$e = \lim_{m \to 0} (1 + m)^{1/m}. \quad [M1.5]$$

is the basis: of the exponential function e^x. [M1.5]

is used: as the base of natural logarithms. [M1.5]

is: an irrational number. [M1.5]

Contrast with the (italic) *e* used to represent the charge on the proton.

e

is: the symbol used to represent the electric charge on a proton, one of the fundamental physical constants.

has the value: $1.602 \times 10^{-19}\,\mathrm{C}$, to three decimal places.

is equal in magnitude: to the negative charge carried by the electron. [P3.3]

See quantization of charge.

Contrast with the (non-italic) e used to represent the base of natural logarithms.

Earth satellite

is: any object in orbit around the Earth, whether natural (the Moon) or artificial (e.g. communication or meteorological satellites). [P2.6]

must have: an orbit that is circular or elliptical (to a first approximation). [P2.6]

earth potential

is usually defined: to be at zero potential and is used as a reference potential in conventional circuit measurements. [P4.1]

earthed

describes: a conducting body, or a point on a body, that is connected to the Earth by an electrically conducting pathway. [P4.1]

implies: that the conducting body or point is at earth potential. (The Earth may be regarded as an enormous reservoir of mobile charge at a fixed potential (earth potential), so any conducting body (or point) that is earthed will quickly acquire earth potential.) [P4.1]

earthing

is: the process of connecting a body to the Earth by a conducting pathway so that it is earthed. [P4.1]

allows: charge on a charged conductor to flow to the Earth until the electric potential of the conductor is equal to that of the Earth, i.e. is at earth potential. [P4.1]

is a special case: of charge sharing. [P3.3]

eccentricity

of: a given conic section

is: the ratio of the distance PF from any point P on the conic section to a focus F of the conic section, to the perpendicular distance PD from the point P to the directrix (i.e. e = PF/PD). [M2.3]

is exemplified: by the eccentricity e of an ellipse for which $0 \le e < 1$, and the lengths of the semi-major axis a and the semi-minor axis b are related by $b = a\sqrt{1-e^2}$.

eddy current

is: an induced current which circulates entirely within the body of a conductor. [P4.4]

effective area

of: a (current-carrying) coil of N turns, all in the same plane and each of geometrical area A

is equal: to NA [P4.3]

See magnetic dipole moment.

efficiency

of: a piece of equipment

generally is: the dimensionless ratio of the amount of a physical quantity extracted from the equipment to the amount of the same physical quantity supplied to the equipment.

efficiency (of a heat engine)

is: the ratio of the useful work delivered from the heat engine, to the heat supplied to the heat engine, $\eta = \Delta W/(Q_1 - Q_2)$. [P7.4]

efficiency of a reversible heat engine

operating: between two fixed temperatures T_{hot} and T_{cold}

is: $\eta = 1 - T_{\text{cold}}/T_{\text{hot}}$. [P7.4]

eigenfunction

of: a mathematical operator as used in quantum mechanics.

is: a function $\psi(x)$ which, when operated on by the operator, produces a real number multiplied by $\psi(x)$. The real number is the eigenvalue of the operator. [P10.4, P11.1, P11.2, P11.3]

See eigenvalue, eigenvalue equation and spatial wavefunction.

eigenvalue

of: a mathematical operator as used in quantum mechanics.

is: the real number which appears when the operator acts on one of its eigenfunctions to produce the eigenfunction multiplied by a real number. [P10.4, P11.1, P11.2, P11.3]

See eigenfunction, eigenvalue equation and energy level.

eigenvalue equation

is: an equation in which an operator acts on an eigenfunction to produce the eigenfunction, multiplied by an eigenvalue. That is, for an operator $\hat{\mathrm{O}}$,

$$\hat{\mathrm{O}}f = \lambda f$$

where f is an eigenfunction of $\hat{\mathrm{O}}$, and λ is the eigenvalue of $\hat{\mathrm{O}}$ belonging to the particular eigenfunction. [P10.4, P11.1, P11.2, P11.3]

permits: more than one (and possibly an infinite number) of eigenvalues and eigenfunctions for a given operator. In physical problems $\hat{\mathrm{O}}$ is most commonly a differential operator, but it can take other forms. In quantum physics, f is commonly a spatial wavefunction (i.e. an eigenfunction of the energy operator, the Hamiltonian). [P10.4, P11.1, P11.2, P11.3]

Einstein model

is: a model of the specific heat of a solid.

postulates: that a solid behaves as though composed of independent quantum harmonic oscillators characterized by a common classical frequency. [P11.4]

predicts: that the specific heat will be small near absolute zero. [P11.4]

See Debye model.

Einstein's mass-energy equation

is: the equation, $E = mc^2$, which gives the mass m associated with an amount of energy E, where c is the speed of light in a vacuum. [P2.4, P9.1]

is one of the consequences: of Einstein's special theory of relativity. [P2.4, P9.1]

Einstein's photoelectric equation

is: an equation that relates the maximum kinetic energy of electrons released in the photoelectric effect to the frequency f of the incident light, the work function ϕ of the surface and Planck's constant h:

$$hf - \phi = \tfrac{1}{2} m_{\rm e} v_{\rm max}^2. \quad \text{[P10.1]}$$

Einstein's special theory of relativity

is based: on two postulates:

Postulate 1: The laws of physics can be written in the same form in all inertial frames of reference.

Postulate 2: The speed of light (in a vacuum) has the same constant value, *c* in any inertial frame of reference.

has deep consequences: among which are these:

1. If two spatially separated events are measured as simultaneous in one inertial frame, they will not generally be measured as simultaneous in another inertial frame which is moving relative to the first frame.

2. If a clock is measured as moving in an inertial frame, it will also be measured as running slow (losing time) in that inertial frame.

3. If an object is measured as moving in an inertial frame, it will also be measured as contracted in the direction of its motion in that inertial frame. Moreover, its mass will be measured as greater than if it were at rest.

has been confirmed: repeatedly by experiment.

elastic

describes: the ability of a body to recover fully from a distortion and to store energy (as strain potential energy) while distorted, so long as it is not strained beyond its elastic limit. [P2.4, P5.2, P5.7]

elastic body

is: a deformable body that returns to its original shape when the cause of any deformation is removed, unless the amount of deformation exceeds the elastic limit of the body. [P2.4]

elastic collision

is: a collision during which the total kinetic energy of the system of interacting bodies is conserved. [P2.4, P2.5]

elastic limit

of: an elastic body.

is: the maximum change in length under which the body still obeys Hooke's law. [P2.3]

is also: the maximum stress that a solid can sustain without undergoing permanent deformation. [P7.6]

equivalently is: the point on the loading curve which marks the end of the elastic region and the start of the plastic region. [P7.6]

is also called: the yield point. [P7.6]

elastic material

is: a material which fully recovers its previous physical and mechanical state, with zero strain, when the stress is removed. [P7.6]

elastic modulus

See modulus of elasticity.

elastic region

is: the part of the loading curve of a material, over which the material behaves as an elastic material. [P7.6]

extends: from zero stress to the elastic limit or yield point. [P7.6]

electric cell

is: a device essentially consisting of two dissimilar electrodes dipping into an electrolyte solution. Chemical reactions between the electrodes and electrolyte produce ions. When the cell is connected to an external circuit, there is a flow of charge within the electrolyte and around the external circuit, i.e. the cell is a source of direct current. [P4.5]

electric charge

is: a fundamental property of matter which determines whether or not particles or bodies experience electrical interactions. [P3.3]

is classified: into two types: positive and negative. Charges of the same type repel each other, charges of opposite types attract each other. [P3.3]

is carried: by some fundamental particles, e.g. the electron carries a charge of $-e$, the proton a charge of $+e$. Some others carry none, e.g. the neutron is uncharged. [P3.3]

has as its SI unit: the coulomb (C), where 1 C = 1 A s (i.e. 1 ampere second).

See quantization of charge.

electric current

through: a surface

is: the rate dq/dt at which (net) charge q is transferred across that surface. [P4.1, P5.5]

is due: in metallic conductors, to the movement of electrons. In other media, it can be due to the movement of other charged particles (e.g. ions in solution). [P4.1]

has direction: which is defined conventionally as the direction in which positive charge would move, though in many cases the current is actually a flow of negatively-charged particles in the opposite direction. [P4.1]

has as its SI unit: the ampere (A). [P4.1]

electric dipole

consists: of equal and opposite electric charges $+q$ and $-q$ separated by a distance d [P3.3]

can be found: in molecules containing a variety of atoms, where the electrons forming the bonds between atoms of different chemical elements are not shared equally between the two atoms involved. The result is equivalent to a dipole, in which one atom has a slight positive charge and the other a slight negative charge. [P3.3]

See electric dipole moment. [P3.3]

electric dipole moment

is: the product of the charge magnitude and charge separation in an electric dipole. For a dipole consisting of charges $+q$ and $-q$ separated by a distance d, the dipole moment is qd. [P3.3]

is strictly: a vector quantity whose magnitude is as defined above, and whose direction is the same as for the displacement from the negative to the positive charge.

electric field

throughout: a region of space

is: a vector field that gives rise to an electrical force on a test charge placed at any point in the region. [P3.1]

is defined: at any point specified by a position vector $\boldsymbol{r}$, as the electrostatic force per unit positive charge that would act on a test charge placed at that point. So, generally,

$$\boldsymbol{E}(\boldsymbol{r}) = \frac{\boldsymbol{F}_{\rm el}(\text{on } q \text{ at } \boldsymbol{r})}{q}$$

whether the test charge q is positive or negative. [P3.1, P3.2]

is related: to the electric potential by the requirement that it points in the direction of most rapid decrease of the potential, and has a magnitude given at every point by the magnitude of the rate of change of the potential in that direction (e.g. in the radial direction from an isolated point charge, so that $E_r = -dV_{\rm el}/dr$). It therefore always points in a direction at right angles to lines or surfaces of equal potential, and from high potential towards low potential. [P3.1, P3.3]

has as its SI unit: the newton per coulomb ($\rm N\,C^{-1}$) or, equivalently, the volt per metre ($\rm V\,m^{-1}$). [P3.1, P3.3]

electric field lines

are: a means of representing an electric field. [P3.3]

are drawn: so that at any point the tangent to the line represents the direction of the field at that point. [P3.3]

therefore are directed: away from a positive charge and towards a negative charge. [P3.3]

have spacing: which is related to the electric field strength, i.e. where the lines are close together the field is strong and where they are further apart the field is weaker. [P3.3]

always cut: equipotential surfaces at right angles. Where these are closest together, their rate of change is greatest, and so there the electric field is strongest. [P3.1, P3.3]

electric field strength

at: any point

is: the magnitude of the electric field at that point. [P3.1]

electric potential

at: a given point in space

is: the electric potential energy per unit positive charge at that point. [P3.1, P3.3]

is also: the electric potential difference (i.e. voltage difference) between the given point and a point at which the electric potential energy is defined to be zero. In an electrical circuit the earth, or the negative terminal of a power supply, is usually taken to be at zero potential. [P3.1, P3.3]

has as its SI unit: the volt, (V). [P4.1]

electric potential difference

between: point A and point B in an electric field

is: the difference $V_B - V_A$, in electric potential energy per unit positive charge between the two points (i.e. $\Delta V_{el} = \Delta E_{el}/q$). [P2.6, P4.1]

is therefore: the negative of the work done per unit charge by an electric field when a unit charge is moved from A to B. [M2.6]

is also called: voltage difference. [P4.1]

has as its SI unit: the volt, (V), where $1\,V = 1\,J\,C^{-1}$ (i.e. 1 joule per coulomb). [P4.1]

electric potential energy

is: the energy a charged particle has by virtue of its position in an electric field. [P3.1, P3.3, P4.1]

requires for its full definition: a position of zero electric potential energy to be arbitrarily chosen, since only differences in electric potential energy are physically meaningful. [P3.1, P3.3]

changes: in going from point A to point B, by an amount equal to the negative of the work done by the electric field when the charged particle is moved from A to B. [P3.1]

is exemplified: by the electric potential energy of a particle of charge q_2 in the electric field of a particle of charge q_1, when the distance between the two particles is d. Subject to the conventional choice that $E_{\rm el} = 0$ when $r \to \infty$, this is given by

$$E_{\rm el} = \frac{q_1 q_2}{4\pi\varepsilon r}$$

where ε is the permittivity of the medium between the charges. [P3.1, P3.3]

is related: to the electric potential $V_{\rm el}$ in a region by $E_{\rm el} = qV_{\rm el}$, so when a charge q moves through a voltage difference (i.e. an electric potential difference) $\Delta V_{\rm el}$, the change in electric potential energy $\Delta E_{\rm el}$, is given by $\Delta E_{\rm el} = q\Delta V_{\rm el}$. [P4.1]

often is referred: to as 'electrical energy' or electrostatic potential energy. [P3.1, P3.3]

has as its SI unit: the joule (J).

electrical

means: pertaining to electricity.

See also electrostatics and electromagnetism.

electrical breakdown

in: an electrical insulator which is subjected to an electric field above a certain threshold

occurs: when some of the electrons become detached from their parent atoms and flow through the material – which thus becomes, temporarily, an electrical conductor. [P3.3]

electrical components

is: a general term for electrical devices, particularly those that are used in circuits.

electrical conductor

is: a material containing an abundance of mobile charged particles that are free to move throughout the whole of the material. [P3.3, P4.1]

has: a low resistivity. [P4.1]

has typically: in terms of the band theory of solids, a partly filled valence band at absolute zero. [P11.4]

is exemplified: by any metal. [P3.3, P4.1, P11.4]

is the opposite: of an electrical insulator. [P3.3, P11.4]

electrical energy

is: energy supplied by an electrical power supply.

See also electric potential energy.

electrical insulator

is: a material containing a negligible number of mobile charged particles. [P3.3, P4.1]

has: an extremely high resistivity. [P4.1]

has typically: in terms of the band theory of solids, an empty conduction band separated by a substantial gap (e.g. 5 eV) from a full valence band at absolute zero. [P11.4]

is the opposite: of an electrical conductor. [P3.3]

can be used: to prevent the flow of current between points at different potential. [P4.1]

See also electrical breakdown.

electrical interaction

See electromagnetic interaction.

electrical oscillator

is essentially: an inductor connected across a capacitor to form a simple circuit in which charge stored on the capacitor may oscillate, possibly also containing a resistor (to provide damping) and possibly subject to an externally supplied voltage to make it a driven oscillator.

See simple harmonic oscillator, damped electrical oscillator, driven oscillator, as appropriate.

electricity

is: a general term for electric charge, whether static or moving, as in an electric current.

electrochemical series

is: a listing of chemical elements in order of their electrode potential. The further apart two elements are in the series, the greater is the open circuit voltage (e.m.f.) produced when they form the two electrodes in a simple electric cell. The element with the greater (more positive) electrode potential forms the positive terminal of the cell. [P4.5]

electrode

is: an electrically conducting structure used to emit or collect charge, often (though not always) a metal plate or grid.

electrode potential (of an element)

is: the open circuit voltage (e.m.f.) obtained by using the element to make one terminal of an electric cell, whose other terminal is a hydrogen electrode. The (theoretical) magnitude of the open circuit voltage (e.m.f.) of any simple cell is found by subtracting the two electrode potentials one from the other. [P4.5]

electrolyte

is: a substance, usually in the form of a solution, which allows the conduction of electricity by the movement of positive and negative ions.   [P4.5]

electrolytic capacitor

is: a capacitor whose plates are made from two different materials separated by an electrolyte.

must be connected: the correct way round in a d.c. circuit. [P4.5]

electromagnet

is: a coil or solenoid would around a core of ferromagnetic material and which then exhibits strong magnetic induction when a current flows. [P4.2]

electromagnetic force

is: the total force on a charged particle in an electric field and/or magnetic field, found by adding the separate electrostatic force and magnetic force that would be produced by each field acting independently. [P4.3]

is described: by the Lorentz force law.

$$\boldsymbol{F} = q(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B}).$$ [P4.3]

is also called: the Lorentz force. [P4.3]

arises: from the electromagnetic interaction, one of the four known fundamental interactions in nature. [P9.2]

electromagnetic induction

is: the phenomenon that results in the production of an induced voltage in a conductor by changing a magnetic field near the conductor, or by moving the conductor within a magnetic field (motional induction). [P4.4]

See Faraday's law and Lenz's law.

electromagnetic interaction

is: the fundamental interaction that gives rise to electromagnetic force. [P9.2]

comprises: together with the weak, strong and gravitational interactions, the four known fundamental interactions of nature. [P9.2]

See gravitational force, strong nuclear force, weak nuclear force.

electromagnetic pick-up

is: the induced voltage caused in a circuit by magnetic field fluctuations near the circuit. [P4.4]

electromagnetic radiation

is: radiation consisting of fluctuating electric and magnetic fields that can propagate through space, or through suitable media, as electromagnetic waves characterized by a wavelength λ and a frequency f. Many aspects of the interaction of electromagnetic radiation with matter require the use of quantum theory for their accurate description.

is exemplified: by familiar phenomena such as visible light, radio waves and X-rays, which are all parts of the electromagnetic spectrum, corresponding to different wavelengths of electromagnetic radiation.

can transfer: energy and momentum. [P7.3]

See radiation pressure.

electromagnetic spectrum

is: the complete range of electromagnetic waves. [P6.1, P7.3]

extends: from long-wavelength radio waves, through microwaves, infrared, visible light, ultraviolet and X-rays to short-wavelength γ-rays. [P6.1, P7.3]

electromagnetic wave

is: a pattern of mutually perpendicular, oscillating electric and magnetic fields that can travel through a vacuum at the speed of light, c. [P6.1]

is a form: of transverse wave. [P6.1]

is characterized: in the simplest case (a linearly polarized, monochromatic, plane wave), by its direction of propagation, plane of polarization, amplitude, wavelength and frequency. (In a vacuum the wavelength and frequency are related by $c = f\lambda$). [P6.1]

has speed: c/μ in materials other than a vacuum, where μ is the refractive index of the material. [P6.1]

electromagnetism

is: the branch of physics that encompasses all electrical and magnetic phenomena, including the interactions of charges and magnets with electric and magnetic fields and the production and propagation of electromagnetic waves. [P4.2]

electromotive force (e.m.f.)

is: an alternative term for the open circuit voltage of a voltage generator. [P4.1]

is not: a force in the sense defined by Newton's second law.

electron

is: an elementary particle that is a constituent of every atom. [P3.3, P8.1]

has: charge $-e = -1.602 \times 10^{-19}$ C and mass $m = 9.109\,56 \times 10^{-31}$ kg, approximately 1/1836 times the mass of a proton. [P3.3, P8.1]

is liberated: from atoms when the atoms are ionized in a discharge tube, as deduced by its discoverer J.J. Thomson (1856-1940). [P8.1]

has: no known internal structure at the time of this writing. [P8.1]

electron antineutrino

is: an elementary particle, the antiparticle of the electron neutrino. [P9.2]

always accompanies: the electron emitted in β^--decay. [P9.2]

electron band

See energy band.

electron cloud

in: the quantum model of the atom

is: the concept that replaces the electron orbits of more primitive models, such as the Bohr model.

has: for a given stationary state of the atom, a density at every point that is proportional to the probability density $|\,\Psi(r,\,\theta,\,\phi)\,|^2$ of the associated wavefunction. [P11.3]

electron diffraction

is: the diffraction of electrons by a regular array of atoms (as in a crystal). [P7.1]

is a consequence: of the wave-like behaviour of electrons, as described by quantum physics. [P7.1]

results in: a diffraction pattern with sharp local maxima of intensity in directions determined by Bragg's law. [P7.1]

See de Broglie wave.

electron microscope

is: a microscope that uses the (short wavelength) wave-like behaviour of beams of electrons to produce images with much better resolution than those possible with optical microscopes. [P7.1]

electron neutrino

is: an elementary particle that has zero charge and such a small mass (if any) that it is currently indistinguishable from zero.

always accompanies: the positron which is emitted in β^+-decay. [P9.2]

electron pair

is: two electrons that occupy the same quantum state apart from having opposed spins.

electron shell

See shell.

electron spin

is: the intrinsic angular momentum of an electron. [P8.3]

is described: by an electron spin quantum number s = 1/2 and hence permits two possible values for the spin magnetic quantum number, m_s = 1/2 or $m_s = -1/2$, implying that the z-component of the spin must be either $+\hbar/2$ or $-\hbar/2$ when measured along an arbitrarily chosen z-axis. [P8.3]

creates: electron spin magnetism. [P4.2]

helps to account: for the magnetic properties of the electron and those of atoms that contain unpaired electrons. [P8.3]

electron spin magnetism

is: an intrinsic property of an electron (like electric charge), such that the electron behaves as a magnet with a measurable magnetic dipole moment.
[P4.2]

electron subshell

See subshell.

electron tunnelling

is: a special case of quantum tunnelling, in which an electron tunnels through a potential barrier whose height exceeds the total energy of the electron. [P10.4]

is important: in various electronic devices, including the tunnel diode.

electronegativity

is: a numerical measure of the ability of an atom to attract electrons to itself during chemical reactions. [P8.4]

is highest: (~4.0) in the region of the periodic table occupied by fluorine and chlorine. [P8.4]

electronic configuration

is: a description of the distribution of electrons within shells and subshells in an atom, using the quantum numbers that describe the quantum states of the electrons. [P8.3, P8.4]

often is presented: in shorthand form using the s-p-d-f notation for subshells. For example, the ground state configuration of sodium is represented as $1s^2 2s^2 2p^6 3s^1$, meaning that

- in the n = 1 shell (the lowest-energy shell, closest to the nucleus), there are two electrons in the s subshell (the subshell in which (l = 0)). This subshell is full.
- in the n = 2 shell, there are two electrons in the s subshell (l = 0)
- in the n = 2 shell, there are six electrons in the p subshell (l = 1)
- in the n = 3 shell, there is one electron in the s subshell (l = 0) [P8.3, P8.4]

electronic structure

is: a synonym for electronic configuration. [P8.3]

electronvolt, eV

is: a non-SI unit of energy.

is defined: as the kinetic energy gained by an electron when it is accelerated through a potential difference of 1 volt. [P8.3, P9.1]

is equal: to 1.602×10^{-19} J (to four significant figures). [P3.3]

is commonly used: in large multiples such as MeV ($1\,\mathrm{MeV} = 10^6\,\mathrm{eV}$) and GeV ($1\,\mathrm{GeV} = 10^9\,\mathrm{eV}$) in nuclear physics and elementary particle physics. [P9.1]

electrostatic constant

is: the physical constant $1/(4\pi\varepsilon_0)$ that appears in Coulomb's law. [P3.1]

has the value: $1/(4\pi\varepsilon_0) = 8.988 \times 10^9\,\mathrm{N\,m^2\,C^{-2}}$ (to four significant figures). [P3.1]

See Coulomb's law, permittivity of free space (ε_0) [P3.1]

electrostatic force

is: the force that acts on a charged body due to its location in a static electric field. For a test charge q located at a point with position vector $\boldsymbol{r}$, where the electric field is $\boldsymbol{E}(\boldsymbol{r})$, the electrostatic force is

$$\boldsymbol{F}_{\rm el}(\text{on } q \text{ at } \boldsymbol{r}) = q\boldsymbol{E}(\boldsymbol{r}).$$ [P3.3]

is exemplified: by the force (described by Coulomb's law) that one charged particle exerts on another by virtue of the electric field that it creates. Two particles with charge of the same sign repel one another, and two particles with charge of the opposite sign attract one another. [P3.1]

is given: for a positive unit charge by the negative derivative of electric potential energy in the direction of maximum change (e.g. in the radial direction from an isolated point charge, $F_r = -dE_{\rm el}/dr$). [P3.1, P3.3]

electrostatic induction

is: the process by which a region of an initially uncharged object can become charged due to the influence of an electric field (usually due to another charged object) which causes a rearrangement of charge on the original object. [P3.3]

electrostatic potential energy

See electric potential energy.

electrostatic screening

is created: by a perfectly conducting shell containing no free charges. [P3.3]

ensures: that no electric field can exist inside the shell. [P3.3]

electrostatics

is: the study of the electrical interaction between charged particles which are not moving in relation to one another, or in relation to the observer. [P3.3]

element

is: a small part of something, often of a given solid body, or a volume of fluid. For example, a body of mass M may be considered to be composed of many separate elements of mass Δm_i such that $\sum_i \Delta m_i = M$.

element (chemical)

See chemical element.

element (of a set)

is: an entity that is a member of a set.

element of integration

is: an infinitesimal increment in the variable with respect to which an integration is to be performed. [M5.1, M5.2]

is exemplified: by the *dx* which appears at the end of the definite integral $\int_a^b f(x)\,dx$. [M5.1, M5.2]

elementary entity

See mole.

elementary functions

are: a slightly ill-defined class of functions including the common (and 'uncomplicated') functions, such as sine, logarithm and arctangent. [M1.7]

See the Maths handbook, which includes graphs of many of these functions.

elementary particles

are: subatomic particles believed, or formerly believed, not to have any constituents. Examples include electrons, protons, neutrons and photons. It is now widely believed that protons and neutrons are in fact composed of constituents called quarks, and a modern listing of 'truly' elementary particles would consist of three families: the leptons (including the electron), the quarks (including the charged constituents of many other 'elementary particles'), and the exchange particles (including the photon and the various other particles that are responsible for the fundamental interactions between quarks and leptons).

elimination (of a variable)

is: the process of manipulating given equations to obtain an equation which does not involve the specified variable, especially in the context of simultaneous linear equations. [M1.4]

is exemplified: by eliminating y between the equations $x + y = 1$ and $x - y = 2$ to yield $2x = 3$. [M1.4]

ellipse

is: a conic section shaped like a flattened circle, that may be described by an equation of the form

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1, \text{ where } b = a\sqrt{1 - e^2} \text{ with } 0 \le e < 1,$$

the longest diameter of which ($2a$) is called the major axis, and the shortest diameter of which ($2b$) is called the minor axis.   [M2.3, P3.2]

See conic sections in the Maths handbook for further details.

ellipsis

consists: of three dots, thus ...

is often used: to indicate that an expression or sequence continues in a similar fashion, as in 1, 2, 3, 4, ... [M1.1, M2.3, P3.2]

emission

of: electromagnetic radiation

is: the outcome of any process whereby the internal energy of a system is wholly or partly transformed into energy carried away by electromagnetic radiation.

should be contrasted: with absorption and reflection.

more generally, is: the process of giving out.

emission lines

are: characteristic frequencies or wavelengths that are particularly prominent in an emission spectrum. [P8.2]

correspond individually: to the radiation emitted in a transition between two bound states of an atom or molecule. [P8.2]

emission line spectrum

is: an emission spectrum consisting of emission lines. [P8.2]

emission spectrum

of: electromagnetic radiation (usually emitted from a specified source)

is: the distribution of spectral brightness with respect to the wavelength or frequency of the radiation.

shows: the set of wavelengths at which the excited atoms or molecules in the source emit radiation. [P8.2]

may consist: of characteristic emission lines (in which case the spectrum is referred to as the emission line spectrum). [P8.2]

emission transition

in: the Bohr model for atomic hydrogen

occurs: when the electron moves from one bound state to another bound state of lower energy. [P8.2]

gives rise: to emitted electromagnetic radiation whose frequency is given by the Planck-Einstein formula. [P8.2]

is more generally: any transition between different quantum states that results in the emission of radiation.

emissivity

of: a surface

is: a constant $\varepsilon \leq 1$, which is introduced into Planck's function for the spectral brightness of a black body in order that it should more closely represent the spectrum of radiation coming from the surface. [P7.3]

is useful: only over a specified range of wavelengths. [P7.3]

empirical

means: based on experiment and/or observation.

emulsion

is: the thin layer on a photographic film which contains the light sensitive material used to record optical images in a camera. [P6.4]

energy

of: a body or system

is: a measure of its capacity to do work. [P2.4]

can exist: in several different forms. The energy that a body has because of its motion is called its kinetic energy (see also rotational, translational and vibrational kinetic energy); while energy arising from its position in relation to other bodies with which it is interacting or from its internal configuration is called its potential energy (see also electrical, gravitational and strain potential energy). [P2.4, P2.5]

is sometimes named: to reflect the situation in which it arises, e.g. mechanical energy, acoustic energy, heat and mass energy.

remains: for an isolated system, constant in sum over all its different forms, according to the principle of conservation of energy (see also first law of thermodynamics). [P2.4, P2.5]

may be converted: from one form into another, subject to various limitations (see also second law of thermodynamics). [P2.4, P2.5]

is: a scalar quantity, with dimensions $\mathrm{M\,L^2\,T^{-2}}$. [P2.5]

has as its SI unit: the joule (J), where $1\,\mathrm{J} = 1\,\mathrm{N\,m} = 1\,\mathrm{kg\,m^2\,s^{-2}}$. [P2.4. P2.5]

See also equipartition of energy and internal energy.

energy band

for: electrons (or other charged particles)

in: a solid

is: a set of narrowly separated energy levels that the electrons (or other charged particles) may occupy. (Note that the energy bands are a property of the solid as a whole, not of the individual atoms within the solid.) [P11.4]

is formed: from an energy level for the electrons in individual atoms, which becomes split and broadened by the influence of other nearby atoms in the solid. [P11.4]

is usually separated: from other bands, just as the individual electron energy level from which it is derived is separated from other energy levels (though it is also possible for different bands to overlap). [P11.4]

See also, band theory, conduction band and valence band.

energy density

is: stored energy per unit volume of a medium. [P4.5]

is given by: $\varepsilon_0\varepsilon_r E^2/2$, in an electric field of magnitude E, where ε_0 is the permittivity of free space and ε_r is the relative permittivity of the medium in which the field is present. [P4.5]

is given by: $B^2/(2\mu_0\mu_r)$, in a magnetic field of magnitude B where μ_0 is the permeability of free space, and μ_r is the relative permeability of the medium in which the field is present. [P4.5]

energy level

of: a system

in: a bound system, for example, in an atom or nucleus

and, furthermore, in: a quantum state of the bound system

is: one of several energies which the particle can have, and which appear as energy eigenvalues of the time-independent Schrödinger equation. [P8.2, P10.3, P10.4]

is also: according to quantum mechanics, a discrete value of energy, so long as the particle is in a bound state. If the particle can occupy the level for only a very short length of time, the Heisenberg uncertainty principle implies a spread in the measured values of the level's energy, but the energy level remains discrete. [P8.4, P10.2, P10.3]

conventionally is: negative; the configuration of zero potential energy being chosen so that the particle's negative potential energy outweighs its positive kinetic energy. [P10.3]

always includes: non-zero kinetic energy, even at the lowest of energy levels: according to quantum mechanics, a particle confined can never be still (see zero point energy). [P8.4]

will be: degenerate if more than one quantum state of the system corresponds to the energy of the level.

energy level diagram

for: a particle in a bound system, such as an atom or nucleus

shows: all the (conventionally) negative energy levels corresponding to bound states of the system, extending from the ground level to the ionization level, each one characterized by the quantum numbers of the state (or states if the energy level is degenerate). [P8.2, P9.2]

also shows: above the ionization level, the continuum of (conventionally) positive energy levels corresponding to the unbound states, in which the particle is free from the rest of the system. [P8.2, P9.2]

enlarged

means: made larger — as for an image formed by a lens or a mirror, when the image is larger than the object. [P6.3]

entrance pupil

is: the image of the aperture stop of an optical system, formed by all the lenses which precede it. [P6.4]

entropy

of: a system

is: a function of its state. [P7.4]

requires for its full definition: a state of fixed entropy to be arbitrarily chosen, since only differences in entropy are physically meaningful.

changes: in going from a state *a* to a state *b* when *a* and *b* are linked by a reversible isothermal process involving heat transfer $\Delta Q_{\rm rev}$ at temperature T by the amount $\Delta S = \dfrac{\Delta Q_{\rm rev}}{T}$. [P7.4]

more generally differs: between two states *a* and *b* which are linked by an arbitrary reversible process, by the amount $\Delta S = S_{\rm b} - S_{\rm a} = \displaystyle\int_{\rm a}^{\rm b} \frac{dQ}{T}$ where the integral is evaluated over the reversible process. (This remains true even if the state is changed from *a* to *b* by some other process.) [P7.4]

is exemplified: by the entropy of n moles of ideal gas at temperature T and occupying volume V:

$$S = \frac{3nR}{2}\log_{\rm e}\left(\frac{T}{T_0}\right) + nR\log_{\rm e}\left(\frac{V}{V_0}\right) + S_0$$

where R is the molar gas constant and S_0 is the entropy arbitrarily assigned to a state with temperature T_0 and volume V_0. [P7.4]

provides: a measure of the extent to which energy transferred in the process is **not** available to do useful work. [P7.4]

in effect is: a measure of disorder. [P7.4]

has as its SI unit: $\rm J\,K^{-1}$. [P7.4]

See also second law of thermodynamics and principle of entropy increase.

envelope

of: a wave group

is: a curve or surface serving to characterize the group by moving with the group speed, and modulating the amplitudes of the individual waves that make up the group, as they move through the group at their individual phase speeds.

environment

is: that part of the Universe which does *not* constitute the system being studied. [P7.3, P7.4]

equating real and imaginary parts

is: a procedure which allows an equation involving complex numbers to be rewritten as two equations involving only real numbers. The procedure consists of equating the real parts of the expressions on either side of the equality, and then equating the imaginary parts. [M3.1]

equation

is: an equality between two algebraic expressions. [M1.1]

See also solution and identity.

equation of a circle

of: radius R

centred: on the origin

is: $x^2 + y^2 = R^2$. [M2.2]

See conic sections in the Maths handbook.

equation of a line in three dimensions

in: a three-dimensional system of Cartesian coordinates

is: $\dfrac{x-a}{l}=\dfrac{y-b}{m}=\dfrac{z-c}{n}$ where (a, b, c) are the coordinates of a point on the line, and the constants l, m, n determine the direction of the line. [M2.2]

equation of a plane

in: a three-dimensional system of Cartesian coordinates

is: $ax + by + cz = d$, where a, b, c and d are constants. [M2.2]

equation of a straight line

in: standard form

is: $y = mx + c$ where m is the gradient (or slope) of the straight line and c is the intercept on the y-axis. [M2.2, M1.3, P1.3]

also can be written: in the form $ax + by + c = 0$. [M2.2]

equation of motion

is: an equation that expresses (explicitly or implicitly) the position of a moving object as a function of time. Such equations often take the form of differential equations and are usually obtained from Newton's second law of motion.
[M6.1]

equation of state

for: any substance

is: an equation (usually an approximation) which relates the mass m or number of moles n of a fixed quantity of the substance to its volume V, pressure P, and temperature T (and/or any other relevant thermodynamic coordinates). [P7.2]

is exemplified: by the equation of state of an ideal gas, $PV = nRT$. [P7.2]

equation of state of an ideal gas

is: the equation $PV = nRT$, which relates the number n of moles, the volume V, the pressure P and the temperature T of a sample of ideal gas, where $R = 8.314\,\mathrm{J\,K^{-1}\,mol^{-1}}$ is the molar gas constant. [P7.2, P7.3, P7.4]

is also known: as the ideal gas law, and may be written in a variety of ways. A particularly common form is $PV = NkT$, where N is the number of molecules in the sample and $k = 1{\cdot}380 \times 10^{-23}\,\mathrm{J\,K^{-1}}$ is Boltzmann's constant. [P7.2, P7.3, P7.4]

equiangular

describes: a polygon when all of its interior angles are equal. [M2.1]

equidistant

describes: two points which are at the same distance from a third. [M2.1]

equilateral

describes: a polygon whose sides are all of the same length. (Used especially in the case of an equilateral triangle.) [M2.1]

equilateral polygon

is: a polygon whose sides are of equal length. [M2.1]

equilateral triangle

is: a triangle with three equal sides, and hence with three equal angles each of 60° (or, equivalently, of $\pi/3$ radians). [M1.6, M2.1]

equilibrium

is: the condition of a system in which its state of motion remains unchanged, i.e. the total linear momentum $\boldsymbol{P}$ and total angular momentum $\boldsymbol{L}$ are constant vectors. [P5.1, P7.3]

See also mechanical equilibrium, translational equilibrium and rotational equilibrium.

equilibrium state

of: a system

is: any state of the system in which it is in equilibrium (stable, unstable or neutral), usually specified in terms of appropriate (thermodynamic) coordinates. [P7.3, P7.4]

is exemplified: by any set of values for n, P, V and T which satisfy the equation of state of an ideal gas. [P7.3, P7.4]

equilibrium surface

See *PVT*-surface.

equilibrium system

is: a system in an equilibrium state.

equipartition of energy theorem

is: a theorem of classical statistical mechanics which relates the average microscopic internal energy of a system $\langle E_{\text{int}} \rangle$ to the temperature via the number of degrees of freedom present in the system.

states that: if there are f degrees of freedom, then the mean internal energy per molecule will be given by $\langle E_{\text{int}} \rangle = fkT/2$, where T is the absolute temperature, and k is Boltzmann's constant. [P7.5]

equipotential contour

of: a specified potential

is: a curve passing only through points at which the specified potential has the same (arbitrarily chosen) value. [P3.1]

has the property: that at any point it is at right angles to the field associated with the potential. [P3.1]

usually is drawn: so that the potential changes by a fixed amount between consecutive equipotential contours. This means that consecutive contours are close together where the field is strong. [P3.1]

often is abbreviated: to 'equipotential'. [P3.1]

equipotential line

See equipotential contour.

equipotential surface

of: a specified potential

is: a surface passing only through points at which the specified potential has the same (arbitrarily chosen) value. [P3.1, P3.3]

has the property: that at any point it is perpendicular to the field associated with the potential. [P3.1, P3.3]

usually is drawn: so that the potential changes by a fixed amount between consecutive equipotential surfaces. This means that consecutive surfaces are close together where the field is strong. [P3.1, P3.3]

often is abbreviated: to 'equipotential'. [P3.1]

equivalent circuit

is: a circuit which produces identical effects to a circuit which it has replaced. [P4.1]

can be used: as an aid to circuit analysis. [P4.1]

erect (image)

means: upright – as for an image formed by a lens or a mirror, when the image is the same way up as the object. [P6.2, P6.3]

Contrast with inverted image.

erecting prism

is: a prism used to invert an already inverted image in an optical system and so make it erect. [P6.4]

error (of observation)

See uncertainty.

error bar

consists: of lines drawn on both sides of a point on a graph, to indicate the size of the experimental error on that point. Lines drawn parallel to the *x*-axis show the size of the uncertainty in the *x*-coordinate; lines drawn parallel to the *y*-axis show the size of the uncertainty in the *y*-coordinate. [P1.3]

error function

is: a function that arises in various contexts, including the analysis of normally distributed (Gaussian) errors.

is defined: by $\operatorname{erf}(x) = \dfrac{2}{\sqrt{\pi}} \displaystyle\int_0^x \exp(-y^2/2)\,dy$. [M5.5]

escape speed

is: the minimum speed which must be given to a projectile for it to completely escape from the gravitational force of the Earth. [P2.4, P3.2]

is given: by $v_{\rm es} = \sqrt{\dfrac{2GM_{\rm E}}{R_{\rm E}}}$

where $M_{\rm E}$ is the mass of the Earth, $R_{\rm E}$ its radius and G is Newton's universal gravitational constant. [P2.4, P3.2]

essential constants

are: independent arbitrary constants which appear in the general solution of a differential equation. [M6.1]

Euler's formula

is: an important relationship between the exponential, sine and cosine functions: $e^{i\theta} = \cos(\theta) + i\sin(\theta)$, where $i^2 = -1$. [M3.2, P5.5]

evaporation

is: a process whereby liquid is converted into gas (or more properly vapour) at a temperature below the boiling point.

involves: the escape of those molecules with above average kinetic energy from the liquid and therefore results in the cooling of the liquid.

is balanced: in a closed vessel containing liquid and vapour in equilibrium, by condensation.

even (function)

is: a function $f(x)$ such that $f(-x) = f(x)$. [M1.6, M4.4, M5.2, P11.2]

event

in: Einstein's special theory of relativity

is: an idealized occurrence at a point in space and an instant of time, and may therefore be located in an appropriate frame of reference by means of four coordinates (x, y, z, t).

exchange particles

See elementary particles.

excitation

is: the process whereby the electron in an atom is given additional energy and so moves to a bound state of higher energy. The additional energy may be provided by incoming radiation, by heating or via collisions with other particles, such as electrons. [P8.2]

excited level

is: the energy level corresponding to each excited state for an electron in an atom. [P8.2]

equivalently is: an energy level other than the ground level. [P10.3]

excited state

of: an electron

in: an atom or some other bound system

is: any bound state, other than the ground state, for the electron. [P8.2, P8.3]

equivalently is: a state of the system in which the energy corresponds to an excited level. [P10.3]

excluded volume

is: the volume occupied by a gas but from which molecules are excluded by virtue of their individual volumes. [P7.5]

exit pupil

is: the image of the aperture stop in an optical system, formed by all the lenses which follow it. [P6.4]

expansion

is: the process of making something larger in size.

expand (an expression)

of: an expression that involves brackets

describes: the process of finding an equivalent expression with fewer brackets. [M1.1]

experiment

A planned investigation of natural phenomena, usually involving equipment, under conditions that are to some extent determined by the investigator.

See also experimental data.

experimental data

consists: of observations, particularly numerical measurements, which have been obtained in an experiment. [P1.1]

exponent

is: a superscript following a number or expression that indicates repeated multiplication (if the exponent is a positive integer) or some related operation in other cases. [M1.5]

See arithmetic and algebra in the Maths handbook.

exponential change

describes: any process in which a quantity exhibits exponential growth or exponential decay. If q is such a quantity, then $q = q_0\,e^{kt}$ where q_0 is a constant, t is an independent variable (e.g. time) and k is a positive or negative constant according to whether q is growing or decaying. [M1.5]

is exemplified: by the change in an investment when the interest is compounded continuously as can be seen from the equation
$e^{kt} = \lim\limits_{m\to 0}(1+m)^{kt/m}$. [M1.5]

exponential decay

describes: an exponential change in which the changing quantity decreases with time. [M1.5]

is exemplified: by the radioactive decay law $N = N_0 e^{-\lambda t}$

exponential form (of a complex number)

represents: a complex number as $z = r\,e^{i\theta}$ where r and θ are real. r is known as the modulus of z and is usually written as $|z|$, while θ is known as the argument of z and usually is written as arg(z). Adding an integer multiple of 2π to θ leaves the value of $r\,e^{i\theta}$ unchanged, so the arguments of a given complex number has infinitely many possible values. The unique value that satisfies the restriction $-\pi < \theta \le \pi$ is called the principal value of the argument. [M3.2, P5.5]

Compare and contrast with Cartesian form and polar form, and see complex numbers in the Maths handbook for the relationship between them.

exponential function

is: the function $\exp(x) = e^x$. [M1.5]

has the general feature: the bigger it is, the faster it grows (or shrinks). [M1.5]

more specifically, has: the property of being its own derivative, which makes it especially useful for doing calculus with exponential functions and logarithms. [M1.5]

sometimes refers: to the function $f(x) = a^x$, which is related to the function $\exp(x) = e^x$ by:

$$a^x = \exp(x \log_e(a))$$ [M1.5]

exponential growth

describes: an exponential change in which the changing quantity increases with time. [M1.5]

exponential law

is: any equation relating two quantities, x and y, that may be written in the form $y = k\,a^x$, where k is any constant and a is any positive constant. (Often a = e). [M1.5, P1.3]

exponential representation (of a complex number)

See exponential form (of a complex number).

exposure

is: a measure of the total light energy reaching a photographic film or emulsion. [P6.4]

determines: the imaging response of the film or emulsion. [P6.4]

exposure time

is: the time interval over which a photographic film or emulsion is exposed to light. [P6.4]

expression

is: a combination of numbers and algebraic symbols. [M1.1]

may be: the sum of several terms, or may be a single number or symbol. [M1.1]

extended body

is: a body for which the size and shape are important. [P2.8]

extended image

is: an image with a finite size in an optical system, being an image of an extended object.

is usually shown: on a ray diagram as a directed line segment drawn at right angles to the optical axis. [P6.3]

extended object

is: an object which has a finite size in an optical system, as opposed to being a point object. Any actual object is an extended object. [P6.2]

is usually shown: on a ray diagram as a directed line segment drawn at right angles to the optical axis. [P6.3]

extension

is: a quantity that describes the displacement of the mobile end of a spring or some other elastic body from its natural (unextended) position. [P2.4]

exterior angle

is: the angle between a side of a polygon and an adjacent side produced. [M2.1]

external force

is: a force whose source lies outside the system being considered. [P2.5]

is given: by the rate of change of linear momentum of the system. [P2.5]

extrapolation

is: the process of using values of a dependent variable, measured over a finite range of the corresponding independent variable(s), to estimate the value of the dependent variable corresponding to a value of the independent variable(s) that falls outside the measured range. [P1.3]

is exemplified: by the extension of a graph beyond the range of values within which measurements have been made. [P1.3]

Contrast with interpolation.

eye lens

in: a compound eyepiece

is: the lens which is nearer to the eye. [P6.4]

also describes: the lens of the eye itself. [P6.4]

See lens (of eye).

eyepiece

in: an optical instrument

is: the lens nearest to the eye. [P6.4]

if compound is: the combination of lenses nearest to the eye. [P6.4]

f-number

of: a lens

is: a quantity that indicates the ratio of the focal length to the diameter of the lens aperture. [P6.4]

controls: the light-gathering ability of a lens for a given focal length; the higher the f-number the smaller the aperture of the lens and the greater the depth of field. [P6.4]

is exemplified: by f/5.6 for a lens with a focal length 5.6 times greater than its aperture diameter. [P6.4]

often is called: f-stop. [P6.4]

factor

of: a product

is: any one of the numbers or expressions that are multiplied together to create the product. [M1.1]

See operation.

factorial

of: a non-negative integer, n

is denoted: by $n!$

is defined: as

$$n! = n(n-1)(n-2)(n-3)\ \ldots\ (2)(1) \text{ for } n \geq 1$$

and as $0! = 1$ for $n = 0$. [M1.7]

factorization

of: an algebraic expression (which may include complex numbers)

is: the procedure by which the expression is converted into factorized form. [M1.3, M1.4, M3.3]

can always be carried out: for a quadratic function or any other polynomial function. [M1.3, M1.4]

factorized form

of: a polynomial function (especially a quadratic function)

is: the form $f(x) = a(x - \alpha)(x - \beta) \ldots (x - \zeta)$, which makes clear the roots of the equation $f(x) = 0$, i.e. any values of x at which the graph of the function $f(x)$ intersects the x-axis. [M1.3, M1.4]

See factorization.

Fahrenheit

describes: a temperature scale which is related to the Celsius scale by the equation $T_F/(°F) = 9T_C/(5\,°C) + 32$ where T_F is a temperature in degrees Fahrenheit and T_C is the corresponding temperature in degrees Celsius.

far point

is: the farthest point from which light entering the eye may be imaged on the retina. [P6.4]

is: for a normal eye, at infinity. [P6.4]

farad, F

is: the SI unit of capacitance. [P4.5]

is defined: as one coulomb per volt: $1\,F = 1\,C\,V^{-1}$. [P4.5]

See capacitor. [P4.5]

Faraday's law

states: that the magnitude of the induced voltage in a circuit is numerically equal to the rate of change of the magnetic flux linkage in the circuit: $V_{\rm ind} = |d\Phi/dt|$. [P4.4]

See also electromagnetic induction and Lenz's law.

fast neutrons

are: neutrons produced directly in nuclear fission and having kinetic energy (typically 1 MeV or more) which is too high to initiate further nuclear fission in uranium, but may do so in plutonium.

Contrast with thermal neutrons.

fast reactor

is: a breeder reactor which uses fast neutrons to induce nuclear fission in plutonium. [P9.3]

Fermat's principle

states: that if a light ray passes from one fixed point to another fixed point, then the time taken to traverse the actual path will, to a first approximation, be equal to the time taken for light rays to traverse adjacent paths. That is, the time taken to traverse the path will be stationary with respect to small variations in the path. [P6.2]

means, in mathematical terms: that if the journey time along conceivable rays from one fixed point to the other is $T(x)$ where x is some suitable parameter, then the actual path (or paths) will be determined by finding the value (or values) of x for which $dT/dx = 0$. [P6.2]

means, in physical terms: that light travels along the path which is locally of least time. [P6.2]

permits deduction: of all the basic rules and principles of geometrical optics. [P6.2]

fermion

is: any particle which has an intrinsic spin angular momentum which is a half-integer multiple of $h/(2\pi)$ where h is Planck's constant.

ferrites

are: ceramic materials made from sintered oxides of iron and barium. [P4.2]

can be formed: into strong permanent magnets. [P4.2]

in granular form can be: bonded with plastics and used in record/erase tapes for information storage. [P4.2]

ferromagnetic

describes: a class of materials which are strongly attracted by a permanent magnet even when not permanently magnetized. [P4.2]

comprise: primarily the five elements iron (Fe), cobalt (Co), nickel (Ni), gadolinium (Gd) and dysprosium (Dy), together with some associated alloys. [P4.2]

fibre bundle

is: a collection of many hundreds or thousands of individual optical fibres, bound together within a single sheath. [P6.2]

field

throughout: a region of space

is: a physical quantity to which a definite value can be ascribed at each point in the region, at a particular time. [P3.1]

See scalar field and vector field.

field ion microscope

is: a microscope that uses the (quantum) wave-like properties of a beam of ions to achieve finer resolution than is possible with an optical or (in some aspects) even an electron microscope. [P7.1]

field lens

in: a compound eyepiece

is: a lens which increases the ability of the eye lens to accept incoming rays over a wide range of angles. [P6.4]

field lines

are: directed curves that provide a means of representing a vector field. [P3.1]

are drawn: so that at any point the tangent to the line represents the direction of the field at that point, and the spacing of the lines is related to the field strength. That is, where the lines are close together the field is strong and where they are further apart the field is weaker. [P3.1]

See also equipotential surface.

field stop

is: a stop or aperture which defines the maximum angle of acceptance of rays passing through the eye lens of a compound eyepiece. [P6.4]

filter circuit

is: a circuit designed to block (or pass) signals in specific frequency ranges. [P5.4]

final velocity

is: the velocity at the end of a period of time. [P2.1]

See uniform acceleration equations.

finite series

is: a series with a limited (finite) number of terms. [M1.7]

Contrast with infinite series.

first derivative test

is: a test to determine the location and nature of local extrema of a given function $f(x)$.

involves: (a) finding the points at which $f'(x) = 0$, (b) investigating the behaviour of the sign of $f'(x)$ in the neighbourhood of these points. If $f'(a) = 0$ and $f'(x)$ changes from positive to negative at $x = a$ then there is a local maximum at a. If $f'(a) = 0$ and $f'(x)$ changes from negative to positive at a then there is a local minimum at a. If $f'(a) = 0$, but $f'(x)$ does not change sign at $x = a$ then further investigation is required. [M4.4]

See stationary points and graph sketching in the Maths handbook.

first focal point

in: the paraxial approximation

is: for a convex lens, the point F_1 on the optical axis, from which rays are refracted by the lens to emerge parallel to the axis. [P6.3]

is: for a concave lens, the point F_1 on the optical axis, from which rays which have been refracted parallel to the axis by the lens, appear to emanate. [P6.3]

is also called: first focus or object focus.

See focal length.

first focus

See first focal point.

first ionization energy

of: an atom

is: the energy required to remove the least tightly bound electron from the atom in its ground state. [P8.4]

first law of thermodynamics

states: that if a system undergoes a change from one equilibrium state to another, the difference between the heat Q supplied **to** the system and the work W done **by** the system will depend only on the initial and final equilibrium states and not on the process by which the change is brought about. [P7.3, P7.4, P7.5]

justifies: the introduction of a function of state known as the internal energy U which changes by an amount

$$\Delta U = Q - W$$

in the process. [P7.3, P7.4, P7.5]

represents: the conservation of energy, but also has an additional implication. Because Q and W are not functions of state, their respective contributions to U cannot be disentangled, and it does not generally make sense to speak of the 'heat content' of a system. [P7.3, P7.4, P7.5]

first-order differential equation

is: a differential equation in which no derivative of the dependent variable of order higher than first order appears. [P5.4]

has: a general solution which always involves the introduction of an arbitrary constant. This constant can only be determined in any particular situation by imposing an appropriate boundary condition. [P5.4]

usually is assumed: to be of the first degree and may be written in the general form

$$a(x)\frac{dy}{dx} + b(x)y = f(x).$$ [M6.2]

first term (of an arithmetic progression)

See arithmetic progression.

fissile

means: capable of undergoing nuclear fission. [P9.3]

fission

See nuclear fission.

fixed point

See calibration point.

flint glass

is: a glass of relatively high refractive index and thus high dispersive power.
[P6.4]

fluid

is: a material which is not a solid and which is incapable of sustaining tensile stress, uni-axial compressive stress or shear stresses in equilibrium but can only sustain uniform stress or volume stress (i.e. pressure).   [P7.6]

more simply, is: any substance which can flow. This is usually taken to mean a liquid or a gas.   [P7.2]

flux

of: particles

if: there are N particles per unit length moving along the x-axis each with velocity v_x

is: the net rate at which particles cross a fixed plane per unit time, i.e. $F = Nv_x$. [P11.1]

See also flux (in quantum mechanics).

flux (in quantum mechanics)

of: particles, in a stream of particles represented by the spatial wavefunction $\psi(x) = A\exp(ikx)$, which is an eigenfunction of the momentum operator.

given that: the average number of particles per unit length is the constant $|A|^2$, and their velocity is obtained from the momentum, $v_x = p_x/m = \hbar k/m$

is: the net number crossing a fixed plane per unit time, i.e. $F = |A|^2\hbar k/m$.
[P11.1]

flux linkage

through: a coil of N turns

is given by: $\Phi = N\phi$ where ϕ is the magnetic flux through a single turn.

flux of a vector field

across: a surface $\boldsymbol{S}$

is defined: to be the surface integral $\int_S \boldsymbol{V} \cdot d\boldsymbol{S}$ where $\boldsymbol{V}$ represents the vector field, and $d\boldsymbol{S}$ is an element of area which is directed along an (abstractly chosen) outward pointing normal to the surface $\boldsymbol{S}$. [M2.6]

fluxmeter

is: a moving-coil galvanometer, designed with a damping force but no restoring force, so that a current pulse produces a non-returning deflection whose size is proportional to the total charge passed. [P4.4]

is used: to measure magnetic fields in conjunction with a search coil. [P4.4]

focal length

of: a lens or mirror

is: for parallel incident light, the distance (the image focal length) from the lens to its image focus; or the distance (the object focal length) from the lens to its object focus; or the distance from the mirror to the focus of the mirror. For a thin lens, the image focal length and object focal length are the same. [P6.3]

is: within the Cartesian sign convention a positive quantity for a convex lens or a concave mirror, and a negative quantity for a concave lens or a convex mirror. [P6.3]

focal point

in: the paraxial approximation

refers: for a lens to the object focus on the optical axis, from which rays are refracted by the lens to emerge parallel to the optical axis; also to the image focus on the optical axis, to which parallel rays converge after refraction by the lens. [P6.3]

is: for a concave mirror the point (called the focus) on the optical axis, to which rays parallel to the optical axis converge after reflection at the mirror. [P6.3]

is: for a convex mirror the point (called the focus) on the optical axis, from which rays parallel to the optical axis appear to diverge after reflection at the mirror. [P6.3]

See first focal point, second focal point, focal length.

focus (of a conic section)

See conic section.

focus (of a lens)

See focal point.

focus (of a mirror)

See focal point.

force

in: Newtonian mechanics

describes: the amount of 'push' or 'pull' exerted on a particle which, if unopposed, causes it to depart from the uniform motion predicted by Newton's first law of motion. [P2.3]

therefore is: that which causes (or tends to cause) acceleration. [M5.1]

is: a vector quantity, so it has both direction and magnitude. [M2.4, P2.3]

is quantified: by means of Newton's second law of motion, which tells us that the acceleration $\boldsymbol{a}$ of a particle is proportional to the resultant force $\boldsymbol{F}$ that acts on it, and inversely proportional to its mass m. Thus, in terms of vectors,

$$\boldsymbol{F} = m\boldsymbol{a}$$

or in terms of (scalar) components,

$$F_x = ma_x, \quad F_y = ma_y, \quad F_z = ma_z$$ [P2.3]

has as its SI unit: the newton (N). [M2.4]

force constant

in: simple harmonic motion

is: the magnitude of the restoring force per unit extension. [P5.2]

force laws

are: rules that allow the prediction of the forces acting in any given situation. [P2.3]

include: Newton's law of gravitation, the law of terrestrial gravitation, the laws of friction, Hooke's law, Coulomb's law and the Lorentz force law. [P2.3]

forced convection

See convection.

forced oscillations

See driven oscillator.

forced oscillator

See driven oscillator.

forced vibration

is: vibration which occurs when a system is supplied with energy periodically in order to keep it oscillating. [P5.2]

See driven oscillator.

forces of adhesion

are: attractive intermolecular forces acting across a boundary or interface between two materials and tending to cause their surfaces to stick together. [P7.6]

forces of cohesion

are: attractive intermolecular forces acting within a material and tending to hold the material together. [P7.6]

Fourier's law

states: that the rate at which heat is transferred along a uniform bar of cross-sectional area A by conduction is proportional to the temperature gradient along the bar:

$$\frac{dQ}{dt} = -\kappa A \frac{dT}{dl}$$

where κ is the thermal conductivity coefficient, a characteristic of the material of the bar. (The minus sign indicates that the direction of heat flow is from high temperature to low temperature.) [P7.3]

fraction

is: the ratio of two integers or algebraic expressions.   [M1.1]

fractional error

is: a dimensionless expression for the error (i.e. uncertainty) in a quantity, obtained by dividing the absolute error by the quantity itself. [P1.1, P1.2]

See also percentage error.

fracture

is: the process of breaking. [P7.6]

frame of reference

is: a three-dimensional physical setting, such as a laboratory, which provides the assumed context in which events takes place. [P2.7]

is normally: fixed with respect to a specific observer. [P2.3]

is represented: by a coordinate system, that allows a unique position to be assigned to each event, and a system of suitably synchronized clocks (or some equivalent system) that enables a unique time to be assigned to each event. [P2.3]

Fraunhofer diffraction

is: diffraction in which a plane wavefront (i.e. parallel light) is incident on an aperture and the resulting diffraction pattern is observed also as plane wavefronts. [P6.1]

therefore: its observation involves either large distances or lenses. [P6.1]

free convection

See convection.

free fall

is: the motion of an object (generally close to the surface of the Earth or other large body) solely under the influence of gravitational force. [P3.2]

free particle

is: a particle moving freely without any force acting on it and therefore with no changes in its energy. [P10.2]

free space

is synonymous: with vacuum.

freezing point

of: a substance

is: the temperature at which the solid and liquid phases of the substance can coexist in equilibrium at a specified pressure (usually, but not necessarily, standard atmospheric pressure).

is synonymous: with melting point.

frequency

is: the number of cycles of a periodic motion occurring per second, at any fixed position. [M6.4, P5.1, P5.5, P5.6, P5.7, P6.1]

therefore is equal: to the reciprocal of the period of the motion: $f = 1/T$. [M6.4, P5.7, P5.1]

has as its SI unit: the hertz (Hz), where $1\,\text{Hz} = 1\,\text{s}^{-1}$. [P5.4]

frequency-stabilized laser

is: a laser whose frequency is stabilized by some process and so constitutes an oscillator of exceedingly high *Q*-factor with a very narrow resonance bandwidth, and hence potential application as a time or frequency standard. [P5.3]

Fresnel lens

is: a flat lens, usually of large aperture and made from plastic, whose thickness (and hence weight) is reduced by a series of concentric steps in the curved surface. [P6.4]

is used: where a large-aperture inexpensive lens is required, e.g. in an overhead projector or in the back window of a bus. [P6.4]

friction

is: the phenomenon whereby a force (called a frictional force) acts on a body when it is in contact with another body (or with a viscous medium) and when there is relative motion, or a tendency for relative motion, between those bodies (or between the body and the medium). [P2.3, P5.2]

frictional force

is: a force that arises from friction. [P5.2]

acts in a direction: that opposes the actual or potential relative motion that gives rise to it. [P5.2]

is, when there is actual relative motion: sliding friction, the magnitude of which is given by $\mu_{\rm slide}R$, where R is the magnitude of the reaction force on the body concerned, and $\mu_{\rm slide}$ is a constant known as the coefficient of sliding friction. [P2.3, P5.2]

is, when there is only potential relative motion: static friction, the maximum magnitude of which is given by $\mu_{\rm static}R$, where R is the magnitude of the reaction force on the body concerned, and $\mu_{\rm static}$ is a constant known as the coefficient of static friction. [P2.3, P5.2]

fulcrum

of: a turning motion

is: the line about which the motion takes place, sometimes called the axis of rotation. [P2.7]

function

consists: of two sets and a rule, such that to each element of the first set (the domain) is associated a single element of the second set (the codomain). If the domain consists of the values of a variable x and the codomain consists of the values of a variable y then x is called the independent variable and y, the dependent variable and we write $y = f(x)$. In such circumstances it is usual to say that f is a function of x and that y is its value. (Note that this definition excludes the possibility of defining a function that is multi-valued.) [M1.3, M5.2]

function of a function

See composite function.

function of a function rule

is: a rule for differentiating composite functions (i.e. functions of functions)

states: that if y is a function of u so that $y = f(u)$ and u is a function of x so that $y = g(x)$, then

$$\frac{dy}{dx} = \frac{dy}{du} \times \frac{du}{dx} = f'(u) \times g'(x) \quad [\text{M4.3}]$$

See the chain rule in the Maths handbook.

function of state

is: any property of a system that is entirely determined at any time by the state of the system at that time. In particular, it does not depend on the processes which brought the system to that state. [P7.3, P7.4]

is exemplified: by the internal energy *U* of a fixed quantity of ideal gas, which is determined by the temperature of the gas at any time (provided the gas is in equilibrium). Thus, changes in internal energy are determined by changes in temperature (one of the thermodynamic coordinates that specify the state) irrespective of the processes that bring them about. [P7.3, P7.4]

is NOT exemplified: by the heat *Q* supplied to a fixed quantity of ideal gas. The heat required to bring about a particular change of state will generally depend on the exact process involved, not just the initial and final states. [P7.3, P7.4]

function of two variables

is: a function whose domain consists of ordered pairs of values such as (x, y) where x and y are independent variables. [M6.4]

fundamental

on: a string of finite length l

is: that standing wave of the string which has the greatest possible wavelength (and hence the lowest possible frequency, known as the fundamental frequency). [P5.6, P5.7]

is exemplified: for a string fixed at both ends with linear mass density μ and under a tension F_T by the standing wave of wavelength $2l$ which has (fundamental) frequency $\dfrac{1}{2l}\sqrt{\dfrac{F_T}{\mu}}$.

may be more generally applied: to other oscillatory systems that exhibit standing waves.

See harmonics.

fundamental constant

See universal constant.

fundamental force

is: any of the four known forms of interaction (gravitational, electromagnetic, strong, and weak) between elementary particles. These interactions (particularly the gravitational and electromagnetic interactions, which have unlimited ranges) are the ultimate cause of all the other 'forces' of physics.

fundamental frequency

See fundamental.

fundamental interaction

is: any of the four known modes (gravitational, electromagnetic, strong, weak) by which elementary particles interact.

fundamental particle

is: a synonym for elementary particle.

is sometimes used more specifically: to mean those particles that are currently thought to be truly 'elementary', thereby including quarks, leptons, and exchange particles but excluding composite particles such as the proton and the neutron.

fundamental theorem of algebra

states: that any polynomial of degree *n* with complex number coefficients has, counting repeated roots an appropriate number of times, exactly *n* complex roots. [M1.4, M3.1]

fundamental theorem of calculus

relates: definite and indefinite integrals of a given function and thereby simplifies the evaluation of a definite integral, provided that an indefinite integral of its integrand can be found. [M5.1, M5.2]

states: that if $F(x)$ is any indefinite integral of $f(x)$ so that $\dfrac{dF}{dx} = f(x)$, then

$$\int_a^b f(x)\,dx = [F(x)]_a^b = F(b) - F(a).$$ [M5.1, M5.2]

fusion

can refer: to melting – the phase transition in which a solid becomes a liquid, upon absorption of the requisite amount of latent heat. [P7.4]

also can refer: to nuclear fusion. [P9.3]

fusion curve

is: the curve on the P–T projection of the *PVT*-surface, which separates the solid phase from the liquid phase. [P7.4]

γ-decay

is: a form of radioactive decay in which a nucleus emits a γ-ray (i.e. a photon with high energy, typically hundreds of keV, and possibly much higher).
[P9.2]

γ-radiation

is: a form of electromagnetic radiation emitted in radioactive decay and characterized by wavelengths shorter than those of X-rays (i.e. less than or approximately equal to 0.4 nm). [P9.2]

galvanometer

See moving-coil galvanometer.

gas phase

is: a fluid phase of matter characterized by the lack of a definite volume or shape other than that imposed by a container. [P7.1]

at the microscopic level, can be described: as a system in which the thermal kinetic energy is much greater than the intermolecular bonding energies. [P7.1]

Gauss' law

states: that for an electric field $\boldsymbol{E}$, in a vacuum, the flux of $\boldsymbol{E}$ out of a closed surface $\boldsymbol{S}$ (as given by the surface integral of $\boldsymbol{E}$ over $\boldsymbol{S}$ with a suitably chosen outward pointing normal at each point on $\boldsymbol{S}$) is equal to the total charge enclosed by $\boldsymbol{S}$ divided by the permittivity of free space, so

$$\int_S \boldsymbol{E} \cdot d\boldsymbol{S} = \frac{1}{\varepsilon_0} \times \begin{Bmatrix} \text{the total charge} \\ \text{within the surface} \end{Bmatrix} \quad \text{[M2.6]}$$

Gaussian distribution

is: a smooth curve (or the function describing such a curve) with the property that in a wide range of practical situations it represents the shape taken by the histogram of a large number of measurements of some quantity as the measurement intervals are made smaller and smaller. [P1.2]

is also known: as a normal distribution. Measurements with histograms that approach Gaussian distributions are said to be normally distributed. [P1.2]

mathematically can be described: by an equation of the form $y = \dfrac{1}{\sigma\sqrt{2\pi}}\exp\left[-\left(x - \langle x \rangle\right) / \left(2\sigma^2\right)\right]$, where $\langle x \rangle$ is the mean of the distribution and σ is the standard deviation of the distribution. (The mean and the standard deviation of a set of normally distributed measurements provide estimates of these two quantities.) [P1.2]

Gaussian integral

is: an integral of the form

$$\int_0^\infty x^{2n}\exp(-ax^2)\,dx, \text{ or } \int_{-\infty}^\infty x^{2n}\exp(-ax^2)\,dx$$

where n is a positive integer or zero, and a is a positive constant. [M5.5]

See further integration in the Maths handbook for details of the evaluation of Gaussian integrals.

general solution

of: a linear differential equation of order *n*

is: a solution that involves *n* essential constants. [M6.1, P5.5]

generator

of: a geometrical surface (e.g. a cone)

is: a straight line which when moved in a prescribed way sweeps out the geometric surface. [M2.3]

generic *PVT*-surface

is: the *PVT*-surface of a 'typical' substance. [P7.4]

is used: to illustrate general statements about features and properties of *PVT*-surfaces. [P7.4]

geometric figure

is: any shape (involving points, lines, curves, etc.) of interest to those studying geometry. [M2.1]

geometric progression

is: a series of the form:

$$\sum_{k=1}^{n} ar^{k-1} = a + ar + ar^2 + \ldots + ar^{n-1}$$

The constant, r is known as the common ratio. [M1.7]

geometric series

See geometric progression.

geometric series for complex numbers

where: z is a complex variable

is: a series of the form $a + az + az^2 + \ldots + az^n$, the sum of which is equal to $(1 - z^{n+1})/(1 - z)$ if $z \neq 1$. [M3.3]

geometric vector

is: a directed line segment that may be used to represent a vector quantity.
[M2.5]

geometrical optics

is: the branch of optics which is based on the ray approximation to the wave model of light. [P6.1, P6.2]

assumes: that light follows paths called rays which obey the principle of reversibility and the principle of rectilinear propagation, and which satisfy the law of reflection and the law of refraction. [P6.1, P6.2]

geometry

is: that branch of mathematics which is concerned with the properties of space and of figures in space. [M2.1]

geostationary

describes: Earth satellites which orbit in such a way that they are permanently located above a particular point on the Earth's surface. Such satellites must travel with the same angular velocity as the Earth itself, and the satellite orbit must be directly above the equator. [P2.6]

also describes: the orbit for such Earth satellites. [P2.6]

geosynchronous

is often used synonymously: with geostationary.

is sometimes used more generally: to indicate an Earth satellite in an orbit with a 24 hour period that might be inclined at an angle to the equator. (Such a satellite would cross the same point on the equator at the same time each day, but would not be permanently located above that particular point.)

global maximum

of: a function

on: an interval

is: the greatest value of the function on that interval. [M4.4]

also known as: absolute maximum.

See stationary points and graph sketching in the Maths handbook.

global minimum

of: a function

on: an interval

is: the least value of the function on that interval. [M4.4]

also known as: absolute minimum.

See stationary points and graph sketching in the Maths handbook.

graded-index fibre

is: an optical fibre in which the refractive index gradually decreases from the axis of the fibre and in which continuous refraction is used to confine light rays within the fibre and away from the surface of the fibre. [P6.2]

gradient

of: a straight line (or the corresponding linear function)

is: a measure of the rate at which one quantity changes with another quantity. As a graph with given scales on the Cartesian axes, the gradient controls the angle between the line and the horizontal.

is often used synonymously with: the slope of the straight line.

is given: for a straight line drawn as a graph on conventional Cartesian axes, with x horizontal and y vertical, by the ratio of a difference in y values to the corresponding difference in x values between any two points on the straight line,

i.e. $\text{gradient} = \dfrac{(y_2 - y_1)}{(x_2 - x_1)} = \dfrac{\Delta y}{\Delta x} = \dfrac{\text{rise}}{\text{run}}$ [M1.3, M2.2, P1.3]

may be easily found: from the gradient-intercept form of the equation of a straight line, $y = mx + c$, where it is represented by the constant m.

may be used more generally: at a point on a curve, to refer to the gradient of the straight line that is a tangent to the curve at the point.

is equal, in this more general sense; to the derivative of the function that describes the curve, evaluated at the point in question

i.e. the gradient of $y = f(x)$, at $x = a$ is $f'(a)$. [M4.2]

gradient-intercept form

of: the equation of a straight line

is: $y = mx + c$

where m is the gradient (i.e. slope) of the straight line and c is the intercept of the straight line with the y-axis. [M2.2, M3.1]

gram, g

is: an SI unit of mass, a submultiple of one of the seven base units.

is defined by: $1\,\mathrm{g} = 10^{-3}\,\mathrm{kg}$.

graph

is: the representation of an equation or function in geometric form, normally using Cartesian coordinates. In the case of a function $f(x)$ the graph is usually that of the equation $y = f(x)$.   [M1.3, M5.2, P1.3]

graph sketching

is: the process of constructing a 'rough' graph of a function, which shows the salient features of the function without requiring detailed plotting. [M4.4]

grating relation

for: a diffraction grating with slits separated by a distance d illuminated by normally incident light of wavelength λ

relates: the angles θ_n, at which n^{th} order maxima in the diffraction pattern will be found, to n, λ and d. [P6.1, P8.2]

states: that $n\lambda = d \sin \theta_n$. [P6.1, P8.2]

grating spacing

is: the distance between the slits in a diffraction grating. [P6.1]

gravitational constant

See Newton’s universal gravitational constant.

gravitational energy

See gravitational potential energy.

gravitational field

throughout: a region of space

is: a vector field which gives rise to a gravitational force on a test mass placed at any point in the region. [P3.1]

is defined: at any point specified by a position vector $\boldsymbol{r}$, as the gravitational force per unit mass that would act on a test mass placed at that point. So, generally,

$$\boldsymbol{g}(\boldsymbol{r}) = \frac{\boldsymbol{F}(\text{on } m \text{ at } \boldsymbol{r})}{m}$$

where m is the test mass. [P3.1, P3.2]

is related: to the gravitational potential by the requirement that it points in the direction of most rapid decrease of the potential, and has a magnitude given at every point by the magnitude of the rate of change of the potential (e.g. in the radial direction from an isolated point mass, so that $g_r = -dV_{\text{grav}}/dr$). It therefore always points in a direction at right angles to lines or surfaces of equal potential, and from high potential towards low potential. [P3.1, P3.2]

has as its SI unit: the newton per kilogram (N kg^{-1}). [P3.1, P3.2]

gravitational field strength

at: any point

is: the magnitude of gravitational field at that point. [P3.1]

therefore is also: the magnitude of the acceleration of a unit point mass in free fall due to gravity at that point. [P3.2]

See also surface gravity.

gravitational force

is: in Newtonian mechanics, an attractive force that acts between particles having mass. [P3.1]

is described: by the universal law of gravitation, which says that the gravitational force on a particle of mass m_2 due to a particle of mass m_1 a distance r away is

$$\boldsymbol{F}_{\rm grav} = \boldsymbol{F}_{21} = -\frac{Gm_1m_2}{r^2}\,\boldsymbol{\hat{r}}$$

where G is Newton's universal gravitational constant and $\boldsymbol{\hat{r}}$ is a unit vector pointing from m_1 to m_2. [P3.1]

arises: from the gravitational interaction, one of the fundamental interactions in nature. [P3.1, P9.2]

See also surface gravity.

gravitational interaction

is: the fundamental interaction that gives rise to gravitational force. [P9.2]

comprises: together with the electromagnetic, weak and strong interactions, the four known fundamental interactions of nature. [P9.2]

gravitational mass

is: the mass of a body as determined by the gravitational force that it experiences or exerts. (See Newton's law of gravitation.) [P2.3]

Contrast with inertial mass.

gravitational potential

at: a point in space where there is a gravitational field

is: the gravitational potential energy per unit mass due to the gravitational field at that point. [P3.1, P3.2]

has as its SI unit: the joule per kilogram ($J\,kg^{-1}$).

gravitational potential energy

is: the potential energy that a body has by virtue of its position in a gravitational field. [P2.4]

requires for its full definition: a position of zero gravitational potential energy to be arbitrarily chosen, since only differences in gravitational potential energy are physically meaningful.

changes: in going from point A to point B, by an amount equal to the negative of the work done by the gravitational field when the body is moved from A to B. [P3.2]

is exemplified: by the gravitational potential energy of a particle of mass m_2 in the gravitational field of a particle of mass m_1 when the distance between the two particles is r. Subject to the conventional choice that $E_{\rm grav} = 0$ when $r \to \infty$, this is given by

$$E_{\rm grav} = -\frac{Gm_1m_2}{r}$$

where G is Newton's universal gravitational constant. [P2.4, P3.1, P3.2, P5.2]

is related: to the gravitational potential $V_{\rm grav}$ in a region by $E_{\rm grav} = mV_{\rm grav}$, so when a mass m moves through a gravitational potential difference $\Delta V_{\rm grav}$, the change in gravitational potential energy $\Delta E_{\rm grav}$ is given by $\Delta E_{\rm grav} = m\Delta V_{\rm grav}$. [P3.1, P3.2, P4.1]

often is abbreviated: to gravitational energy. [P3.1, P3.2]

has as its SI unit: the joule (J).

gravity

is: the phenomenon that gives rise to gravitational effects such as the gravitational force on an object.

gray, Gy

is: the SI unit of absorbed dose of ionizing radiation.

is defined: by $1\,\mathrm{Gy} = 1\,\mathrm{J\,kg^{-1}}$. [P9.3]

See also sievert.

grazing incidence

is: a situation in which the angle of incidence at a surface is very close to 90°. [P6.2]

ground level

of: an atom

is: the energy level corresponding to the ground state of an electron in an atom. [P8.2]

more generally is: the energy level corresponding to the minimum energy for a system. [P10.3]

ground state

of an atom, is: the state of the atom in which all the electrons occupy the lowest possible energy levels. [P8.2, P8.3, P8.4]

generally, is: a condition or state for a system in which its energy has the minimum value. [P10.3]

group

of: chemical elements

is: a set of chemical elements, commonly placed in a vertical column in a periodic table because of similarities in chemical properties. [P8.4]

group speed

of: wave groups composed of superpositions of waves with a variety of frequencies

in: dispersive media (i.e. when waves of different frequencies propagate at different speeds)

is: the speed at which the envelope of the wave group propagates. [P5.6]

generally will differ: from the phase speed of any of the individual waves which contribute to the formation of the wave group. [P5.6]

gyroscope

is: a spinning wheel, mounted on very low friction bearings called gymbals, which exert no torque and so allow the axis of rotation to maintain its direction through conservation of angular momentum, even if the support on which the gyroscope and gymbals are mounted, alters its orientation. [P2.8]

therefore can be used: as a navigational device on ships, aeroplanes, and spacecraft. [P2.8]

half-angle formulae

are: a class of trigonometric identities. [M1.6]

See trigonometric functions in the Maths handbook.

half-argument identities

are: a class of hyperbolic function identities. [M4.6]

See hyperbolic functions in the Maths handbook.

half-life

of: radioactive nuclei in a prepared sample

is: the time taken for half the nuclei in the sample to decay. [M1.5, P9.1, P9.2]

hence is: the time taken for the activity to halve. [P9.2]

is: a property of radionuclides, unaffected by the physical or chemical environment. [P9.2]

half-power points

on: the power absorption curve of an oscillator

are: the frequencies on either side of the resonance, at which the power absorption has half its peak value. [P5.3]

Hall effect

is: the creation of a potential difference, the Hall voltage, when a current-carrying specimen is placed in a magnetic field having a component at right angles to the current. [P4.3]

Hall probe

is: a device to measure magnetic fields using the Hall effect. [P4.3]

usually contains: a semiconductor wafer and a sensitive voltmeter. [P4.3]

Hall voltage

is: the transverse potential difference created by the Hall effect. [P4.3]

arises: when a current-carrying specimen is placed in a transverse magnetic field. [P4.3]

is: transverse to the directions of both the magnetic field and the current. [P4.3]

arises from: the Lorentz force on the current-carrying charged particles. [P4.3]

halogens

are: the chemical elements fluorine, chlorine, bromine, iodine and astatine. [P8.4]

occupy: Group VII of the periodic table. [P8.4]

are named after: the Greek words *hals* (sea-salt) and *gennao* (I produce) because three of the elements (chlorine, bromine and iodine) can be prepared from this source. [P8.4]

Hamiltonian operator

in: quantum mechanics

is: the differential operator which corresponds to the total energy of a system. [P10.4, P11.3]

has: the time-independent Schrödinger equation as an eigenvalue equation. [P10.4, P11.3]

is represented: for a particle of mass m moving in one dimension, parallel to the x-axis, with a potential energy function $U(x)$, by

$$\hat{\mathrm{H}} = \frac{-\hbar^2}{2m}\frac{d^2}{dx^2} + U(x)$$ [P10.4]

harmonic oscillator

is: an oscillator undergoing simple harmonic motion (SHM). [P5.3]

harmonically driven linearly damped harmonic oscillator

is: a harmonic oscillator with a damping force which is a linear function of the velocity of the oscillator (i.e. of the first derivative of the displacement of the oscillator), and which is driven by an external driving force of a simple sinusoidal form. [P5.3, P5.5]

harmonics

for: standing waves on a string

are: the sequence of allowed frequencies. The first in the series is the fundamental. Those other than the fundamental are sometimes referred to as overtones. [P5.6, P5.7]

heat

is defined: as energy transferred as a direct result of temperature difference. [P5.2, P7.2, P7.4, P7.5]

therefore is seen: as energy undergoing a particular process rather than as a particular 'form' of energy. [P5.2, P7.2, P7.4, P7.5]

contributes: along with work, to changes in the internal energy of a system, though it is impossible to say how much of the internal energy was provided as heat and how much as work unless the entire history of the system is known. [P5.2, P7.2, P7.4, P7.5]

may be transferred: from place to place by conduction, convection or radiation. [P7.3]

is also used to refer, somewhat improperly: to the internal kinetic energy of a body arising from the random microscopic motion of the atoms and molecules that it contains. [P7.3]

heat capacity

of: a system with uniform temperature

is: the ratio $\Delta Q/\Delta T$ of the heat transferred to a single-phase system, to the corresponding change in temperature of the system. [P7.4]

strictly should be defined: as the limit of this quantity as ΔT becomes vanishingly small, since the value of the ratio will depend on the state of the system. [P7.4]

therefore also depends: on the constraints applied during heating; see principal specific heats. [P7.4]

has as its SI unit: $\mathrm{J\,K^{-1}}$. [P7.4]

See also molar specific heat and specific heat. [P7.4]

heat energy

is: an archaic term which casts heat as a 'form' of energy, that is still sometimes used to refer to part or all of the internal energy of a system.

is exemplified: by the statement that when one body collides inelastically with another, part of the kinetic energy is transformed into heat energy which results in a rise in temperature of the colliding bodies. [P5.2]

See heat.

heat engine

is: a device (such as a steam engine) where the supply and removal of heat (generally in a closed cycle) results in the device doing work. [P7.4]

heavy damping

of: a damped harmonic oscillator

is: a condition in which the oscillator will not complete any oscillations before coming to rest, but having a higher level of damping than in critical damping. [P5.2, P5.5]

is often used as synonymous: with overdamping.

See critical damping and light damping.

Heisenberg uncertainty principle

imposes: a fundamental limitation on the combined precision with which certain pairs of observables can be simultaneously determined. [P10.2, P10.3, P11.1]

can be regarded: as a consequence of the wave nature of matter. [P10.2, P10.3]

is exemplified: for the uncertainty Δx in the x-coordinate of a particle's position, and the uncertainty Δp_x in the corresponding momentum component, by the relationship: $\Delta x\,\Delta p_x \geq \dfrac{h}{4\pi}$, where h is Planck's constant. [P10.2, P10.3]

is also exemplified: by the relationship $\Delta E\,\Delta t \geq \dfrac{h}{4\pi}$, between the uncertainties in a measurement of energy and the time taken to make the measurement. [P10.2, P10.3, P11.1]

has nothing to do: with the methods employed to make the measurements. [P10.2, P10.3, P11.1]

helical

in: geometry

means: pertaining to a helix. [M2.1]

helix

is: a curve drawn around a cylinder, with successive turns displaced in the axial direction. [P4.2]

henry, H

is: the SI unit of inductance.

is defined: by 1 H = 1 V s A^{-1}, so a closed circuit will have an inductance of 1 H when the current in it varies at a rate of 1 A s^{-1} to produce an induced voltage of 1 V. [P4.4, P4.5]

is, for practical purposes: a medium sized unit. Widely used inductances vary from a few microhenry to hundreds of henry. [P4.5, P5.4]

See also coefficient of mutual inductance and coefficient of self inductance.

hertz, Hz

is: the SI unit of frequency.

is defined: by $1\,\text{Hz} = 1\,\text{s}^{-1}$, so a frequency of 1 Hz is equivalent to one cycle per second. [P5.1]

hidden variable theory

is: any theory that makes use of variables which, if their values were known, would permit more precise predictions of the outcomes of experimental measurements than those of conventional quantum theory. [P10.2]

implies: that quantum theory is an incomplete theory, and that the 'fuzziness' of its predictions is a reflection of our limited understanding and not a feature of the Universe itself. [P10.2]

is opposed: to the conventional Copenhagen interpretation of quantum physics. [P10.2]

high-pass filter

is: a filter circuit that passes high frequency signals with relatively undiminished amplitude, but blocks low frequency signals. [P5.4]

Contrast with low-pass filter.

higher derivatives

of: a function $y = f(x)$ with first derivative $\dfrac{dy}{dx} = f'(x)$

are: the derivatives $\dfrac{d^n y}{dx^n} = f^n(x)$ where $n \geq 2$. [M4.3]

histogram

is: a graphical representation of a set of measurements. [P1.2]

consists of: a number of rectangles, the areas of which are proportional to the number of measurements falling within a given interval, represented by the width of the rectangles. [P1.2]

hole

is: a vacancy in the one of the normally filled energy bands in a solid. [P11.4]

behaves: like a positive charge carrier and thereby contributes to the electrical conductivity of the solid. [P11.4]

hole conduction

is: electrical conduction due to mobile holes, such as may occur in a p-type semiconductor. [P4.3]

homogeneous differential equation

is: a differential equation in which every term involves the same single variable or one of its derivatives. [P5.3, P5.5]

homopolar generator

is: a device that generates a steady d.c. voltage by spinning a conducting disc in a magnetic field. [P4.4]

Hooke's law

states: that for sufficiently small stress, the strain in a material is directly proportional to the stress causing it. [P7.6]

therefore requires: that the restoring force, F_x, exerted by a spring that obeys Hooke's law is proportional to the extension or compression, x, of the spring from its unstretched length, so that $F_x = -k_s s_x$, where k is the spring constant. [P2.3, P2.4, P5.1, P5.2]

sometimes is expressed: in terms of the applied force $F_x^{\rm app} = -F_x$ which is required to maintain a given extension. [P2.3, P2.4, P5.1, P5.2]

leads: to the definition of a range of elastic moduli such as Young's modulus, shear modulus and bulk modulus. [P7.6]

horizontal asymptote

is: an asymptote which is horizontal and which therefore has zero gradient. [M4.4]

horizontal point of inflection

is: a point of inflection at which the first derivative is zero.

horsepower, hp

is: a non-SI unit of power.

is defined: by $1\,\text{hp} = 7.457 \times 10^2\,\text{W}$. [P2.4]

Hund's rule

for: a subshell of an atom in its ground state.

is: an empirical rule requiring that the number of unpaired electrons in the subshell has its maximum value. [P8.3]

Huygens' principle

states: that each point on a wavefront may treated as a source of secondary wavelets, or waves, that expand radially from their source with the same speed as the original wave. [P6.1]

hydrogen bond

is: a weak bond which may occur in hydrogen-containing materials, resulting from the 'sharing' of a hydrogen atom between two other atoms. [P7.1]

typically has: an bonding energy of less than 0.5 eV [P7.1]

is important: in many organic molecules and solids. [P7.1]

hydrostatic pressure

is: the pressure (which is the same in all directions) developed internally in a body of fluid due to the weight of the elements of fluid above. [P7.6]

hyperbola

is: a conic section that may be described by an equation of the form

$$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1 \text{ where } b = a\sqrt{e^2 - 1} \text{ with } e > 1,$$

though it often arises in the form of a rectangular hyperbola for which $y = k/x$. [M1.3, M2.3, P1.3, P3.2]

See conic sections in the Maths handbook for further details.

hyperbolic functions

are: the functions sinh, cosh, tanh and (usually) the related reciprocal functions sech, cosech and coth. [M4.6]

take their name: from the fact that

$x = a\cosh(t)$

$y = b\sinh(t)$

are parametric equations for a hyperbola. [M4.6]

See hyperbolic functions in the Maths handbook for further details.

hyperbolic function identities

are: identities relating the hyperbolic functions, such as
$\cosh^2(x) - \sinh^2(x) = 1$. [M4.6]

See hyperbolic functions in the Maths handbook for a detailed listing.

hypermytropia (long sight)

is: the condition in which eyes are unable to focus on objects as close as the standard near point (taken to be at 25 cm). [P6.4]

occurs: when the lens of the eye has too long a focal length, even when fully accommodated. [P6.4]

usually is corrected: by using an auxiliary converging lens. [P6.4]

Contrast with myopia.

hypotenuse

of: a right-angled triangle

is: the side opposite the right angle. [M1.6, M2.1]

is also: the longest side of such a triangle. [M1.6, M2.1]

i

symbolizes: the algebraic quantity satisfying the rule $i^2 = -1$; the basis of imaginary numbers. [M3.1]

ideal elastic string

See ideal string.

ideal gas

is: a gas that obeys the ideal gas equation of state, $PV = nRT$, where P is the pressure of the gas, V is its volume, n is the amount of gas (expressed in moles), R is the molar gas constant and T is the absolute temperature. [P7.2, P7.3, P7.4, P7.5]

exists: only as an idealized entity, but is well approximated by a real gas at sufficiently low density. [P7.2, P7.3, P7.4, P7.5]

ideal gas absolute temperature scale

is: a temperature scale based on measurements made with real gases using a constant-volume gas thermometer, and extrapolated to the limit of zero pressure in which the gas may be considered to be an ideal gas. [P7.2]

is defined: by the thermometric relation

$$T = \lim_{P_{\text{triple}} \to 0} \left(\frac{P}{P_{\text{triple}}} \right) \times 273.16\,\text{K}$$

where P is the pressure of a fixed volume of gas at temperature T, and P_{triple} is the pressure of the same sample of gas, occupying the same volume, at the triple-point temperature of H_2O which is defined to be 273.16 K. [P7.2]

ideal gas equation of state

is: a relationship between pressure P, volume V and temperature T, which is obeyed by an ideal gas. [P7.2, P7.5]

sometimes is referred to: as the ideal gas law. [P7.2, P7.5]

is written: as

$$PV = nRT \quad \text{or} \quad PV = NkT$$

where n is the number of moles of gas, R is the molar gas constant, and T is the absolute temperature. Equivalently, N is the number of molecules in the system and k is Boltzmann's constant. [P7.2, P7.5]

ideal gas law

See ideal gas equation of state.

ideal spring

is: an elastic body which may be compressed or extended by an external force and in which Hooke's law is obeyed. [P2.3]

ideal string

is: an elastic string which always obeys Hooke's law when it is stretched, irrespective of the amount of stretching. [P2.3]

ideal transformer

is: a transformer with 100% flux linkage between the primary and secondary coils and with 100% transfer of electrical power between the two coils, with no dissipation of power. [P4.4]

ideal voltage generator

is: a voltage generator with zero output resistance (i.e. zero internal resistance). [P4.1]

is symbolized: by an open circle with a labelled arrow alongside to indicate the magnitude and polarity of the voltage. [P4.1]

identity

is: an equation relating two expressions that is true for all meaningful values of the variables involved in those expressions. [M1.6]

is exemplified: by $(x + 1)^2 = x^2 + 2x + 1$. [M1.6]

sometimes is indicated: by using the symbol ≡ in place of the more usual =. [M1.6]

ill-conditioned

describes: a system of equations for which small changes in the coefficients cause large changes in the solutions. [M2.2]

image

is: a representation of an object. [P6.2, P6.3]

is produced: by reflection at a mirror surface, or refraction at an interface between transparent media or at a combination of interfaces such as a lens or some other optical system. [P6.2, P6.3]

arises: when light rays leaving a point on the object are brought back together (real image) or appear to be brought back together (virtual image) to a common point. [P6.2, P6.3]

can be seen: either as a point image or an extended image. [P6.2, P6.3]

image distance

is: the distance v, measured along the optical axis, between an image and a lens or mirror. [P6.3]

might more appropriately be termed: the image position, since (according to the Cartesian sign convention) it may be a positive or negative quantity, depending on the side of the origin on which it lies. [P6.3]

See also thin lens equation and spherical mirror equation. [P6.3]

image focus

See second focal point.

imaginary axis

is: the axis in a complex plane (or Argand diagram) along which the imaginary part of a complex number is represented. [M3.1]

imaginary number

is: a complex number of the form iy where y is a real number and $i^2 = -1$. [M1.4, M3.1]

therefore is: a complex number in which the real part is zero. [M1.4, M3.1]

imaginary part

of: a complex number, $z = x + iy$ (where x and y are real numbers)

is: the term y. [M1.4, M3.1, P5.5]

often is denoted: by $\mathrm{Im}(z)$. [M1.4, M3.1, P5.5]

impedance (electrical)

of: a single electrical component or a two terminal network, in which an alternating current of peak value I_0 flows in response to an externally supplied alternating voltage of peak value V_0

is: the quantity $Z = V_0/I_0$. [P5.4, P5.5]

is analogous: to the resistance of a d.c. circuit component. [P5.4, P5.5]

is given: by $Z = \sqrt{R^2 + X^2}$ where R is the resistance and X is the reactance of the component or network. [P5.4]

has as its SI unit: the ohm (Ω). [P5.4, P5.5]

generally depends: on the angular frequency of the supply (since X depends on that frequency).

is at a minimum: for a series LCR circuit at the circuit's natural frequency. [M6.3, P5.3, P5.4]

is at a maximum: for a parallel LCR circuit at the circuit's natural frequency. [M6.3, P5.3, P5.4]

See complex impedance, mechanical impedance.

impedance matching

is: a method of linking two circuits which have different impedances to ensure the maximum transfer of power between them. [P4.4]

may be achieved: using the primary and secondary coils of a transformer. [P4.4]

implicit differentiation

is: a form of differentiation using the chain rule. [M4.3]

is used: for differentiating implicit functions which are defined by an equation that relates the dependent variable (y) and the independent variable (x) but where neither variable is the subject of the equation. [M4.3]

is done: by differentiating both sides of the equation, which yields, in general, an expression in y and x for dy/dx. [M4.3]

is exemplified: by implicit differentiation of $x^2 + y^2 = a^2$ with respect to x, which yields $2x + 2y(dy/dx) = 0$, so that $(dy/dx) = -x/y$. [M4.3]

implicit function

is: a function defined by an equation that relates the dependent variable (y) and the independent variable (x) but where neither variable is the subject of the equation. [M4.3, M6.1]

is exemplified: by the function $y(x)$ defined by $y + \sin y = 3x$. [M4.3, M6.1]

improper integral

is: a definite integral in which:

(a) one or both of the limits of integration is an infinite quantity (positive or negative), or

(b) the integrand becomes infinite at some point or points in the range of integration, or

(c) both of the above apply. [M5.2]

may be evaluated: as limits of appropriate proper integrals. [M5.2]

impulse

is: the product of the force acting and the time over which it acts,
(i.e. impulse = $\boldsymbol{F}\,\Delta t$ for a constant force).

is: a vector quantity

has as its SI unit: the N s (i.e. newton second).

is equal: to the change in momentum which follows from the impulse, i.e.
$\Delta\boldsymbol{p} = \boldsymbol{F}\,\Delta t$. [P2.5]

impurity conduction

is: electrical conduction due to impurities that contribute electrons or holes to a material (particularly a semiconductor). [P11.4]

in anti-phase

describes: the phase relationship between two specified oscillations such as $A = A_0 \sin(\omega t + \phi_1)$ and $B = B_0 \sin(\omega t + \phi_2)$ that have the same angular frequency ω and which respectively involve phase constants ϕ_1 and ϕ_2 that differ by an odd integer multiple of π so that $\phi_2 - \phi_1 = (2n + 1)\pi$, where n is any integer. The maxima of one oscillation then coincide with the minima of the other. [P5.1, P5.7, P6.1]

may also be applied: to waves at a common point (or possibly at separate points) by comparing the oscillations caused by the waves at the relevant point(s).

See phase relationship, in phase and out of phase.

in phase

describes: the phase relationship between two specified oscillations such as $A = A_0 \sin(\omega t + \phi_1)$ and $B = B_0 \sin(\omega t + \phi_2)$ that have the same angular frequency ω and which respectively involve phase constants ϕ_1 and ϕ_2 that differ by an integer multiple of 2π so that $\phi_2 - \phi_1 = 2n\pi$, where n is any integer. The maxima of one oscillation then coincide with the maxima of the other, as do all other stages of the oscillation. [P5.1, P5.4, P5.6, P5.7, P6.1]

may also be applied: to waves at a common point (or possibly at separate points) by comparing the oscillations caused by the waves at the relevant point(s).

See phase relationship, in anti-phase and out of phase.

incident ray

is: an incoming ray which falls on (is incident on) some surface or interface.
[P6.1, P6.2]

incoherent

describes: two waves sufficiently unrelated that knowing the phase of one at some particular time and position does not enable the phase of the other to be predicted at some other position (if spatially incoherent) or time (if temporally incoherent). Usually the phase difference between incoherent waves varies rapidly and randomly. [P6.1]

may also be applied: in its temporal sense, to two oscillations. [P5.3]

incompressible

describes: a sample of (idealized) material (usually a liquid or a solid) that cannot be compressed (i.e. which does not change its volume in response to applied forces). [P7.2]

inconsistent

describes: a set of equations that cannot all be true simultaneously. [M1.4]

increasing function

is: a function $f(x)$ for which $f(a) < f(b)$ for all $a < b$

always exists: over an interval, if its derivative $f'(x)$ is positive at all points of the interval. [M4.4]

indefinite integral

of: a function $f(x)$

is denoted: $\int f(x)\,dx$

where $f(x)$ is called the integrand, and the symbol dx is the element of integration which shows the integration variable, x with respect to which the integration is to be performed. [M5.1, M5.2]

is: any function $F(x)$ such that $\dfrac{dF}{dx} = f(x)$. [M5.1, M5.2]

is not: unique, since if $F_1(x)$ is an indefinite integral of $f(x)$, then so is $F_2(x) = F_1(x) + C$, where C is an arbitrary constant. For this reason, if $F(x)$ is a particular indefinite integral of $f(x)$, it is customary to write

$$\int f(x)\,dx = F(x) + C$$

where C represents an arbitrary additive constant, called the constant of integration. [M5.1, M5.2]

is also called: inverse derivative or anti-derivative or primitive of $f(x)$.

indefinite integration

is: the procedure whereby indefinite integrals are analysed and determined. [M5.2]

independent

describes: a set of simultaneous linear equations with the property that none of the equations can be expressed as a sum of multiples of the other equations.
[M1.4]

independent arbitrary constants

in: the solution to a differential equation

are: two or more arbitrary constants which cannot be replaced by a single arbitrary constant. [M6.1]

See essential constants.

independent errors

are: errors such that the size of one does not influence the size of the other. [P1.2]

independent oscillators

are: oscillators for which the displacement of one does not affect the restoring force acting on the other. [P5.1]

independent variable

in: an experiment (or a calculation)

is: the quantity whose value is set by the experimenter (or by the person doing the calculation). [P1.3]

controls: the value of any dependent variables to which it is connected by a set of experimental observations (or by a mathematical function). [M1.3]

on graphs is plotted: conventionally along the horizontal axis. [P1.3]

index

is: a synonym for power (mathematical) or exponent. [M1.1]

as a term is sometimes used: in preference to power because of the possibility of confusing power (mathematical) with power (physical). [M1.1]

induced current

is: a current produced by electromagnetic induction in a complete circuit.
[P4.4]

is exemplified: by the current that flows around a closed loop of wire, placed with its plane perpendicular to a uniform magnetic field, when either the magnitude of the field is changed, or when the area of the loop is altered.

induced fission

is: a process in which an atomic nucleus is induced by an external agency to undergo nuclear fission. [P9.3]

is exemplified: by the fission of ${}^{235}_{92}U$ when induced by the absorption of a thermal neutron. [P9.3]

induced magnetisation

See magnetic induction.

induced voltage

in: a complete circuit of resistance R carrying an induced current I_{ind}

is: the voltage $V_{\mathrm{ind}} = I_{\mathrm{ind}}R$. [P4.4]

is described: in magnitude by Faraday's law: $V_{\mathrm{ind}} = |d\mathit{\Phi}/dt|$, where $d\mathit{\Phi}/dt$ is the rate of change of the flux linkage $\mathit{\Phi}$ through the relevant closed circuit. [P4.4]

is described: in polarity by Lenz's law, which says that the induced voltage will act to oppose the change that caused it. (For this reason it is sometimes said to be a back voltage or back e.m.f.) [P4.4]

may be determined in more general situations: e.g. between the ends of a conductor moving through a magnetic field, so that it cuts magnetic flux at the rate $d\mathit{\Phi}/dt$, by applying Faraday's law and Lenz's law, or by using the Lorentz force law. [P4.4]

inductance

is: the property of a coil which causes an induced voltage to arise across the coil when the current in the coil is changing (self inductance), or when the current in a nearby coil is changing (mutual inductance).

is also: an abbreviation for the coefficient of self inductance, L that quantifies the self inductance of a coil by means of the relation

$$V_{\rm ind} = L\left|\frac{dI}{dt}\right|$$

where $V_{\rm ind}$ is the magnitude of the induced voltage, and $|dI/dt|$ is the magnitude of the rate of change of the current in the coil. [P4.4, P4.5, P5.4]

The polarity of the voltage is such as to oppose the change in the current (Lenz's law): it is a back e.m.f. The back e.m.f. generated by an inductance L is $-LdI/dt$, so the voltage drop across such an inductance is LdI/dt.

has as its SI unit: the henry (H). [P5.4, P5.5]

induction (electromagnetic)

is: the phenomenon that gives rise to an induced voltage in a conductor due to the presence of a changing magnetic field, or because of relative motion between the conductor and a magnetic field.

induction (electrostatic)

See electrostatic induction.

induction (mathematical)

is: a technique of proving a theorem by showing that *if* a result is true for some value of a parameter, such as n, then it is also true for $n + 1$. Completion of the proof then consists of showing explicitly (and usually trivially) that the result is indeed true for the smallest allowable value of n.

inductive reactance

of: an inductor with inductance L when passing alternating current of angular frequency ω

is: the ratio of the peak voltage to the peak current, V_0/I_0. [P5.4, P5.5]

is given: by $X_L = \omega L$. [P5.4, P5.5]

See complex inductive reactance, impedance, reactance.

inductive time constant

is: the time for the induced voltage, magnetic flux or current in an inductive circuit to decay exponentially by a factor e. [P4.5]

is given: for a circuit with resistance R and self inductance L by $\tau = L/R$. [P4.5]

inductor

is: a coil designed to have a large inductance so as to produce a large induced voltage when the current in it changes. [P4.4, P4.5]

typically is: a solenoid with many closely-wound turns around a magnetic material (e.g. an iron core). [P4.5]

in a circuit is: a circuit component of fixed inductance and, ideally, negligible resistance. [P5.4, P5.5]

inelastic collision

is: a collision during which some or all of the kinetic energy is converted into other forms of energy. [P2.4, P2.5]

inequality

is: a mathematical statement expressing the fact that one number (or algebraic expression) is less than, or greater than, another. [M1.1]

may be combined with: the equality to express "greater than or equal to", or, "less than or equal to".

uses: one or more of the symbols: > (greater than), ≥ (greater than or equal to), < (less than), or ≤ (less than or equal to), or their variants. The symbols >> and << are used to express "much greater than" and "much less than", respectively. [M1.2]

inert gases

See noble gases.

inertia

of: a body

is: the tendency of the body to continue in a state of uniform motion. [P2.3]

is measured: by the inertial mass of the body, according to Newton's second law. [P2.3]

inertial confinement

is: confinement of a plasma by virtue of the inertia of the material in the plasma - so that it stays together for a sufficient time for nuclear fusion to begin within it. [P9.3]

requires: that the plasma be created within a very short time scale. This is done through irradiation by an intense pulsed laser beam or beam of particles. [P9.3]

inertial frame of reference

is: a frame of reference in which Newton's first law holds; that is, one which is not itself accelerating, and in which objects do not accelerate unless a resultant force (i.e. a net force) acts on them. [P2.3]

inertial mass

of: a body

is: the mass of the body as determined by its acceleration in response to a known applied force. (See Newton's second law of motion) [P2.3]

Contrast with gravitational mass.

infinite potential well

is: a potential well with infinitely high potential energy at the edges and thus capable of confining any particle, however high its (finite) energy. [P10.4]

infinite series

is: a series with an unlimited number of terms. [M1.7]

infinitesimal

is: a quantity that is much smaller than others under consideration, and which can be considered to vanish in an appropriate limit.

infinitesimal calculus

See calculus.

infinity

is: a concept used to represent a far larger number or quantity than any other under consideration. [M1.3, M1.7]

is also: used in the term “projecting to infinity” to indicate extending the varying quantity to a very distant point or time. [M2.3]

is denoted: by the infinity symbol, ∞

infinity symbol, ∞

is: a symbol used to represent a far larger number or quantity than any other under consideration. [M1.3, M1.7]

infrared (radiation)

is: a type of electromagnetic radiation characterized by wavelengths in the range between those of visible light and microwaves (i.e. approximately 700 nm to 1 mm).

See electromagnetic spectrum.

inhomogeneous differential equation

is: a differential equation which is not a homogeneous differential equation. [M6.3]

is exemplified by: $a\dfrac{d^2y}{dx^2} + b\dfrac{dy}{dx} + cy = d$

since at least one of the terms (the one on the right) is not proportional to y nor to any one of its derivatives.

initial conditions

are: the n conditions given with a differential equation of order n which specify the value of the dependent variable and of its derivatives up to order $(n - 1)$ at a particular value of the independent variable. [M6.1]

are sufficient: to determine the n essential constants which appear in the general solution to the differential equation. [M6.1]

describe: the initial state of a physical system at some initial time (usually $t = 0$) if the differential equation describes the behaviour of the system. [P5.4, P5.5]

initial phase

is synonymous: with phase constant. [M6.3, P5.5]

initial state

of: a system

is: the state of the system at the beginning of a process.

initial velocity

is: the velocity of a body or particle at the start of a period of time. [P2.1]

See uniform acceleration equations.

inner shell

of: an atom

is: an (electron) shell of lower energy (i.e. higher binding energy) than most of the other shells in the atom. (According to Bohr's model of the atom, electrons with such energies would be in orbits of relatively small radius.)

insoluble

describes: an equation (or system of simultaneous equations) which has no solution. [M1.4]

more loosely, also describes: an equation (or system of simultaneous equations) for which no formula or procedure for solving it is known. [M1.4]

instantaneous a.c. power

dissipated between: two points that differ in voltage by $V(t)$ and between which a current $I(t)$ flows

is given by: $P = V(t)I(t)$. [P5.4]

instantaneous acceleration

of: a particle (relative to a specific frame of reference)

at: a given time t

is: a vector quantity that specifies the rate of change of the particle's velocity $\boldsymbol{v} = (v_x, v_y, v_z)$ at time t. [M4.1, P2.1, P2.2]

is represented: by the vector $\boldsymbol{a} = d\boldsymbol{v}/dt$. That is, $a_x = dv_x/dt$, $a_y = dv_y/dt$, $a_z = dv_z/dt$. [M4.1, P2.1, P2.2]

has as its SI unit: $\mathrm{m\,s^{-2}}$. [M4.1]

can be determined: as the limiting value of average acceleration, calculated over shorter and shorter time intervals. [M4.1, P2.1, P2.2]

also can be determined: as the gradient of a velocity-time graph at time t. [M4.1, P2.1, P2.2]

usually is known: simply as acceleration. [M4.1, P2.1, P2.2]

instantaneous angular speed

is: the modulus of the instantaneous rate of change of angular position with time, i.e. $\omega = |d\theta/dt|$. [P2.6]

is also: the magnitude of the angular velocity.

instantaneous speed

is: the magnitude of the instantaneous velocity. [M4.1]

instantaneous velocity

of: a particle (relative to a specific frame of reference)

at: a given time t

is: a vector quantity that specifies how fast a body is moving and its direction of motion. [M2.4]

is more specifically: the rate of change of the particle's position $\boldsymbol{r} = (x, y, z)$ at time t [M4.1, M5.1, P2.1, P2.2]

is represented: by the vector $\boldsymbol{v} = d\boldsymbol{r}/dt$. That is, $v_x = dx/dt$, $v_y = dy/dt$, $v_z = dz/dt$. [M4.1, M5.1, P2.1, P2.2]

has as its SI unit: $\mathrm{m\,s^{-1}}$. [M4.1]

can be determined: as the limiting value of average velocity, calculated over shorter and shorter time intervals. [M4.1, P2.1, P2.2]

also can be determined: as the gradient of a position-time graph at time t. [M4.1, P2.1, P2.2]

usually is known: simply as velocity. [M4.1, P2.1, P2.2]

has: as its magnitude, the speed of the particle. [M2.4, P2.1, P2.2]

See relative velocity.

insulator (electrical)

See electrical insulator.

insulator (thermal)

is: a material with a low coefficient of thermal conductivity, typically less than $1.0\,\mathrm{W\,m^{-1}\,K^{-1}}$.

integer

is: a positive or negative whole number, or zero i.e. an element of the set
$\{\ldots -2, -1, 0, 1, 2, 3, \ldots\}$. [M1.2]

integral

is: a term used to refer to a definite integral or an indefinite integral. [M5.1, P2.4]

integral sign

is: the distorted 'S' symbol $\int$ used (together with an element of integration) to indicate the operation of integration. [M5.1, M5.2]

integrand

is: the function to be integrated in a integral. [M5.1, M5.2]

integrating factor

is: a function by which each term of a linear first-order differential equation is multiplied, in order that the equation may be solved by direct integration.
[M6.2]

integration

is: the process of analysing and evaluating an integral. [M5.1, M5.2, P2.4]

See definite integral and/or indefinite integral for further details, or see integration in the Maths handbook.

integration by parts

is: a technique of integration applicable to (some) functions that may be written as products of functions, based on the formula

$$\int f(x)\,g(x)\,dx = F(x)g(x) - \int F(x)\frac{dg}{dx}\,dx \quad [\text{M5.3}]$$

See techniques of integration in the Maths handbook.

integration by substitution

is: a technique of integration based on the replacement of the original integration variable by a new integration variable that is a function of the original variable.

See techniques of integration in the Maths handbook.

integration element

See definite integral or indefinite integral.

integration variable

is: the variable over which the integration is performed.

See also definite integral or indefinite integral.

intensity

of: a wave or beam

is: the amount of energy transported by the wave or beam per unit time per unit area perpendicular to the direction of propagation. [P6.1]

intensity level

of: a sound of intensity I (measured in $\mathrm{W\,m^{-2}}$)

is given by:

$$\beta = 10 \times \log_{10}\left(\frac{I}{I_0}\right) \text{ decibel}$$

where $I_0 = 1 \times 10^{-12}\,\mathrm{W\,m^{-2}}$. [P5.7]

has as its SI unit: the decibel, represented by the symbol dB. Audible, non-painful sounds usually have intensity levels in the range 0 to 120 dB. [P5.7]

interaction (fundamental)

describes: the action of fundamental forces between particles. [P9.1]

is classified: in four kinds: gravitational, electromagnetic, strong (nuclear) and weak (nuclear), although it is now known that the weak and electromagnetic interactions are linked. [P9.1]

interatomic or intermolecular forces

are: the forces that act among atoms or molecules. [P7.1, P7.5]

normally are important: in the liquid phase or solid phase. [P7.1, P7.5]

result: essentially from a combination of electrostatic forces and quantum mechanical exchange effects. [P7.1, P7.5]

intercept

of: a straight line

is: the constant c in the equation of a straight line, $y = mx + c$.   [P1.3]

therefore is: the value of y when $x = 0$, i.e. the point at which the straight line crosses the y-axis.   [M2.2, M3.1, P1.3]

more generally refers: to the common point of two straight lines that intersect.   [M2.1]

intercept form

of: the equation of a straight line

is: $\dfrac{x}{a}+\dfrac{y}{b}=1$

where the straight line meets the x-axis at a and the y-axis at b. [M1.3]

interface

between: one optical medium and another

is: a boundary surface at which a ray may undergo reflection or refraction. [P6.2]

is more generally: a surface separating two different materials.

interference

between: coherent waves in a region of space

is: the phenomenon that allows the waves to combine to result in a wave whose properties at any point are determined by the properties of the various contributing waves. (The procedure for combining the individual waves in simple (linear) cases is specified by the superposition principle.) [P5.6]

over the whole region produces: an interference pattern. [P6.1]

See constructive and destructive interference.

interference filter

when illuminated: from a specific direction

uses: the phenomenon of interference to prevent all but a narrow range of wavelengths from passing through. [P6.1]

typically consists: of a thin transparent coating on a glass base (in which case the interference is between beams successively reflected from the back and front surfaces of the coating), or of a thin cavity between two glass plates (in which case the interference is between beams successively reflected from the front and back surfaces of the cavity). [P6.1]

works: by accumulated destructive interference between all wavelengths which are not close to twice the path length between the two reflective surfaces. [P6.1]

interference fringes

are: patterns of bright and dark fringes produced by the interference of two or more coherent light beams. [P6.1]

can be observed: on a screen or directly. [P6.1]

are exemplified: by the two-slit interference pattern in Young's experiment. [P6.1]

interference pattern

is: the observed pattern of varying intensity that results from the interference of coherent waves (usually beams, often beams of light) over a region of space. [P6.1]

See diffraction pattern.

interior angle

is: the angle between two adjacent sides of a geometric figure, which is enclosed within the boundary of the figure. [M1.6]

is exemplified: by the three interior angles of any triangle, whose sum always is 180°. [M1.6]

intermolecular forces

See interatomic or intermolecular forces.

internal energy

of: a system

is: the energy arising from the kinetic energy of the system's constituents and the potential energy of their mutual interaction. [P7.3, P7.4, P7.5]

does not include: any contribution from the motion or position of the system as a whole. [P7.3]

changes: only as a result of heat transferred **to** the system or work done **by** (or **on**) the system, according to the first law of thermodynamics. Thus $\Delta U = \Delta Q - \Delta W$. [P7.3, P7.4]

is: a function of state of the system. [P7.3, P7.4]

internal force

is: a force which occurs within a system. [P2.5]

occurs: between a pair of interacting bodies. [P2.5]

is always: one of a pair of action-reaction forces associated with the pair of interacting bodies. [P2.5]

internal resistance

is: the intrinsic resistance of a voltage generator. [P4.1]

is also called: output resistance. [P4.1]

is responsible: for the decrease in terminal potential difference of a non-ideal voltage generator when the current through it increases. [P4.1]

International Practical Temperature Scale 1990

is: an internationally agreed set of devices and procedures for the measurement of temperature. [P7.2]

is: at the time of writing (August 1995), the latest in an evolving sequence of internationally agreed practical temperature scales. [P7.2]

embodies: the best advice for those who need to calibrate and/or use thermometry which is practical but which is also as close to the Kelvin temperature scale as modern instrumentation will allow. [P7.2]

interpolation

is: the process of using values of a dependent variable, measured at a finite set of values of the corresponding independent variable(s), to estimate the value of the dependent variable corresponding to a value of the independent variable(s) that falls between those at which measurements were made. [P1.3]

Contrast with extrapolation.

intersect

is: what two curves (including straight lines) do if they have a point in common.   [M2.1]

interval

is: an unbroken range of real numbers which may be regarded as a segment of the number line. [M4.4]

usually is specified: using inequality symbols, i.e. by statements such as $-2 < x \le 4$ or $1.2 \le x \le 3$. [M4.4]

may or may not include: the endpoints which are used to define it. [M4.4]

intrinsic angular momentum

See spin angular momentum.

intrinsic conduction

is: electrical conduction arising from charged particles present in a pure material (especially a semiconductor). [P11.4]

Contrast with impurity conduction.

invariant

under: a specified process or transformation

describes: a quantity that is left unchanged by the specified process or transformation. [P2.5]

is exemplified by: the numbers 0 and 1 which are invariant under the process of squaring numbers, or the centre of a sphere which is invariant under the process of rotating the sphere about an axis through its centre. [P2.5]

inverse derivative

is: the result of inverse differentiation. [M5.1]

See indefinite integral.

inverse differentiation

of: a function $f(x)$

is: the process of finding another function $F(x)$ called the inverse derivative or indefinite integral of $f(x)$. [M5.1, M5.2]

usually is called: indefinite integration. [M5.1, M5.2]

is also known as: anti-differentiation.

inverse function

of: $f(x)$

is: the function that reverses the action of $f(x)$. If f is the given function and g is its inverse, then $g(f(x)) = x$ for all x in the domain of f. [M1.3]

usually is denoted: by f^{-1} [M1.3]

should not be confused: with a reciprocal. Note that a special notation is adopted when dealing with the inverses of the exponential, logarithmic, trigonometric functions and hyperbolic functions. [M1.3]

inverse hyperbolic functions

are: the inverse functions of the basic hyperbolic functions and the reciprocal hyperbolic functions.

comprise: $\text{arcsinh}\,(x)$, $\text{arccosh}\,(x)$, $\text{arctanh}\,(x)$, $\text{arccosech}\,(x)$, $\text{arcsech}\,(x)$ and $\text{arccoth}\,(x)$. [M4.6]

See hyperbolic functions in the Maths handbook for further details.

inverse power

is: a term used to refer to a negative power (i.e. index) or powers appearing in the denominator of a mathematical expression. Thus Newton's law of gravitation (an inverse square law) may be referred to as an inverse power law. [M1.1]

inverse reciprocal trigonometric functions

are: the inverses of the reciprocal trigonometric functions. [M1.6]

comprise: the functions $\mathrm{arcsec}\,(x)$, $\mathrm{arccosec}\,(x)$, $\mathrm{arccot}\,(x)$. [M1.6]

See inverse trigonometric functions and trigonometric functions in the Maths handbook.

inverse square law

states: that a quantity decreases as the square of some relevant distance. [P2.4, P3.1, P3.3]

is exemplified: by Newton's law of gravitation and Coulomb's law:

$$\boldsymbol{F}_{\text{grav}} = -\frac{Gm_1m_2}{r^2}\hat{\boldsymbol{r}}$$

$$\boldsymbol{F}_{\text{el}} = \frac{q_1q_2}{4\pi\varepsilon_0 r^2}\hat{\boldsymbol{r}}$$ [P2.4, P3.1, P3.3]

See also inverse square law of illumination.

inverse square law of illumination

is: a law relating the intensity of electromagnetic radiation, or other wave, radiating from a point source to the inverse square of the distance from that source. [P5.7, P6.1]

is a consequence: of geometry and the conservation of energy. [P6.1]

is exemplified: by the intensity of a propagating spherical wave, such as a sound wave or a light wave. [P5.7, P6.1]

inverse trigonometric functions

are: the inverses of the standard trigonometric functions and (usually) the inverses of the related reciprocal trigonometric functions. [M1.6]

comprise: $\arcsin(x)$, $\arccos(x)$, $\arctan(x)$ and $\mathrm{arcsec}(x)$, $\mathrm{arccosec}(x)$, $\mathrm{arccot}(x)$. [M1.6]

See trigonometric functions in the Maths handbook for further details.

inversely proportional

describes: the relationship between two variables, x and y, if their product xy remains constant as x and y are varied. [M1.1]

is symbolized: $x \propto 1/y$. [M1.1]

Contrast with directly proportional.

inversion rule

states: that if $y = g(x)$ is a function of x which possesses an inverse function $x = h(y)$ then

$$\frac{dg}{dx} = \frac{1}{dh/dy}$$ [M4.3, M5.3, M6.2]

less formally, states: that $dy/dx = 1/(dx/dy)$. [M4.3, M5.3, M6.2]

inverted

means: upside down - as for an image formed by a lens or a mirror, when the image is the other way up as compared with the object. [P6.3]

ion

is: formed from an atom or molecule that has become electrically charged by ionization, usually through having lost or gained one or more electrons.

can be symbolized: by means of an appropriate chemical symbol together with a superscript indicating the sign of the ion's charge and its magnitude in units of *e* (e.g. Na^+, Cl^- or He^{2+}). [P8.1, P8.2]

has properties: that are usually quite different from the atom or molecule.

ionic bonding

is: a type of chemical bonding in which appropriate chemical substances are regarded as collections of ions. The principal force between the ions is the attraction between their opposite charges. [P8.4]

ionization

is: the process in which an atom is stripped of one or more of its electrons.

ionization energy

of: an atom (in a specified state, usually the ground state)

is: the minimum energy required to just remove the most weakly bound electron from the atom, and thereby to create a singly charged ion. [P8.2, P8.3, P8.4]

is also called: the first ionization energy of the atom. [P8.2, P8.3, P8.4]

is synonymous: with ionization potential. [P8.2]

ionization level

for: an electron

in: an atom

is: the energy level that marks the boundary between the negative energy levels of the bound states of the atom and the positive energies of the unbound states in the continuum. [P8.2, P8.3]

therefore is: the energy below which the electron must remain bound in the atom, and above which the electron becomes free from the atom. [P8.2, P8.3]

thus is taken: as the energy zero. [P8.2, P8.3]

ionization potential

is synonymous: with ionization energy. [P8.2]

ionized

describes: an atom or molecule which has become an ion. [P8.2, P11.3]

ionizing radiation

is: radiation (particles or photons) that can produce ionization in matter. [P9.2, P9.3]

therefore is: radiation which is sufficiently energetic to supply the necessary ionization energy and which is capable of interacting with electrons. [P9.2, P9.3]

is exemplified: by X-rays, α-particles, β-particles, γ-radiation and neutrons. [P9.2, P9.3]

iris

of: the eye

is: the coloured tissue in front of the lens and whose variable aperture, the pupil, controls the amount of light entering the eye. [P6.4]

iris diaphragm

is: a mechanical system of overlapping metal leaves which can form an aperture of variable size for a lens. [P6.4]

irradiation

is: the process of exposing something to radiation.

irrational number

is: a real number which cannot be expressed as a fraction (for example, e, π or, $\sqrt{2}$). [M1.2, M3.1]

irreversible process

is: a process in which it is not possible to return the system undergoing the process and its environment to their original states after the process has taken place. [P7.4]

increases: the entropy of the Universe (system + environment), according to the principle of entropy increase. [P7.4]

isobaric

describes: a process that takes place at constant pressure. [P7.4]

isochoric

describes: a process that takes place at constant volume. [P7.4]

isolated system

is: a system which does not interact with its environment.

has: different shades of meaning for different kinds of system.

is exemplified: by a mechanical system that is not acted upon by any external forces and which neither gains or loses energy. For such a system, the only forces acting are internal forces, and the total energy and the total momentum are conserved. [P2.4, P2.5]

isosceles triangle

is: a triangle with two sides of equal length, and hence with two equal interior angles. [M1.6]

isotherm

is: a curve on a *PVT*-surface (or some similar surface), or on one of its projections, passing only through points that represent states of the same temperature. [P7.4]

isothermal condition

for: a fixed quantity of ideal gas

is: a condition that characterises an isothermal process in the sense that all the states involved in the process must satisfy the condition. (Though it is not the case that all states satisfying the condition must be involved in the process.) [P7.4]

may be written: in the form PV = constant, where the value of the constant is characteristic of the process. [P7.3, P7.4]

may also be written: in the form $P_\mathrm{a}V_\mathrm{a} = P_\mathrm{b}V_\mathrm{b}$. [P7.3, P7.4]

isothermal phase transition

is: a phase transition that occurs without any change of temperature. (Temperature changes during a phase transition such as melting can be brought about by changing the pressure or other external conditions during the transition.)

isothermal process

is: a process that occurs at constant temperature, so that $\Delta T = 0$. [P7.3]

is characterized: for an ideal gas by the isothermal condition PV = constant, where P is the pressure, V is the volume, and the constant is determined by the initial state of the gas. [P7.3]

isotopes

of: a given chemical element

have: the same number of protons in their nuclei as all other isotopes of that element, but different numbers of neutrons. [P9.1]

therefore have: the same atomic number but different mass numbers. [P8.1]

sometimes are referred to loosely: as nuclides. [P9.1, P9.2]

iteration

is: a numerical procedure which uses a formula (called an iteration formula) to obtain a succession of approximations (usually) to the root of an equation.
[M1.4]

iteration formula

See iteration.

iterative methods

See iteration.

I-*V* characteristic

for: any circuit component

of: an electric circuit

is: a graph of current, I against voltage, V. [P4.1]

See linear component.

Josephson junction

is: a device in which a thin electrically insulating film is sandwiched between two pieces of superconductor. The existence of quantum tunnelling allows this device to exhibit highly non-classical behaviour that is exploited in more complicated devices such as SQUIDS. [P11.1]

joule, J

is: the (derived) SI unit of energy and work.

is defined: by $1\,\mathrm{J} = 1\,\mathrm{N\,m} = 1\,\mathrm{kg\,m^2\,s^{-2}}$.

represents: the energy transferred when the point of application of a constant force of magnitude one newton is displaced by one metre in the direction of the force. [P2.4, P2.5]

Joule heating

is: heating produced by an electric current in a resistive circuit component.

is explained microscopically: in a metal, as the result of collisions between electrons and lattice ions. [P4.1]

kelvin, K

is: the SI unit of temperature, one of the seven base units.

is defined: as 1/273.16 of the triple-point temperature of H_2O on the thermodynamic Kelvin temperature scale.

is equal: to a degree Celsius (°C), though due to differences in the zero points of the Celsius and thermodynamic Kelvin temperature scales, the absolute temperature of an object in kelvin (T_K) is related to its Celsius temperature (T_C) by the formula:

$$T_K/\mathrm{K} = T_C/(°\mathrm{C}) + 273.15$$ [P7.2]

is never referred to: as degrees kelvin or °K but only as kelvin or K.

Kelvin temperature scale

See thermodynamic Kelvin temperature scale.

Kepler's laws of planetary motion

describe (approximately): the basic features of planetary motion. [P2.8, P3.2]

state: that

1 The orbits of planets in the solar system are ellipses with the Sun at one focus.

2 The radial line from the Sun to a planet sweeps out equal areas in equal intervals of time.

3 The square of the orbital period is proportional to the cube of the semi-major axis of the ellipse. [P2.8, P3.2]

were deduced empirically: by Johannes Kepler (1571-1630). [P3.2]

were later explained: by Isaac Newton (1642-1727), using Newton's laws of motion and Newton's law of gravitation. [P3.2]

kilogram, kg

is: the SI unit of mass, one of the seven base units. [P1.1, P2.3]

is defined: by the international prototype kilogram, which is kept at the International Bureau of Weights and Measures at Sevres in France, and takes the form of a cylinder made from a platinum-iridium alloy. Replicas are kept in other standards laboratories.

kilowatthour, kWh

is: a non-SI unit of energy.

is defined: by $1\,\text{kWh} = 1\,\text{kW} \times 1\,\text{h} = 3.6 \times 10^6\,\text{J}$
i.e. 3.6×10^6 joule. [P4.1]

commonly is used: by electricity supply companies for billing customers and referred to in that context as the 'unit' of electrical energy.

kinematics

is: the branch of mechanics concerned with motion and its description, but not its causes.   [M5.1, P2.3]

Compare with dynamics.

kinetic energy

is: the energy which an object possesses by virtue of its motion. An object of mass m moving with speed v has a translational kinetic energy $E_{\text{tran}} = \frac{1}{2}mv^2$. [P2.4]

is classified: in three types: translational kinetic energy, vibrational kinetic energy and rotational kinetic energy. [P2.4]

kinetic theory

is: a theory which attempts to explain the bulk thermodynamic and transport properties of systems in terms of the interactions of atoms or molecules (often treated as hard spheres in rapid unhindered motion apart from collisions and encounters with the walls of a containing vessel, and usually subject to Newton's laws of motion), and generally assuming that the energy and momentum is randomly distributed among the particles in the system. [P7.5]

kinetic theory of ideal gases

is: kinetic theory specifically applied to the model system of the ideal gas, leading to the equation $PV = \frac{1}{3}Nm\langle v^2 \rangle = \frac{2}{3}N\langle E_{\rm kin} \rangle$ where $\langle v^2 \rangle$ is the mean of the squares of the molecular speeds and $\langle E_{\rm kin} \rangle$ is the average translational kinetic energy per molecule. The gas has pressure P volume V and contains N molecules, each of mass m. [P7.3, P7.5]

Kirchhoff's laws

for: the an electric current in a circuit.

See Kirchhoff's current law and Kirchhoff's voltage law.

Kirchhoff's current law

states: that the algebraic sum of the currents at a node is zero, or equivalently that the total current flowing into each node is equal to the total current flowing out of the node. [P4.1]

Kirchhoff's voltage law

states: that the algebraic sum of the voltages across all electrical components in a closed loop or mesh is zero, or equivalently, the sum of the voltage increases is matched by the sum of the voltage decreases. [P4.1]

lag

See phase lag.

lanthanides

are: the 14 closely similar chemical elements from La to Yb (atomic numbers from 57-70) inclusive. [P8.4]

span: a region of the periodic table in which the 4f subshell of atoms in their ground state is being progressively filled. [P8.4]

Laplace's equation

is: a linear, homogeneous, second-order, partial differential equation of the form

$$\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} + \frac{\partial^2 U}{\partial z^2} = 0 \quad [\text{M6.4}]$$

laser

is: a light source of high coherence that produces a nearly parallel beam, often of high intensity. [P6.1]

is named: for Light Amplification by Stimulated Emission of Radiation. [P6.1]

laser action

is: the process by which stimulated emission produces amplification of light within the cavity of a laser. [P5.3]

latent heat

is: the heat absorbed or emitted by a sample during an isothermal phase transition. [P7.4]

See also specific latent heat, molar latent heat.

lateral magnification

in: an optical system

is: the ratio of the size of an extended image to the size of the corresponding extended object, when measured normal to the optical axis. [P6.3]

for a lens is called: lens transverse magnification. [P6.3]

lattice

is: a regular array of points in space that underlies the specification of crystal structure in terms of a given arrangement of one or more atoms reproduced at every point of the lattice. [P11.4]

is less rigorously: a regular array of points within a (crystalline) solid about which atoms or ions may be considered to oscillate. [P4.1]

law of inertia

See Newton’s first law of motion.

law of physics

is: a relationship between physical variables that is believed to be valid under a wide range of circumstances and is (ideally) well supported by experimental evidence.

law of reflection

for: a ray of light

from: a surface

states: that

(i) the reflected ray, the incident ray and the normal to the surface all lie in one plane, and

(ii) the angle of reflection is always equal to the angle of incidence: $\theta_i = \theta_R$. [P6.1, P6.2]

law of refraction

of: a ray of light

from: one medium into another

states: that

(i) the incident ray, the refracted ray and the normal to the boundary all lie in one plane, and

(ii) the angle of incidence θ_1 and the angle of refraction θ_2 are related by Snell's law:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\mu_2}{\mu_1} = \text{constant}$$

where μ_1 and μ_2 are the refractive indices of the two media, respectively. (The refractive indices normally depend somewhat on the frequency of the light giving rise to dispersion.) [P6.1, P6.2]

law of static moments

states: that a body is in rotational equilibrium if the clockwise moments balance the counter clockwise moments in every plane. [P2.7]

law of terrestrial gravitation

states: that close to the Earth's surface, any body of mass m experiences a gravitational force that acts vertically downwards and has magnitude mg, where g is the magnitude of the acceleration due to gravity (approximately $9.81\,\mathrm{N\,m\,s^{-2}}$). [P2.3]

law of universal gravitation

was first formulated: by Isaac Newton (1642-1727). [P2.3, P3.1]

states: that every particle of matter in the Universe attracts every other particle with a force that is directly proportional to the product of the masses of the particles and inversely proportional to the square of the distance between them. [P2.3, P3.1]

can be expressed: for two masses m_1 and m_2 separated by a distance r as

$$\boldsymbol{F}_{\rm grav} = \boldsymbol{F}_{21} = \frac{-Gm_1m_2}{r^2}\,\hat{\boldsymbol{r}}$$

as the force on m_2 due to m_1

where G is Newton's universal gravitational constant and $\hat{\boldsymbol{r}}$ is a unit vector pointing from m_1 to m_2. [P2.3, P3.1, P3.2]

also known as: universal law of gravitation.

Lawson criterion

for: 'break even' conditions in a plasma fusion reactor, so that fusion energy output is just equal to the energy expended to produce this output

requires: that the product of the number density of nuclei in the plasma and the confinement time be greater than a given value. This value depends on the reaction concerned and the temperature. [P9.3]

LCR circuit

is: an electrical circuit containing an inductance L, a capacitance C and a resistance R.

lead

See phase lead.

lead-acid accumulator

is: a storage cell made from two lead electrodes with a sulphuric acid electrolyte, 'charged' by passing a direct current through it. [P4.5]

is also: a battery of such storage cells. [P4.5]

is used: to make car batteries. [P4.5]

least distance of distinct vision

is: the distance from the eye to the closest point at which objects can be clearly focused (i.e. the near point). [P6.4]

varies: with age but is commonly taken to be 25 cm. [P6.4]

Leclanché dry cell

is: an electric storage cell consisting of a carbon electrode surrounded by a moist electrolytic paste enclosed in a zinc case which forms the cell's other terminal. [P4.5]

is used widely: as a portable power source, e.g. in torches and portable radios, but is increasingly being replaced by the broadly similar alkaline cell. [P4.5]

left-handed (Cartesian) coordinate system

is: a three-dimensional Cartesian coordinate system (consisting of three mutually perpendicular coordinate axes which meet at a point called the origin), in which an observer located at the origin and looking along the *z*-axis in the direction of increasing *z* finds that a left-handed screw motion through 90° (i.e. a 90° anticlockwise rotation) is needed to bring the *x*-axis into the position previously occupied by the *y*-axis. [P6.2]

Contrast with right-handed coordinate system, which is more commonly used.

length

is: one of the fundamental dimensional quantities of mechanics (along with mass and time).

is used: to describe the distance from one end of an object or interval to the other end.

has as its SI unit: the metre (m), one of the seven base units.

lens

is: a piece of glass or other transparent material shaped so that its surfaces curve inwards or outwards. Usually the surfaces are spherical in shape. [P6.3]

is used: generally to make parallel light converge to form an image, or to form parallel light from light diverging from an object. [P6.3]

lens (of eye)

is: the flexible lens of the eye. [P6.4]

has: a focal length which can be varied by change of the shape of the lens, through contraction of the ciliary muscles. [P6.4]

lens maker's equation

is: an equation which relates the focal length f of a lens to the radii of curvature, r_1 and r_2 of its surfaces and the refractive index μ of the material used:

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$ [P6.3]

lens transverse magnification

is: the lateral magnification of a lens. [P6.3]

therefore is: the ratio of image height to object height measured in the direction perpendicular to the optical axis of the lens. [P6.3]

Lenz's law

states: that the polarity of any induced voltage or the direction of any induced current is such as to oppose the change causing it. (This law is a consequence of the law of conservation of energy.) [P4.4]

lever arm

of: a force causing, or tending to cause, rotation about a fulcrum

is: the perpendicular distance between the line of action of the force and the fulcrum. [P4.3]

lepton

See elementary particle.

Lewis structure

is: a diagram, named after the American chemist Gilbert Lewis (1875-1946), which shows how the outer electrons of the atoms in a chemical compound are shared in order to create electron pair bonds, in accordance with the theory of covalent bonding. [P8.4]

light

is: a form of electromagnetic radiation, visible to the human eye, and characterized by wavelengths in the approximate range 400 nm to 700 nm.

See electromagnetic spectrum.

light damping

of: a damped oscillator

is: the condition in which the oscillator will complete many oscillations (with gradually decreasing amplitude) before coming to rest. [P5.2, P5.5]

is often used as synonymous: with underdamping.

See damped mechanical oscillator and/or damped electrical oscillator for further details.

Contrast with critical damping and heavy damping.

light ray

is: a directed line (i.e. a line with an arrow on it) drawn to represent the passage (or potential passage) of light. [P6.1, P6.2]

usually is drawn: at right angles to the wavefront. [P6.1, P6.2]

has direction: which indicates the direction of energy flow. [P6.1, P6.2]

normally is restricted: to situations in which diffraction effects are negligible. [P6.1, P6.2]

light wave

is: an electromagnetic wave with a wavelength in the approximate range 400 nm to 700 nm that can be used to model certain aspects of the behaviour of light.

limit

of: the function $f(x)$

as: x approaches a

if: $f(x)$ can be made as close as we wish to L by making x sufficiently close to a

is: L. [M4.1, M4.2, P2.1]

is indicated: by writing $\lim\limits_{x \to a} \big(f(x)\big) = L$. [M1.5]

is exemplified: by $\lim\limits_{x \to \infty} \left(\dfrac{1}{x}\right) = 0$. [M1.5]

limit of a sequence

See convergent sequence.

limits of integration

refers: to the upper limit of integration and lower limit of integration. [M5.1]

See definite integral.

line

is: an abbreviation for straight line.

line integral

from: point A to point B

along: a curve C in three (or possibly two) dimensions

of: a vector quantity $\boldsymbol{F}(x, y, z)$ that depends on position and is defined at all points on C

is given: by

$$\int_{\mathrm{A}}^{\mathrm{B}} \boldsymbol{F} \cdot d\boldsymbol{s} = \lim_{\Delta \boldsymbol{s} \to 0} \sum \boldsymbol{F} \cdot \Delta \boldsymbol{s}$$

where: $\Delta \boldsymbol{s}$ is a small displacement along C, and the sum is over a sequence of small displacements that lead from A to B along C. Note that in this definition $\boldsymbol{F} \cdot \Delta \boldsymbol{s}$ represents a scalar product. [P2.4]

line of action (of a vector)

of: a vector (particularly, though not necessarily, a force)

is: a construction line of indefinite length running through the vector. [P2.7]

is useful: for calculating moments and in analysing problems. [P2.7]

line segment

is: a finite part of a straight line.

line source

is: a source of light whose height is generally much greater than its width. Ideally the width should be less than the wavelength of the light and the height much greater than the wavelength of the light. [P6.1]

line spectrum

of: electromagnetic radiation (usually from a specified source)

describes: the emission spectrum or the absorption spectrum when these involve radiation of definite characteristic wavelengths. [P8.2]

is more specifically called: the emission line spectrum or the absorption line spectrum. [P8.2]

linear

describes: a linear function or its corresponding straight line graph. [P1.3]

linear combination

of: two quantities or expressions y_1 and y_2 (often two solutions to a differential equation)

is: a quantity or expression of the form $ay_1 + by_2$, where a and b are constants. [M5.2, P5.6]

linear component

of: an electric circuit

is: a circuit component in which the current I is directly proportional to the applied voltage V, giving rise to an I–V characteristic that is a straight line through the origin. [P4.1]

linear differential equation

in: a dependent variable y

is: a differential equation in which every term that contains y at all contains no powers of y and its derivatives other than the first, no functions of y and its derivatives, and no products of y and its derivatives among themselves. [M6.1, P5.5]

therefore is: of first degree. [M6.1]

is exemplified: by

$$a(x)\frac{d^n y}{dx^n}+b(x)\frac{d^{n-1}y}{dx^{n-1}}+\ldots+q(x)\frac{dy}{dx}+r(x)y=f(x).$$

(This is linear in y, but is also inhomogeneous unless $f(x) = 0$)

has the property: if homogeneous, that a linear combination of solutions is also a solution.

linear differential equation with constant coefficients

is: a linear differential equation in which the coefficients of y and its derivatives are constants rather than functions of x. [M6.2, M6.3]

linear energy density

in: a one-dimensional system

is: the energy per unit length. If ΔE is the energy associated with a short length Δl, centred on a point with position coordinate x at time t, then the linear energy density at point x at time t is

$$D_E(x,t) = \lim_{\Delta l \to 0}\left(\frac{\Delta E}{\Delta l}\right). \quad [\text{P5.6}]$$

has as its SI unit: the joule per metre (J m^{-1}), though this is identical to the newton (N). [P5.6]

linear equation

in: a variable x

is: an equation that may be written in the form $ax + b = 0$, where a and b are independent of x. [M1.4]

therefore is: a polynomial equation in x of degree 1. [M1.4]

linear form

is: an expression which involves only the first power of the independent variable.

is exemplified: by $3x + 2(x - 1)$ but *not* by $3/(x - 1)$.

linear function

is: a function of the form $f(x) = ax + b$, (the right-hand side is a linear form). [M1.4, P1.3]

therefore is: a function whose graph is a straight line. [M1.3]

linear homogeneous differential equation

is: a linear differential equation of the form

$$a(x)\frac{d^n y}{dx^n} + b(x)\frac{d^{n-1} y}{dx^{n-1}} + \ldots + q(x)\frac{dy}{dx} + r(x)y = 0 \quad [\text{M6.3}]$$

contains: no non-zero term that does not involve the dependent variable y or one of its derivatives. [M6.3]

in particular contains: no constant term. [M6.3]

has the property: that a linear combination of its solutions is also a solution.

linear inhomogeneous differential equation

is: a linear differential equation that is not homogeneous. [M6.3]

linear mass density

of: a uniform body (particularly a body of uniform cross-sectional area, such as a string) of mass M and length L

is: the mass per unit length of the body, M/L

is defined more generally: at a point with position coordinate x in a (possibly non-uniform) body by

$$\rho(x) = \lim_{\Delta l \to 0}\left(\frac{\Delta m}{\Delta l}\right)$$

where Δm is the mass of a small element of the body, of length Δl centred on the point specified by x.

linear momentum

of: a body

is given: by $\boldsymbol{p} = m\boldsymbol{v}$, where m is the mass of the body and $\boldsymbol{v}$ is the velocity of the centre of mass of the body. [P2.5]

is equal: for a system of particles or bodies, to the vector sum of the individual momenta. [P2.5]

is fully specified: by giving *both* its magnitude and its direction. [P2.5]

is conserved: for a system of interacting objects which are not subjected to external forces. The bodies collide and exchange momentum with each other, but the total momentum is constant. [P2.5]

at high speeds must be replaced by: relativistic momentum. [P2.5]

linear motion

of: an object

is: motion of the object along a straight line.

can be represented: if the straight line is taken to be the x-axis of a Cartesian coordinate system, in terms of the instantaneous position, instantaneous velocity and instantaneous acceleration of the object: $x(t)$, $v_x(t)$ and $a_x(t)$. [M4.1, M5.1, P2.1]

linear relationship

between: two variables (x and y say)

can be represented: by a linear function or a linear (i.e. straight line) graph. [P1.3]

is exemplified: by $y = mx + c$ where m and c are constants.

linear restoring force

is: a force, directed towards a fixed point, that is linearly proportional to the displacement from that point and in the opposite direction to that displacement. [P5.1]

in one dimension may be written: $F_x = -kx$, where x is the displacement from the fixed point. A particle moving under the influence of such a force (and no other) will execute simple harmonic motion about the fixed point. [P5.1]

linear second-order differential equation

is: a differential equation in which every term is linear in a single variable or one of its derivatives, and where the highest derivative appearing is the second derivative. [P5.3]

is exemplified: by the equation of the linearly damped harmonic oscillator.

linear system

is: an equilibrium system in which the response of the system (e.g. the restoring force) is linearly dependent on displacement from equilibrium. [P5.1]

linearity

of: an equation (such as the wave equation, the time-dependent Schrödinger equation, or a general linear homogeneous differential equation)

is: a property whereby if y_1 and y_2 are both solutions, then so is any linear combination of the form $ay_1 + by_2$, where a and b are constants. [P5.6]

linearization

is: the procedure whereby a non-linear relationship between two or more variables (x and y say) is represented by a linear relationship between two or more other variables (u and v say) which are expressed in terms of the original variables. In appropriate circumstance, this process may allow the constants involved in the original non-linear relationship to be determined from an analysis based on the corresponding linear relationship. [P1.3]

also can describe: the procedure whereby a non-linear relationship between variables is approximated by a linear relationship between the same variables. [M6.1, P1.3]

linearly damped harmonic oscillator

is: a harmonic oscillator with a damping force which depends linearly on the velocity of the oscillator, or on the first derivative of the displacement of the oscillator. [P5.3]

is exemplified: by a damped mechanical oscillator with the equation of motion

$$m\frac{d^2x}{dt^2} = -kx - b\frac{dx}{dt}$$

linearly independent

describes: a set (e.g. a set of functions) in which no element can be expressed as a linear combination of other elements of the set.

linearly polarized

describes: an electromagnetic wave whose electric field oscillates in the same plane at all points. [P6.1]

also known as: plane polarized.

liquid phase

is: the state of fluid matter characterized by a definite volume but no definite shape. [P7.1]

Lissajous figures

are: figures which result when two simple harmonic motions, which may differ in amplitude, frequency or phase, are added in perpendicular directions. [P5.1]

normally are viewed: on an oscilloscope. [P5.1]

litre, ℓ

is: a non-SI unit of volume.

is defined: by $1\ \ell = 10^{-3}\ \mathrm{m}^3$ (i.e. 10^{-3} metre cubed).

load resistor

is: a resistor that is treated as 'external' to the circuit that supplies it with current. [P4.1]

loading curve

is: a graph of stress against strain for a material.

local action

is: the destruction or permanent change of an electrode in a storage cell as a result of chemical reactions. [P4.5]

local extrema

is: a collective term for local maxima and local minima. [M4.4]

local maximum

is: a point $(a, f(a))$ on the graph of a function $f(x)$ for which $f(x) \le f(a)$ for all points x close to a. At such a point, $df/dx = 0$ and $f(x)$ is said to be stationary.

always exists: if $df/dx = 0$ and $d^2f/dx^2 < 0$. This is a sufficient condition. [M4.4, P6.2]

See stationary points and graph sketching in the Maths handbook.

local minimum

is: a point $(a, f(a))$ on the graph of a function $f(x)$ for which $f(x) \geq f(a)$ for all points x close to a. At such a point, $df/dx = 0$ and $f(x)$ is said to be stationary.

always exists: if $df/dx = 0$ and $d^2f/dx^2 > 0$. This is a sufficient condition. [M4.4, P6.2]

See stationary points and graph sketching in the Maths handbook.

localized particle

is: a particle whose position is known, at least within prescribed limits. [P10.2]

locus

is: a collection of points specified by some conditions. [M2.1]

logarithm to base 10

of: a number, x

is: the number, y which satisfies the equation, $x = 10^y$. [M1.5]

usually is written: as $\log_{10}(x)$ or $\log_{10} x$. [M1.5]

sometimes is called: the common logarithm. (This does *not* imply that it is more common than the natural logarithm in physics!) [M1.5]

logarithm to base *a*

of: a number, x

is: the number, y which satisfies the equation, $x = a^y$. [M1.5]

usually is written: as $\log_a(x)$. [M1.5]

logarithm to base e

of: a number, x

is: the number, y which satisfies the equation, $x = e^y$. [M1.5]

usually is written: as $\log_e(x)$, $\log_e x$ (or sometimes $\ln x$). [M1.5]

is known: as the natural logarithm. [M1.5]

less commonly is called: the Napierian logarithm or the hyperbolic logarithm. [M1.5]

logarithmic decrement

in: damped harmonic motion

is: the natural logarithm of the ratio of two successive displacement maxima, i.e. $\log_e[A(t+T)/A(t)]$, where T is the period of the oscillation. [P5.2]

is equal approximately: to $\pi\gamma/\omega_0$, where γ is the damping constant and ω_0 is the natural frequency of the oscillation. [P5.2]

See damped mechanical oscillator.

logarithmic function

is: a general term used to refer to any function that is the inverse of a function of the form $y = a^x$. [M1.5]

is indicated symbolically: by $x = \log_a(y)$, (so $x = \log_a(a^x)$), where the positive constant a is said to be the base of the logarithmic function. [M1.5]

long sight

See hypermytropia.

longitudinal wave

is: a wave in which the disturbances that constitute the wave involve displacements along the direction of propagation of the wave. [P5.6]

is exemplified: by a sound wave.

Contrast with transverse wave.

Lorentz force law

is: the general equation for the electromagnetic force, or Lorentz force, $\boldsymbol{F}$ on a particle of charge q in an electric field $\boldsymbol{E}$ and/or magnetic field $\boldsymbol{B}$. [P4.3]

is given: by $\boldsymbol{F} = q\,[\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B}\,]$. [P4.3]

Lorentz force

on: a charged particle

in: an electric field and/or a magnetic field

is found: by adding the separate forces that would be produced by each field acting independently, as described by the Lorentz force law. [M2.7, P4.3]

is also called: the electromagnetic force. [M2.7, P4.3]

low-pass filter

is: a filter circuit that passes low-frequency signals with relatively undiminished amplitude, but blocks high-frequency signals. [P5.4]

Contrast with high-pass filter.

lower limit (of summation)

See summation symbol.

lower limit (of integration)

See definite integral.

Lyman series

See series (spectroscopic).

Mach number

for: the speed of an object through a fluid

is: the ratio of the speed of the object to the local speed of sound. [P5.7]

macroscopic

describes: size scales sufficiently large that no account need be taken of the behaviour of individual atoms or molecules. [P7.2, P7.5]

magnet

is: a body which exhibits magnetism. [P4.2]

may: be either a permanent magnet or an electromagnet.

magnetic

is: the property of being attracted by a magnet.

magnetic confinement

of: a plasma

is achieved: by means of a magnetic field which produces an electromagnetic force on the plasma to prevent it from making contact with the vessel walls. [P9.3]

See plasma confinement.

magnetic dipole

is: a pair of equal strength magnetic north and south poles, as found in a bar magnet. [P4.2]

more generally is: any source of a magnetic field of the same configuration as that produced by a short bar magnet. [P4.2]

is exemplified: by a single loop of wire enclosing an area A and carrying a current I.

magnetic dipole moment

of: a magnetic dipole

is: a vector quantity μ that determines the torque acting on the magnetic dipole when it is placed in a given magnetic field (the torque depends on the orientation of the magnetic dipole). [P4.3]

is defined: as having a magnitude given by the ratio of the maximum torque magnitude to the magnitude of the magnetic field: $\mu = \Gamma/B$. (In vector form the torque is written as $\boldsymbol{\Gamma} = \boldsymbol{\mu} \times \boldsymbol{B}$) [P4.3]

is exemplified: for a magnetic dipole consisting of a single loop of wire of area A carrying a current I, by $\mu = IA$. If the loop has N turns, all in the same plane and each of area A then $\mu = NIA$. [P4.3]

magnetic field

throughout: a region of space

is: a vector field which gives rise to a magnetic force on moving charged particles at each point in the region, provided they are not travelling parallel to the magnetic field at the point in question. [P3.1]

is defined: at any point specified by a position vector $\boldsymbol{r}$, as the vector quantity $\boldsymbol{B}(\boldsymbol{r})$ whose direction is identical to that in which the north pole of a vanishingly small compass needle, free to rotate in three dimensions, would point, and whose magnitude $B(\boldsymbol{r})$, is obtained from the magnitude, $F_{\rm mag}$, of the magnetic force that acts - by virtue of the Lorentz force law - on a particle of charge q as it moves through the point $\boldsymbol{r}$ in a direction at right angles to the magnetic field with a speed $v_\perp$

$$F_{\rm mag} = |q|v_\perp B(\boldsymbol{r})$$

So $$B(\boldsymbol{r}) = \frac{F_{\rm mag}(\text{on } q \text{ as it moves through } \boldsymbol{r})}{|q|v_\perp}$$ [P4.2]

may be more simply defined: as the vector field $\boldsymbol{B}(\boldsymbol{r})$ that determines the magnetic force $\boldsymbol{F}_{\rm mag}$ on a particle of charge q travelling with velocity $\boldsymbol{v}$ at the point $\boldsymbol{r}$ through the relationship

$$\boldsymbol{F}_{\rm mag} = q\boldsymbol{v} \times \boldsymbol{B}(\boldsymbol{r}).$$ [P4.3]

has as its SI unit: the tesla (T), where $1\,{\rm T} = 1\,{\rm N\,s\,C^{-1}\,m^{-1}}$. [P4.2]

also may be denoted: $\boldsymbol{B}(x, y, z)$, since $\boldsymbol{r} = (x, y, z)$. [P4.2]

magnetic field lines

are: a means of representing a magnetic field using directed curves (i.e. curves with arrows on them). [P4.2]

are drawn: so that at any point the magnetic field is tangential to the line and points in the direction indicated by the direction of the field line. [P4.2]

therefore are directed: away from north magnetic poles and towards south magnetic poles. (This direction is that in which the north pole of a freely suspended compass needle would point - which means of course that the north geographical pole of the Earth is actually a south magnetic pole!) [P4.2]

have spacing: which is related to the magnitude of the magnetic field, i.e. where the lines are close together the field is strong and where they are further apart the field is weaker. [P4.2]

magnetic field strength

at: any point

is: the magnitude of the magnetic field at that point. [P4.3]

magnetic flux

loosely is: the 'amount of magnetic field' enclosed by a circuit. [P4.4]

more precisely is: for a loop of area A whose axis makes an angle θ with a uniform magnetic field $\boldsymbol{B}$, the quantity $\phi = BA\cos\theta$. [P4.4]

has as its SI unit: the weber (Wb), where $1\,\mathrm{Wb} = 1\,\mathrm{T\,m^2}$. [P4.4]

magnetic flux density

is: the strength of a magnetic field, expressed in terms of the magnetic flux per unit area when the area is at 90° to the field direction. [P4.4]

has as its SI unit: $\mathrm{Wb\,m^{-2}}$. ($1\ \mathrm{Wb\ m^{-2}} = 1\ \mathrm{T}$). [P4.4]

magnetic flux linkage

for: a circuit of N turns, each enclosing a magnetic flux ϕ

is: $\Phi = N\phi$. [P4.4]

has as its SI unit: the weber (Wb). [P4.4]

conventionally is expressed also: in units of Wb turns. [P4.4]

magnetic force

is: the force $\boldsymbol{F}_{\rm mag}$ produced by a magnetic field on a moving charged particle, or on a stream of charged particles constituting an electric current. [P4.3]

is quantified: for a particle with charge q and velocity $\boldsymbol{v}$ in a magnetic field $\boldsymbol{B}$ by $\boldsymbol{F} = q\boldsymbol{v} \times \boldsymbol{B}$. [P4.3]

is quantified: for a wire of length l carrying a current I in a uniform magnetic field $\boldsymbol{B}$ by $\boldsymbol{F}_{\rm mag} = I\boldsymbol{l} \times \boldsymbol{B}$. where $\boldsymbol{l}$ is a vector of length l in the direction of the conventional current. [P4.3]

magnetic induction

is: the creation of temporary magnetic properties in a material through the presence of an external magnetic field. [P4.2]

magnetic monopole

is: a (hypothetical) isolated north or south magnetic pole. [P4.2]

magnetic pole

is: one of the two centres within a magnetic dipole at which the lines of magnetic field appear to originate or terminate. [P4.2]

is classified: in two types: north magnetic poles and south magnetic poles. The forces between poles are such that like poles repel and unlike poles attract. [P4.2]

magnetic (orbital) quantum number

See orbital magnetic quantum number, m_l.

magnetic (spin) quantum number

See spin magnetic quantum number, m_s.

magnetically coupled

describes: a situation in which one circuit is influenced electrically by electrical changes in a nearby circuit through the mechanism of electromagnetic induction and mutual induction. [P4.4]

magnetically hard

describes: materials, such as steel, which retain much of their induced magnetism when the magnetizing magnetic field is removed. [P4.2]

See magnetic induction and permanent magnetism. [P4.2]

magnetically soft

describes: materials, such as soft iron, which retain very little of their induced magnetization when the magnetizing magnetic field is removed. [P4.2]

See magnetic induction. [P4.2]

magnetism

is: the mutual attraction or mutual repulsion of two bodies that produce magnetic fields. [P4.2]

magnetron

is: an electronic device which generates microwaves using the resonance of electromagnetic waves confined in a cavity. [P5.3]

magnifying power

is: the ratio of the angles subtended at an observer's eye by an optical image and by the object from which it is derived, when that object is placed at the near point. [P6.4]

magnitude (of a complex quantity)

See modulus (of a complex number).

magnitude (of a real quantity)

See modulus (of a real number).

magnitude (of a vector or vector quantity)

for: a vector (or vector quantity) $\boldsymbol{v} = (v_x, v_y, v_z)$.

is: a scalar quantity that describes the 'size' or 'length' of the vector $\boldsymbol{v} = (v_x, v_y, v_z)$. [M2.4, M2.5, P2.1, P2.2, P2.7]

is always: positive. [M2.4, M2.5, P2.1, P2.2, P2.7]

is denoted: by $|\boldsymbol{v}|$ or simply by v. [M2.4, M2.5, P2.1, P2.2, P2.7]

is defined: by $|\boldsymbol{v}| = \left(v_x^2 + v_y^2 + v_z^2\right)^{1/2}$ [M2.4, M2.5, P2.1, P2.2, P2.7]

magnitude of the acceleration due to gravity

in: the absence of any other influences

is: the magnitude of the acceleration due to gravity of a falling body close to the Earth's surface.

is also: the magnitude of the gravitational field close to he Earth's surface.

is denoted: by g. [P2.2]

varies: from place to place across the Earth's surface, but generally is within $\pm 0.028\,\mathrm{m\,s^{-2}}$ of $9.805\,\mathrm{m\,s^{-2}}$. [P3.2]

magnitude of the area under a graph

refers: to the sum of the (positive) areas of the various distinct regions contained between a given graph and a given axis between given limits. [M5.4]

Compare with area under a graph, which is the corresponding sum of (signed) areas.

main group elements

See typical elements.

mains voltage

is: the voltage supplied by standard power sockets connected to the national (mains) electricity supply. [P5.4]

major arc

is: the larger of the two arcs of a circle joining two points on the circumference that are not at opposite ends of a diameter. [M2.1]

major axis

is: the longest diameter of an ellipse.

major segment

is: the region bounded by the major arc of a circle and the chord that joins its end points. [M2.1]

many universe interpretation

in: quantum physics

suggests: that all possible paths for all particles are actually followed. In our Universe, when we detect a particle which has, for example, passed through a slit, we only see the end result of one path, but all the other paths have led to different results in an infinity of other universes. [P10.2]

is opposed: to the Copenhagen interpretation of quantum physics. [P10.2]

mass

is: one of the fundamental dimensional quantities of mechanics (along with length and time).

is: a property that determines both the acceleration an object will experience in response to an applied force (according to Newton's second law) and the magnitude of the gravitational force it will experience in response to a given gravitational field. These ways of interpreting mass are (at present) believed to be equivalent. [M5.1, P1.1]

has as its SI unit: the kilogram (kg), one of the seven base units. [P1.1, P2.3]

should not be confused: with weight. [P2.3]

is also: an abbreviation used to indicate a particle or body of non-zero mass.

mass defect

is: the difference between the total mass of the free protons and neutrons of which a nucleus is made and the (smaller) mass of the nucleus itself. [P9.1]

is attributed: to the mass energy equivalence of the binding energy when the protons and neutrons are bound together. [P9.1]

mass energy

of: an object

is: the energy the object has by virtue of its mass, as described by Einstein's mass-energy equation: $E = mc^2$. [P2.4, P9.1]

mass number

of: an atom

is: the total number of protons and neutrons (i.e. the total number of nucleons) in the nucleus of the atom. [P8.1, P9.1]

usually is denoted: by the symbol A. [P8.1, P9.1]

is: for all known isotopes the closest whole number to the relative atomic mass A_r of the isotope. [P8.1, P9.1]

mass spectrometer

is: a device that uses electric and magnetic fields to determine the masses of molecules and submolecular particles, including atoms, nuclei and (some) elementary particles. (Strictly speaking it is used to determine the mass of a related ion, rather than the electrically neutral particles themselves.) [P4.3, P8.1, P9.1]

is also used: to determine the relative abundances of various kinds of particles within a given sample.

occurs: in various types, using different arrangements of fields.

mass spectrometry

is: the study of ionic masses using a mass spectrometer. [P4.3]

mass spectrum

is: the output from a mass spectrometer. [P8.1]

shows: the relative abundance of the various ions derived from a sample, as a function of their mass. [P8.1]

typically takes the form: of a graph in which ion current is plotted against charge-to-mass ratio (or possibly against relative atomic mass). [P8.1]

mathematical

means: pertaining to mathematics.

mathematical model

of: a physical situation or problem

is: an equation or a system of equations (possibly differential equations) that represent the situation or problem. [M6.1]

mathematics

is: the study of number, order, shape, form and numerical data, including their representation by abstract symbols and the rules for manipulating those symbols.

matter

is: a general term for material substance irrespective of its specific form.

Maxwell-Boltzmann energy distribution

is: a distribution function which describes the number of molecules in a gas that have energy in a small interval between E and $E + \Delta E$, usually taken in the limit at ΔE tends to zero. [P7.5]

is given: by

$$n(E)\Delta E = 2\pi N\left(\frac{1}{\pi kT}\right)^{3/2} E^{1/2} e^{-E/kT}\,\Delta E$$

where k is Boltzmann's constant, N is the total number of molecules in the gas and T is the absolute temperature of the gas. [P7.5]

Maxwell-Boltzmann speed distribution

is: a distribution function which describes the number of molecules in a gas that possess a speed in a small interval between v and $v + \Delta v$, usually taken in the limit as Δv tends to zero. [P7.5]

is given: by

$$n(v)\Delta v = 4\pi N\left(\frac{m}{2\pi kT}\right)^{3/2} v^2 \exp(-mv^2/2kT)\,\Delta v$$

where k is Boltzmann's constant, m is the mass of a molecule, N is the total number of molecules in the gas and T is the absolute temperature of the gas. [P7.5]

Maxwell's theory of electromagnetism

is: a classical theory of electromagnetic phenomena based on a set of partial differential equations that relate the electric and magnetic fields in a region to the charges and currents in and around that region, and to any non-uniformities or inconstancies in the fields within that region.

predicts: the existence of electromagnetic waves that travel through a vacuum with speed $c = 1/\sqrt{\varepsilon_0\mu_0}$

mean (of values)

of: n values x_1, x_2, x_3, x_4, … $x_{n\text{-}2}$, $x_{n\text{-}1}$, x_n of a quantity x

is symbolized: by $|x|$. [P1.1, P1.2]

is obtained: by adding all those quantities together and dividing the resulting sum by n. Thus

$$\langle x \rangle = \frac{x_1 + x_2 + x_3 + x_4 + \ldots + x_{n-2} + x_{n-1} + x_n}{n}$$ [P1.1, P1.2]

mean (of a distribution)

of: a normalized distribution $f(x)$, i.e. a distribution for which $\int_a^b f(x)\,dx = 1$.

is: the integral $\int_a^b x\,f(x)\,dx$ where the upper and lower limits a and b depend on the range of possible values for the quantity x. [M5.4]

mean collision frequency

of: a molecule in a gas

is: the average number of collisions per second made by a molecule in the gas. [P7.5]

therefore is: the reciprocal of the mean free time. [P7.5]

mean free path

of: a molecule in a gas

is: the average distance which the molecule will travel between collisions with other molecules. [P7.5]

therefore is: the product of the average speed and the mean free time. [P7.5]

mean free time

for: a molecule in a gas

is: the average time spent by the molecule between collisions with other molecules. [P7.5]

therefore is: the reciprocal of the mean collision frequency. [P7.5]

measure

means: (as a verb) to determine a quantitative value.

also means: (as a noun) a quantity that expresses in quantitative terms the extent to which a given quality is present.

See also measurement.

measurement

is: a process that determines the (usually) numerical value of a quantity.

is also: used to describe the numerical value itself.

more specifically is: in quantum mechanics, a process that entails the interaction of a system with a measuring device, the possible outcomes of which are restricted by the state of the system immediately prior to the measurement.

mechanical

means: pertaining to mechanics.

mechanics

is: the branch of physics concerned with the motion of bodies or systems with (effectively) a finite number of degrees of freedom and the response of such bodies to forces.

traditionally is: divided into the branches of statics, kinematics and dynamics.

mechanical energy

of: a physical system

is: the sum of the kinetic energy and the potential energy of the system. [P2.4]

mechanical equilibrium

is: the condition in which a system is in both translational equilibrium and rotational equilibrium. [P2.7]

mechanical impedance

of: a driven damped mechanical oscillator in which a periodic driving force $F_0 \sin(\Omega t)$ produces velocity oscillations described by $v_0 \sin(\Omega t - \delta)$

is: the quantity $Z_m = F_0/v_0$

is given: for a mass m oscillating on a spring of spring constant k and subject to a damping force of magnitude bv (where v is the speed of the particle), by

$$Z_m = \sqrt{b^2 + \left(\frac{k}{\Omega} - \Omega m\right)^2}$$

has as its SI unit: $\mathrm{N\,s\,m^{-1}}$.

Compare with impedance (electrical).

mechanical oscillator

is essentially: a mass on a spring, possibly subject to a damping force and a driving force.

See simple harmonic oscillator, damped mechanical oscillator, driven oscillator, as appropriate.

median

of: a triangle

is: a line drawn from one vertex of the triangle to the mid-point of the opposite side. [M2.1]

medium

is: a material of interest

is exemplified by: an optical medium.

medium (for elastic waves)

is: a deformable material in which an equilibrium state can be identified and in which energy is required to bring about (at least some) deformations from the equilibrium state. [P5.6]

is exemplified: by an elastic solid, and by an open body of water in a uniform gravitational field. [P5.6]

medium (for light)

is: a transparent material through which light can travel. [P6.2]

includes: a vacuum as a special case, even though it does not consist of any 'substance' in the normal sense. [P6.2]

melting point

of: a substance

is: the temperature at which the solid and liquid phases of the substance can coexist in equilibrium at a specified pressure (usually, but not necessarily, standard atmospheric pressure).

is synonymous: with freezing point.

meniscus

is: the curved surface of a liquid, usually when it is in contact with a solid surface. [P7.6]

mercury barometer

is: a device for measuring one pressure relative to another (commonly atmospheric pressure relative to a vacuum). [P7.2]

consists: of mercury contained in a U-tube. [P7.2]

works: when the two pressures are applied to the two sides. The difference is registered as a level difference. The pressure difference ΔP is related to the level difference h by the formula $\Delta P = \rho g h$, where ρ is the density of mercury and g the magnitude of the acceleration due to gravity. [P7.2]

mercury-in-glass thermometer

is: a glass capillary with a bulb containing mercury. Changes in temperature cause the glass and mercury to expand (or contract) by different amounts, and the result is that the meniscus moves to different positions in the capillary. [P7.2]

can be calibrated: by marking meniscus positions corresponding to fixed points such as the boiling and freezing points of water, and then interpolating between them. [P7.2]

mesh

within: a circuit

is: any continuous closed path. [P4.1]

is often called: a loop.

metal

is: a material that can be modelled as an array of positive ions immersed in a pool of free electrons. [P7.1]

therefore is: an excellent electrical conductor. [P7.1]

See metallic bond and metallic bonding.

metallic bond

is: a bond that does not involve the localization of any electron with a particular atom. [P11.4]

has: the bonding electrons effectively free to move throughout the lattice of a (crystalline) solid, so the electrons are shared by the crystal as a whole. [P11.4]

See metallic bonding.

metallic bonding

is: the type of chemical bonding that holds metals together. A simple model for a metal is an array of positive ions immersed in a sea of free electrons, and the bonding arises partly from electrostatic attraction between the ions and the intervening electrons. [P7.1, P8.4]

therefore is: a type of chemical bonding in which an atom shares its bonding electron(s) with a very large number of other atoms. [P8.4]

See metallic bond.

method of least squares

is: a numerical method for determining the gradient and intercept of the straight line that best fits a given set of data points. [P1.3]

assumes: that the errors in the independent variable are negligible and that the error in each measurement is the same. [P1.3]

See statistics in the Maths handbook for further details.

method of mixtures

is: a standard calorimetry procedure, in which heat from an object whose heat capacity is already known, is supplied to another object whose thermal properties are under investigation. Or vice versa. [P7.4]

method of undetermined coefficients

is: a method for finding a particular solution to some types of linear inhomogeneous differential equations. [M6.3]

is based: on equating coefficients of like terms when a trial solution is substituted into the equation. [M6.3]

metre, m

is: the SI unit of length, one of the seven base units. [P1.1]

is defined: as the distance light travels in a vacuum in 1/299 792 458 second. [P1.1]

microscope

is: an instrument for viewing nearby objects with high magnifying power. [P6.4]

microscopic

describes: size scales below visibility by the human eye and sufficiently small that the behaviour of molecules, or atoms may need to be considered. [P7.2, P7.5]

microstructure

of: a material, especially a solid,

is: the actual structure at the atomic level, which reflects the ideal state of the atom positions, modified by the presence of impurities and defects. [P7.6]

microwave radiation

is: a form of electromagnetic radiation characterized by wavelengths in the approximate range 1 mm to 0.03 m.

See electromagnetic spectrum.

millibar, mbar

is: a non-SI unit of pressure.

is defined: as one thousandth of a bar, where
10^3 mbar = 1 bar = 10^5 N m^{-2} = 10^5 Pa (= 1.013 25 atm). [P7.2]

Millikan's oil drop experiments

are: a series of experiments first performed by Robert Millikan (1868-1953). [P3.3]

used: balanced gravitational and electrostatic forces on charged oil drops, to make the first accurate determinations of the charge on the electron, $-e$. [P3.3]

minimum deviation

of: a light ray

passing: through a prism

occurs: when the ray passes through the prism symmetrically. This is the arrangement which gives the maximum possible dispersion. [P6.3]

minor arc

is: the smaller of the two arcs of a circle joining two points on the circumference that are not at opposite ends of a diameter. [M2.1]

minor axis

is: the shortest diameter of an ellipse.

minor segment

is: the region bounded by the minor arc of a circle and the chord that joins its end points. [M2.1]

minute of arc, ′

is: a unit of angular measure. [M1.6]

is equal: to 1/60 of a degree. [M1.6]

is abbreviated: arcmin. [M1.6]

is exemplified: by $20' = 20$ arcmin $= 1°/3$. [M1.6]

See also second of arc. [M1.6]

mirage

is: an optical illusion arising from continuous refraction. [P6.2]

mirror

is: a surface at which reflection can take place. Its quality is determined in part by its reflectivity. [P6.2]

mirror transverse magnification

is: the ratio of image height to object height measured in the direction perpendicular to the optical axis of the mirror. [P6.3]

missing mass

See mass defect.

mixed partial derivative

are: partial derivatives of second or higher order that involve (partial) differentiation with respect to two or more independent variables. [M6.4]

mixed symmetry

of: a function $f(x)$

is found: when the function is neither an even function nor an odd function. Such a function may be written as a sum of odd and even parts by writing it in the form

$$f(x) = \tfrac{1}{2}[f(x) + f(-x)] + \tfrac{1}{2}[f(x) - f(-x)]$$ [M5.2]

mode

See modes of vibration.

model

is: an artificial construction invented to represent or to simulate the properties, the behaviour, or the relationships among individual parts of the real entity being studied. [P1.1]

often is: a mathematical model. [P1.1]

moderator

in: a nuclear fission reactor

is: a material whose function is to slow down fast neutrons to produce thermal neutrons and hence to maintain the nuclear chain reaction. [P9.3]

modes of vibration

of: a body

are: the different types of vibration (linear, torsional, pendulum-like, etc.) that the body can exhibit simultaneously. [P5.1]

See normal modes.

modulus (of a complex number)

of: the complex number $z = x + iy$.

is denoted: by $|z|$. [M3.1, P5.5, P10.3]

is defined: by $|z| = (x^2 + y^2)^{1/2}$. [M3.1, P5.5, P10.3]

is always: positive. [M3.1, P5.5, P10.3]

modulus (of a real number)

of: a real number x

is denoted: by $|x|$. [M1.2, P2.7]

is defined: by $|x| = (x^2)^{1/2}$. [M1.2, P2.7]

is always: positive. [M1.2, P2.7]

is synonymous: with the absolute value or magnitude.

modulus of elasticity

is: the ratio of stress to strain in an elastic material, within the region of validity of Hooke's law where these are linearly related. [P7.6]

is exemplified: by bulk modulus, shear modulus, and Young's modulus. [P5.7]

molar gas constant

is: the physical constant R that appears in the equation of state of an ideal gas; $PV = nRT$.   [P7.2, P7.3, P7.4, P7.5]

has: the value R = 8.314 J K^{-1} mol^{-1} (to four significant figures).   [P7.2, P7.3, P7.4, P7.5]

is related: to Boltzmann's constant k and Avogadro's constant $N_{\rm A}$ by $R = N_{\rm A}k$.

is synonymous: with universal gas constant.

See also mole.

molar heat capacity

See molar specific heat.

molar latent heat

is: the amount of heat absorbed or emitted per mole of a substance during an isothermal phase transition. [P7.4]

has as its SI unit: $\mathrm{J\,mol^{-1}}$. [P7.4]

See also latent heat, specific latent heat.

molar mass

is: the mass per mole of a substance. [P7.2]

has as its SI unit: $\mathrm{kg\,mol^{-1}}$. [P7.2]

molar specific heat

is simply: the heat capacity per mole of a substance. [P7.4, P7.5]

should not be confused: with specific heat, which is heat capacity per kilogram of a substance. [P7.4, P7.5]

is quantified: as $C = \Delta Q/n\Delta T$ where n is the number of moles of the substance in the sample. (Strictly speaking the molar heat capacity should be defined as the limit of this ratio as ΔT becomes vanishingly small, since the heat capacity depends on the state of the sample.) [P7.4]

depends: on the constraints applied during heating: may be the molar specific heat C_V at constant volume, or may be the molar specific heat C_P at constant pressure. [P7.4]

has as its SI unit: $\mathrm{J\,mol^{-1}K^{-1}}$. [P7.4]

sometimes is referred to: as molar specific heat capacity. [P7.4, P7.5]

Compare with specific heat, principal specific heats.

mole, mol

is: the SI unit of amount of substance, one of the seven base units. [P7.1, P7.2]

is defined: as the amount of a substance that contains the same number of elementary entities as the number of atoms in 12 g of the ^{12}C isotope of carbon. (Measurements show that 12 g of the ^{12}C contain (to four significant figures) 6.022×10^{23} atoms of ^{12}C) The elementary entities may be atoms or molecules. For example, one mole of MgF_2 contains 6.022×10^{23} magnesium atoms and 12.044×10^{23} fluorine atoms. [P7.1, P7.2]

facilitates: the evaluation of the molar mass of a substance, the numerical value of the molar mass in grams per mole being obtained by adding together the relative atomic masses of the atoms in the molecule. The relative atomic mass of magnesium is 24.3, and of fluorine is 19.0. Thus, one mole of MgF_2 has a mass of $[24.3 + (2 \times 19.0)]$ g, or approximately 62.3 g. [P7.1, P7.2]

See Avogadro's constant and Avogadro's number.

molecular beam

is: a stream of directed molecules

is created: by allowing the molecules to escape from a container through a fine slit by molecular impacts on the slit space into a region beyond, where the pressure is lower. The pressure must be sufficiently low to avoid intermolecular collisions within the slit. Usually, the directionality of the beam is improved using a second slit placed behind the first. [P7.5]

molecule

is: the smallest freely existing part of a chemical element or chemical compound that retains the chemical identity of that chemical element or chemical compound. [P7.1, P8.1]

therefore is usually: a group of atoms bound together. For compounds composed of identical molecules, the type and relative number of each sort of atom present in each molecule is indicated by the chemical formula of that substance. For example, a molecule of water contains one atom of oxygen and two atoms of hydrogen, and is represented by H_2O. [P7.1, P8.1]

exceptionally: some molecules consist of single atoms (e.g. noble gases).

moment

of: a vector $\boldsymbol{v}$ about a point P

is: the vector product $\boldsymbol{s} \times \boldsymbol{v}$ of the vector $\boldsymbol{v}$ with a displacement vector $\boldsymbol{s}$ from the point P to any point on the line of action of the vector. [M2.7]

moment of a force

for: a force $\boldsymbol{F}$ causing, or tending to cause, rotation about a point P

is: a measure of the turning effect of the force. [P2.7, P4.3]

is given: by $\boldsymbol{r} \times \boldsymbol{F}$ where $\boldsymbol{r}$ is a displacement vector from P to any point on the line of action of $\boldsymbol{F}$. [M2.7, P2.7]

is therefore: identical to the torque of $\boldsymbol{F}$ about P. [P2.7]

is mainly used: when dealing with coplanar forces, in which case the resultant moment of the forces about P may be obtained by adding the magnitudes of the individual moments (found by multiplying the magnitude of the force by the perpendicular distance between P and the line of action of the force) subject to the sign convention that those forces that promote anticlockwise rotation have positive moments while those that promote clockwise rotation have negative moments. [P2.7, P4.3]

moment of inertia

of: a body

is: a measure of its reluctance to be rotationally accelerated. [P2.7, P2.8]

is calculated: from the distribution of mass in the body about the axis of rotation. [P2.7, P2.8]

may be defined: in terms of mass elements Δm_i located at perpendicular distances r_i from the axis of rotation by

$$I = \sum_i r_i^2 \, \Delta m_i$$ [P2.7, P2.8]

may be defined: in terms of infinitesimal elements by

$$I = \int r^2 \, dm$$

moment of momentum

is: a synonym for angular momentum.

momentum

See linear momentum and angular momentum

monatomic ideal gas

is: an ideal gas (and therefore obeying $PV = nRT$) in which the internal energy at any temperature T is given by $U = 3NkT/2$. [P7.4]

can be used: to model the behaviour of a real gas of single atoms (that have no effective rotational or vibrational degrees of freedom) at low density. [P7.4]

monochromatic

describes: light which may be modelled by electromagnetic waves of a single wavelength (or frequency) or by photons of a single energy. [P6.1, P6.3]

monolayer

is: a very thin layer of molecules, just one molecule thick. [P8.1]

most probable speed

of: gas molecules

corresponds: to the peak in the speed distribution function. [P7.5]

See Maxwell-Boltzmann speed distribution.

motion

is: continuous change of position.

motional induction

is: electromagnetic induction arising from the motion of an electrical conductor within (and relative to) a magnetic field. [P4.4]

moving-coil galvanometer

is: a generic term for ammeters and voltmeters that use the equilibrium orientation of a pivoted current carrying coil in a magnetic field (subject to some suitable restoring force or torque) to make electrical measurements. [P4.1]

multi-electron atom

is: an atom containing more than one orbital electron. [P8.3]

multi-valued function

is: an improper use of function, describing situations in which two or more values are associated with a single value of the argument. [M1.3]

is exemplified: by $f(x) = \sqrt{x}$, which can take on two values of opposite signs unless (as is usual) the convention is adopted that $\sqrt{x}$ only represents the positive square root of x. [M1.3]

multimeter

is: an instrument for measuring resistance, and voltages or currents (either d.c. or a.c.). [P4.1]

multiple roots

are: roots having the same value, but which must be counted separately for the purposes of the fundamental theorem of algebra. [M4.4]

are exemplified: by the two roots of $x^2 - 2x + 1 = 0$, both of which are equal to 1. [M4.4]

multiplicity

of: a root α of a polynomial equation $p(x) = 0$

is: the number of times the factor $(x - \alpha)$ occurs in the factorized form of $p(x)$. [M3.1]

mutual inductance

See coefficient of mutual inductance.

mutual induction

is: the production of an induced voltage in one coil or circuit due to the changing current in another coil or circuit. [P4.4]

See coefficient of mutual inductance.

myopia (short sight)

is: the condition in which eyes are unable to focus on objects as far away as the standard far point (taken to be at infinity). [P6.4]

occurs when: the lens of the eye has too short a focal length, even when unaccommodated. [P6.4]

usually is corrected: by an auxiliary diverging lens. [P6.4]

n-type semiconductor

is: a semiconductor in which the majority of mobile charge carriers are negatively charged (usually electrons). [P11.4]

n-dimensional

describes: an object or situation which requires the use of a coordinate system with n independent axes for its adequate description. [P2.1, P2.2]

natural angular frequency

is: the angular frequency that a harmonic oscillator would have if it were neither damped nor driven. [P5.4]

is exemplified: by a pure LC circuit, in which the charge (and the current) have a natural angular frequency $\omega_0 = \sqrt{\dfrac{1}{LC}}$. [P5.4]

natural exponential function

is: the function, e^x. [M1.5]

is so called: to distinguish it from the function, a^x.

See exponential function. [M1.5]

natural frequency

is: the frequency that a simple harmonic oscillator has if it is neither damped nor driven. [P5.2, P5.3, P5.4]

is exemplified: by an electrical oscillator, in which the charge (and the current) have a natural frequency $f_0 = \dfrac{1}{2\pi}\sqrt{\dfrac{1}{LC}}$. [P5.4]

is exemplified: by a mechanical oscillator, in which the oscillating mass m has a natural frequency $f_0 = \dfrac{1}{2\pi}\sqrt{\dfrac{k}{m}}$, where k is the spring constant. [P5.2]

natural logarithm

See logarithm to base e.

natural number

is: a positive whole number, an element of the set {1, 2, 3, …}. [M1.2, M3.1]

natural radioactive series

is: any of the four nuclear decay chains arising from naturally occurring (very long-lived) unstable nuclei. [P9.2]

natural unit

is: a unit that is defined in terms of a natural, reproducible quantity. [P1.1]

is exemplified: by the second, which is defined in terms of periods of the radiation from a specified source (but not by the kilogram).

also describes: any unit in a (non-SI) system in which specified fundamental constants (usually the speed of light in a vacuum and Planck's constant, and sometimes Newton's universal gravitational constant) are each set equal to 1.

near point

is: the nearest point from which light entering the eye may be imaged on the retina. [P6.4]

is generally taken to be: 25 cm for a normal eye. [P6.4]

negative lens

is: a lens having a negative optical power. [P6.3]

See also concave lens or diverging lens.

nested (brackets)

describes: brackets that enclose an expression that itself includes brackets. In a calculation, the contents of the innermost brackets must be evaluated first.
[M1.1]

net force

See resultant force.

neutral equilibrium

of: a system

describes: a state of equilibrium in which a small disturbance of the system does not result in any tendency for the system to return to its initial equilibrium state, nor for it to depart further from its initial equilibrium state. [P5.1]

neutral point

is: a point in space where two or more vector fields combine to give a resultant of zero. [P3.1]

neutrino

is: a fundamental subatomic particle that has zero charge and such a small mass (if any) that it is currently indistinguishable from zero. [P9.2]

is classified: in six kinds: the electron neutrino and antineutrino, the muon neutrino and antineutrino, and the tauon neutrino and antineutrino. [P9.2]

neutron

is: an uncharged elementary particle found in the nucleus of every atom, except for the lightest form of hydrogen (whose nucleus is a single proton). [P3.3, P8.1, P9.1]

has mass: 1.675×10^{-27} kg, i.e. a relative atomic mass of 1.009 slightly greater than that of the proton: $m_{\rm n}/m_{\rm p} \approx 1.001$. [P3.3, P8.1]

is of size: 10^{-15} m, similar to that of the proton. (The 'size' of an elementary particle needs careful definition, so this statement should be treated with caution.) [P3.3]

is thought to contain: charged constituents called quarks. [P8.1, P9.1]

can be counted: in any particular nucleus by subtracting the relevant atomic number Z from the mass number A. [P8.1]

neutron diffraction

is: the diffraction of neutrons by a regular array of atoms (as in a crystal). [P7.1]

is a consequence: of the wave-like behaviour of neutrons, as described by quantum physics. [P7.1]

results in: a diffraction pattern with sharp local maxima of intensity in directions determined (in sufficiently simple cases) by Bragg's law. [P7.1]

See de Broglie wave.

newton, N

is: the SI unit of force. [P2.3]

is defined: by $1\,\mathrm{N} = 1\,\mathrm{kg\,m\,s^{-2}}$, so a constant force of 1 N will cause a mass of 1 kilogram to accelerate at a rate of 1 metre per second squared in the direction of the force. [P2.3]

is roughly: the weight of an apple!

Newton's law of cooling

for: the rate of heat transfer by a combination of conduction, convection, and radiation in everyday situations

is: a 'rule of thumb' which is actually very reliable so long as temperature differences are not large. [P7.3]

states: that $\dfrac{dQ}{dT} = hA\Delta T$ where h is used here, as in convection, as a general purpose empirical heat loss coefficient whose value has to be measured, guessed, or looked up, A is the effective area of the surface from which the heat is being transferred, and ΔT is the temperature difference between that surface and the surroundings. [P7.3]

Newton's law of gravitation

is: the law, first formulated by Isaac Newton (1642-1727), which describes the gravitational force between masses. [P3.1]

states: that for two particles of masses m_1 and m_2 separated by a distance r, the force $\boldsymbol{F}_{21}$ on mass m_2 due to mass m_1 is,

$$\boldsymbol{F}_{\rm grav} = \boldsymbol{F}_{21} = \frac{-Gm_1m_2}{r^2}\boldsymbol{\hat{r}}$$

where $G = 6.673 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$ is Newton's universal gravitational constant, and $\boldsymbol{\hat{r}}$ is a unit vector pointing from m_1 to m_2. The force is therefore an attractive one, directed along the line joining the masses. [P2.3, P3.3]

Newton's law of viscosity

is: an empirical law that describes the behaviour of some fluids under a limited range of conditions. (Such fluids are called Newtonian fluids.) [P7.6]

states: that when a shear stress is applied to a fluid, the velocity gradient that it produces in the direction perpendicular to the stress is proportional to the applied shear stress, and the resulting velocity decreases with distance from the plane over which the shear stress is applied, so

$$\sigma_x = -\eta \frac{dv_x}{dy}$$

where η is a constant, known as the coefficient of viscosity, that is characteristic of the (state of the) fluid. [P7.6]

Newton's laws of motion

is: a collective phrase for Newton's first law, Newton's second law and Newton's third law. [P2.3]

Newton's first law of motion

for: the motion of a particle

states: that every particle continues in a state of motion with constant velocity unless acted on by unbalanced forces. (If the particle is initially at rest, this velocity is zero.) [P2.3]

implies: that if no unbalanced force acts on a particle that starts from the origin at time $t = 0$ with initial velocity u_x and moves along the x-axis, then the subsequent motion of that particle is described by the uniform motion equations: $s_x = u_x t$, $v_x = u_x$ and $a_x = 0$. [P2.3]

can be regarded: as defining a class of frames of reference; the inertial frames of reference.

Newton's second law of motion

for: the motion of a particle

states: that the total force acting on the particle is equal to the product of the particle's mass and its acceleration. [M5.1, P2.3]

is expressed: if the particle moves along the x-axis, by the scalar equation $F_x = ma_x$. [M5.1]

is expressed: in three dimensions, by the vector equation $\boldsymbol{F} = m\boldsymbol{a}$. [P2.3]

Newton's third law of motion

for: the motion of a body

states: that when two bodies interact, the force exerted by the first on the second is equal in magnitude and opposite in direction to the force exerted by the second on the first. [P2.3]

is equivalent to: the principle of conservation of momentum. [P2.5]

Newton's theorem

states: that the gravitational effects outside any spherically symmetric body of mass *M* are the same as those of a point mass *M* located at the object's geometric centre. [P3.2]

Newton's universal gravitational constant

is: the fundamental constant G that appears in Newton's universal law of gravitation. [P2.6]

has: the value $G = 6.673 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$ (to four significant figures). [P2.6]

is synonymous: with universal gravitational constant and gravitational constant.

Newton-Raphson formula

is: an iteration formula used to find approximate solutions to equations of the form $f(x) = 0$.   [M4.5]

has the form: $x_{n+1} = x_n - \dfrac{f(x_n)}{f'(x_n)}$ (provided $f'(x_n) \neq 0$)

where x_n is the n^{th} approximation to the solution, and x_{n+1} is the $(n+1)^{\text{th}}$ approximation.   [M4.5]

Newton-Raphson method

See Newton–Raphson formula.

Newtonian fluid

is: a fluid in which there is a linear relationship between the velocity gradient and the viscous force or the viscous shear stress. (Newton's law of viscosity.
[P7.6]

Newtonian mechanics

is: a branch of physics which attempts to explain the motion (including the lack of motion) of objects in terms of the forces acting on them. [P2.3]

is based: on Newton's laws of motion. [P2.3]

incorporates: other important principles such as the conservation of energy, conservation of momentum, and conservation of angular momentum. [P2.3, P2.5, P2.7, P2.8]

also known as: classical mechanics.

noble gases

are: the gaseous chemical elements helium, neon, argon, krypton, xenon and radon, whose molecules consist of single atoms. [P8.4]

are placed: in a group of the periodic table. [P8.4]

are so-named: because of their marked reluctance to 'lower' themselves by combining with other chemical elements to form compounds. [P8.4]

are also called: inert gases.

node (in a standing wave)

is: a position at which the disturbance caused by the standing wave remains zero. [P5.6, P10.3]

always can be found: at a fixed boundary of a standing wave, as a result of the destructive superposition of an incoming wave and a wave in anti-phase that is reflected from the boundary. [P11.2]

node (in a spatial wavefunction)

in: a spatial wavefunction $\psi(x)$ (i.e. an eigenfunction of energy)

is: any point (specified by a value of x) at which $\psi(x) = 0$, so that the corresponding wavefunction $\psi(x, t)$ is also zero at that point for all values of t. [P11.2]

node (in a circuit)

is: a junction between two or more connections to electrical components in the circuit. [P4.1]

non-conservative force

is: a force which is not a conservative force, so that there is no unique potential energy at each point and the work that it does between two points is dependent on the path chosen. [P2.4]

is exemplified: by frictional forces and muscular forces. [P2.4]

non-inertial frame of reference

is: a frame of reference in which Newton's first law does not hold. [P2.3]

therefore is: one which is itself accelerating and in which objects may accelerate without any resultant force acting. [P2.3]

non-linear differential equation

is: any differential equation which is not a linear differential equation. [M6.1]

non-linear systems

are: equilibrium systems in which the restoring force, or the response of the system, is not linearly dependent on the displacement from equilibrium. [P5.1]

non-negative integer

is: any of the natural numbers or the number 0. [M3.1]

therefore is: any element of the set {0, 1, 2, 3, …}. [M3.1]

normal

to: a chosen line or surface or interface

is: a line drawn at right angles to the chosen line or surface or interface, and meeting it at a point of interest such as the point of incidence of a light ray. [M1.6, M2.3, P5.7, P6.1, P6.2]

normal distribution

See Gaussian distribution.

normal incidence

is: the condition in which one entity (e.g. a light ray) approaches another (e.g. the surface of a plane mirror) at right angles.

normal modes

of: two or more coupled oscillators

are: independent steady state oscillations of the coupled oscillators. If the system is set oscillating in a single normal mode then the system continues to oscillate in this mode. [P5.3]

permit the description: of any coupled oscillation, as a superposition of normal modes. Usually the frequencies of these normal modes differ and so any superposition of them produces beating. [P5.3]

normalization

of: a given wavefunction $\Phi(x, t)$, (or, where appropriate, its spatial part $\phi(x)$)

is: the process of determining a (complex) constant c such that $\Psi(x, t) = c\Phi(x, t)$ is a normalized wavefunction that satisfies the condition

$$\int_{-\infty}^{\infty} |\Psi(x,t)|^2\, dx = 1.$$ [P10.4, P11.2]

ensures: that the probability of finding the particle described by $\Psi(x, t)$ somewhere is 1.

also ensures: that the squared modulus of the wavefunction at any point gives the probability density of finding the particle at that point. [P10.3]

more generally is: the process of multiplying a function or quantity by an appropriately selected factor in order that the resulting product should satisfy a specified 'normalization condition.'

normalized wavefunction

is: a wavefunction which has been subjected to normalization and therefore satisfies the condition:

$$\int_{-\infty}^{\infty} |\Psi(x,t)|^2 \, dx = 1.$$ [P10.3, P10.4, P11.2]

normally distributed

See Gaussian distribution.

north magnetic pole

is: the pole of a compass needle which, when allowed to move freely under the influence of the Earth's magnetic field, points in a northerly direction. (This means that the Earth's north geographic pole is close to a south magnetic pole!) [P4.2]

is: the magnetic pole from which magnetic field lines emerge and diverge. [P4.2]

sometimes is called: the north-seeking pole. [P4.2]

See magnetic pole.

n^{th} root of unity

is: a complex number, z such that $z^n = 1$ for some integer, n. Any given complex number has n distinct n^{th} roots. [M3.3]

nuclear binding energy graph

is: a graph showing the binding energy per nucleon in nuclei plotted against mass number. [P9.1]

shows that: the binding energy per nucleon is highest for nuclei with mass numbers close to that of iron.

nuclear chain reaction

is: a sequence of nuclear fission reactions in which neutrons released in the fission of one nucleus produce induced fission in further nuclei. [P9.3]

nuclear decay chain

is: a sequence of radioactive decays of nuclei in which the daughter nucleus from one decay becomes the parent nucleus for the next. [P9.2]

stops: when a stable daughter nucleus is produced. [P9.2]

nuclear decay channel

is: one of the ways in which a nucleus can undergo radioactive decay. Some nuclei have more than one possible decay channel, e.g. the ${}^{214}_{83}\mathrm{Bi}$ nucleus can undergo either β^--decay ${}^{214}_{83}\mathrm{Bi} \rightarrow {}^{214}_{84}\mathrm{Po} + \mathrm{e}^- + \bar{\nu}_\mathrm{e}$, or α-decay ${}^{214}_{83}\mathrm{Bi} \rightarrow {}^{210}_{81}\mathrm{Po} + {}^{4}_{2}\mathrm{He}$. [P9.2]

nuclear fission

is: the splitting of an atomic nucleus. The nucleus that splits generally has a large mass number and usually splits into two smaller nuclei and a number of neutrons, with a net conversion of mass energy into kinetic energy. [P9.3]

nuclear fusion

is: the combining of two atomic nuclei into one nucleus (and possibly other particles). If the initial nuclei have very low mass numbers, there is generally a net conversion of mass energy into kinetic energy. [P9.3]

nuclear model (of the atom)

provides: a description of the internal structure of the atom in which it is presumed that a positively charged centrally located nucleus, accounting for the major part of the atom's mass, is surrounded by negatively charged electrons which account for its chemical properties. [P8.1]

nuclear fission reactor

is: a reactor in which energy is derived from the process of nuclear fission. (All currently operating commercial nuclear reactors are fission reactors.)

nuclear fusion reactor

is: a reactor in which energy is derived from the process of nuclear fusion. (Such reactors are still under development and are not yet commercially viable.)

nucleon

is: basic building block of all nuclei. [P9.1]

is classified: in two kinds: neutrons and protons. [P9.1]

nucleus

is: the tiny, positively charged core of an atom, which accounts for nearly all of the mass of the atom. [P8.1]

consists: of protons and neutrons. [P8.1]

has diameter: typically 10^{-14} m. [P8.1]

nuclide

is: that atom of an element which is distinguished by a particular number of neutrons in its nucleus and their internal energy state. [P9.1, P9.2]

therefore is: an isotope of the element, but may be further distinguished by its internal energy state. [P9.1, P9.2]

number density

is: the number of molecules (or any other specified entities) per unit volume. [P7.5]

can be calculated: as $n_\rho = \rho/m$, given the mass density ρ and the molecular mass m. [P7.5]

has as its SI unit: m^{-3}.

number line

is: the representation of the set of all real numbers as a straight line with each point on the line corresponding to a unique number and with all points to the left of any given point representing lesser numbers than that represented by the given point, and all points to the right representing greater numbers. [M1.1]

numerator

is: the top of a fraction. [M1.1]

numerical integration

is: a procedure whereby a definite integral may be (approximately) evaluated by using an appropriate finite sum to provide an estimate of the limit of a sum that defines the integral. [M5.1]

numerical procedures

are: methods of finding a numerical approximation to a quantity of interest (usually to the root of an equation) by manipulating numbers, rather than by dealing with abstract algebraic quantities. [M1.4]

object

in: optics

is: a source of light rays, either as a point object or as an extended object.
[P6.3]

object distance

is: the distance *u* measured along the optical axis, between an object and a lens or mirror. [P6.3]

might be more appropriately termed: the object position, since, within the Cartesian sign convention, it may be a positive or negative quantity, depending on which side of the origin it lies. [P6.3]

See also thin lens equation and spherical mirror equation.

object focus

See first focal point.

objective (lens)

is: the lens or combination of lenses in an optical instrument, which is positioned nearest to the object. [P6.4]

observable

in: quantum mechanics, but also in general,

is: a measurable physical quantity for a system, such as position, momentum or energy. [P10.4]

observation

is: the act of an observer that results in a measurement.

results: in quantum mechanics, in an unavoidable and to some extent unpredictable disturbance of the system being measured.

observer

in: physics

is: one who observes, measures and records data.

is not necessarily: one who directly sees what he or she observes and measures using an observation system. (This distinction is especially important in Einstein's special theory of relativity.)

obtuse angle

is: an angle between 90° and 180°. [M2.1]

odd (function)

is: a function $f(x)$ such that $f(-x) = -f(x)$. [M1.6, M4.4, M5.2, P11.2]

is also known as: antisymmetric.

ohm, Ω

is: the SI unit of resistance.

is defined: by $1\,\Omega = 1\,\mathrm{V\,A^{-1}}$ (i.e. 1 volt per ampere). [P4.1]

Ohm's law

is: an empirical relation between current I and voltage V of the form $V = IR$, where R (the resistance) has a constant value for a wide range of V and I. [P4.1, P5.5]

describes: the behaviour of certain metals, provided the temperature is maintained at a constant value, and characterizes the behaviour of various circuit components, particularly resistors. [P4.1]

ohmic resistor

is: an electrical circuit component in which Ohm's law is satisfied. [P4.1, P5.5]

one-dimensional

describes: an object or situation which requires the use of a coordinate system with only *one* independent axis for its adequate description. [P2.1, P2.2]

one-dimensional box

in: quantum physics

is: an idealized confinement in which a particle is able to move freely in two dimensions but with its motion restricted or confined in one dimension. The Heisenberg uncertainty principle then allows us to set two of the momentum components to be zero, hence one-dimensional motion.[P10.3, P10.4]

can be visualized: as the space between two parallel infinite planes separated by a distance D measured along the one dimension. The particle's potential energy is usually taken to be zero from $x = 0$ to $x = D$ and to be infinite outside this region. [P10.3, P10.4]

one-dimensional SHM

is: simple harmonic motion in one spatial dimension, or simple harmonic motion describable in terms of displacements from equilibrium in one coordinate only. [P5.1]

one-dimensional wave

is: a wave whose mathematical description involves only a single independent variable (e.g. *x*) in addition to the time *t*. [M6.4]

open circuit

is: a path of very high (effectively infinite) resistance. [P4.1]

generally is used: in the context of a voltage generator supplying zero current. [P4.1]

open circuit voltage

is: the terminal potential difference of a voltage generator when no current is being supplied by the generator. [P4.1, P4.5]

is also called: the electromotive force (e.m.f.). [P4.1]

operation (mathematical)

is: the process of applying an operator to a function. [M1.1]

operations (of arithmetic)

are: addition, subtraction, multiplication and division. Addition results in a sum, subtraction results in a difference, multiplication results in a product, and division (by a divisor) results in a quotient (often known as a ratio). [M1.1]

operator

is: a symbolic instruction to carry out some (mathematical) action on a function. [P10.4, P11.3]

can range: from simple multiplication by a number, to quite complicated acts such as taking repeated derivatives with respect to a given variable. [P10.4, P11.3]

may correspond: in quantum mechanics, to an observable such as momentum or kinetic energy, (in which particular cases the operator is a differential operator). [P10.4, P11.3]

opposite side

in: a right-angled triangle

is: the side, other than the hypotenuse, that is opposite to a specified angle.
[M1.6]

optic nerve

is: the bundle of nerve fibres which carry electrical impulses from the receptor cells of the retina to the brain. [P6.4]

optical

means: pertaining to optics, the study of light and its propagation.

optical axis

is: a line drawn through the axis of symmetry of a set of lenses or mirrors. The components are arranged with their surfaces normal to the axis. [P6.3]

optical density

is: a property which ranks transparent optical media in terms of refractive index. Higher refractive index corresponds to higher optical density. [P6.2]

optical element

is: a part of an optical system that transmits or reflects light: typically a lens or a mirror.

optical fibre

is: a very thin strand of glass (usually of the order of 0.2 mm or less in diameter). [P6.2]

is used: to confine light rays at a sufficiently small angle to the axis of the fibre, by total internal reflections and thereby to convey these rays up to many kilometres with little power loss. Usually many individual fibres are bundled together to form a cable. [P6.2]

optical medium

See medium (for light).

optical path length

is: the product of the actual (geometrical) length of a light path in a transparent material and the refractive index of that material. [P6.1]

optical power (of a lens)

is: the reciprocal of the focal length of a lens, expressed in m^{-1} or dioptres. [P6.3]

measures: the ability of the lens to converge (positive lens) or diverge (negative lens) incident light. [P6.3]

orbit

is: the path followed by an object moving in a field of force. [P3.2]

orbital (in classical physics)

means: pertaining to an orbit.

orbital (in quantum physics)

is: an alternative term for the wavefunction that provides a mathematical description of the quantum state of an electron in an atom or molecule.   [P8.3]

also describes: the various attempts to depict the information contained in the wavefunction diagrammatically (see electron cloud).   [P8.3]

orbital angular momentum

is: in classical physics, the angular momentum associated with orbital motion.

is: in the quantum mechanics of the atom, the observable of magnitude L represented by the operator,

$$\hat{\mathrm{L}} = -i\hbar\left(y\frac{\partial}{\partial z} - z\frac{\partial}{\partial y}, z\frac{\partial}{\partial x} - x\frac{\partial}{\partial z}, x\frac{\partial}{\partial y} - y\frac{\partial}{\partial x}\right)$$

and with $\hat{L}^2$ having the eigenvalues $l(l+1)\hbar^2$, where l is the orbital angular momentum quantum number.

orbital angular momentum quantum number

is: the quantum number l that characterizes the subshells of an atom. [P8.3, P8.4]

can have: any one of the integer values 0, 1, 2, … $n - 1$, where n is the principal quantum number. [P8.3, P8.4]

determines: the magnitude $L^2 = l(l+1)\hbar^2$ of the square of the orbital angular momentum of an atomic electron. [P8.3, P8.4]

orbital electron

is: an electron bound to an atom or ion.

orbital magnetic quantum number

is: the quantum number m_l that describes the orientation of the orbital angular momentum of an atomic electron relative to an arbitrarily chosen z-axis. [P8.3]

may have: any integer value ranging from $-l$ to $+l$, where l is the orbital angular momentum quantum number, implying that the z-component of the orbital angular momentum vector may take on any value $L_z = m_l \hbar$. [P8.3]

labels: degenerate energy levels within a subshell in an atom. [P8.3]

orbital period

of: an object following a closed orbit

is: the time required for an object to complete one full orbit. [P3.2]

order (of a derivative)

is: the number of times the original function has been differentiated to produce the derivative.

is indicated: by the superscript at the top of the differential operator, e.g. the 2 in $\dfrac{d^2 f}{dx^2}$ or $\dfrac{\partial^2 \Psi}{\partial x \partial t}$.

order (of a differential equation)

is: the order of the highest derivative in the differential equation. [M6.1]

order (of a singularity)

See singularity.

order of degeneracy

of: an energy level

is given: by the number of linearly independent wavefunctions that share this same energy level. ('Linearly independent' implies that none of the wavefunctions can be expressed as a linear combination of the others.) [P10.3, P11.3]

See degeneracy.

order of diffraction

See diffraction grating.

order of interference

generally is: a whole number that characterizes the relative locations of various prominent features in an interference pattern. [P6.1]

often is more simply: the number of full wavelengths in the optical path difference between two interfering beams at an interference maximum. [P6.1]

is exemplified by: the integer n in the grating relation $n\lambda = d\sin\theta_n$, which describes the angles at which bright intensity maxima are seen when light of a single wavelength λ from a line source is incident normally on a diffraction grating in which adjacent slits are separated by distance d. [P6.1]

order of magnitude

is: an approximation to the value of a quantity which rounds the value up or down to the nearest integer power of ten. For example, if one quantity is roughly 10^3 times another, the former quantity is said to be three orders of magnitude greater than the latter. [P1.1]

is indicated: by ~, which may be read as 'has the order of magnitude'. For example $2.4 \times 10^{-7} \sim 10^{-7}$ and $876.5 \sim 10^3$. [M1.2]

ordered pair

is: a pair of numbers or quantities written in such a way that their order is significant.

is exemplified: by the ordered pair (2, 5) which might represent the x- and y-coordinates of a point on a graph that would be quite different from (5, 2). [M2.2, M2.5, P1.3, P2.2]

ordered multiple

is: a set of numbers or quantities arranged, according to a certain rule, to represent an entity and such that any change in the order represents a change (or a potential change) in the represented entity.

is exemplified: by the ordered triple representing the coordinates of a point in three-dimensional space; the point (1, 2, 3) is different from the point (2, 1, 3) because of the rule that the first number appearing in the triple represents the x-coordinate, the second number the y-coordinate, and so on.

ordered triple

is: a set of three elements, often written in the form (a, b, c), in which the relative position of each element indicates its significance. [M2.5, P2.2]

is exemplified: by the position coordinates (x, y, z) of a point in space. [M2.5, P2.2]

ordinary differential equation

is: a differential equation in which the dependent variable depends on only one independent variable. [M6.1]

organic

in: chemistry

means: relating to the chemistry of carbon

more commonly means: pertaining to living, or once living, things.

origin

is: the point corresponding to the coordinates (0, 0, 0) in a system of Cartesian coordinates.

more generally, is: the point in a coordinate system from which coordinates are measured.

can be defined: in any number of dimensions. [M1.3, M2.2, P1.3]

orthogonal

means: at right angles.

orthogonal component vector (of a vector)

is: one of a set of mutually perpendicular vectors that may be summed together using vector addition to produce a resultant that is equal to the given vector. [M2.4]

is exemplified: for a particle moving with velocity $\boldsymbol{v}$ in a uniform magnetic field, by the orthogonal component vectors $\boldsymbol{v}_{\rm p}$ and $\boldsymbol{v}_{\rm n}$ that are respectively parallel and perpendicular to the field; $\boldsymbol{v}_{\rm p} + \boldsymbol{v}_{\rm n}$. [M2.4]

orthogonal resolution (of a vector)

is: the process whereby a given vector is split into orthogonal component vectors along a chosen set of mutually perpendicular directions. [M2.4]

oscillatory

means: pertaining to oscillation.

oscillation

is: a back and forth motion, usually periodic or at least approximately periodic, in one or more dimensions. [M6.4]

is also: a periodic or approximately periodic variation in a physical quantity such as a voltage, a pressure or a density. [M6.4]

See simple harmonic motion.

out of phase

describes: the phase relationship between two specified oscillations that are not in phase. [P5.1, P5.6, P6.1]

is sometimes used: in the phrase 'exactly out of phase' to mean 'in anti-phase.' [P5.1, P5.6, P6.1]

may be applied: to waves at a common point (or possibly at separate points) by comparing the oscillations caused by the waves at the relevant point(s). [P5.6, P6.1]

Contrast with in phase.

outer shell

of: an atom

is: an (electron) shell of higher energy (i.e. lower binding energy) than all of the other occupied shells in the atom. (According to Bohr's model of the atom, electrons with such energies would be in orbits of relatively large radius.)

output resistance

See internal resistance.

overdamping

is: the condition in which a damped harmonic oscillator is subject to such a strong damping force that it is unable to complete a single oscillation and is unable to return to rest as rapidly as in the case of critical damping. [P5.2, P5.4]

overtones

are: the harmonics, other than the first or fundamental, that can be supported by a vibrating system such as a string with fixed ends. [P5.7]

π

is: a mathematical constant given to eight decimal places by $\pi = 3.141\,582\,65$.

See pi.

p-type semiconductor

is: a semiconductor in which the majority of mobile charge carriers are positively charged (usually holes). [P11.4]

P-*T* diagram

of: a thermodynamic system with equilibrium states characterized by pressure P, volume V, and temperature T

is: a projection of the *PVT*-surface of the system onto a plane parallel to the P- and T-axes.

is used: to show the variation of P with T during a process.

pair annihilation

is: a process in which a particle (e.g. an electron) and its corresponding antiparticle (e.g. a positron) interact destructively and annihilate each other, releasing energy in the form of γ-rays.

is exemplified: by the reaction $e^+ + e^- \rightarrow 2\gamma$. [P9.2]

paired electrons

are: two electrons in a single atom that have identical quantum numbers apart from their respective values of the spin magnetic quantum number m_s. [P8.3]

parabola

is: a conic section that may be described by an equation of the form

$$y = ax^2 + bx + c \text{ where } a \neq 0$$

though it often arises in other forms, such as the factorized form and the completed square form. [M1.3, M1.4, M2.3, P1.3, P2.2, P3.2]

is exemplified: by the trajectory of a projectile moving under the sole influence of a uniform gravitational field. [P2.2]

See conic sections in the Maths handbook for further details.

paraboloid

is: the two-dimensional surface produced by rotating a parabola about its axis of symmetry [M2.3]

has the property: that any ray of light travelling parallel to the axis that is reflected from the inner surface of a paraboloid will pass through the focus of the original parabola. [P2.3]

may be represented: by the equation $\dfrac{x^2}{a^2} + \dfrac{y^2}{b^2} = \dfrac{z}{c}$

parallax

is: a change in the apparent direction or position of an object due to movement of the observer. Objects at different distances from an observer will exhibit different amounts of parallax for a given movement of the observer. [P1.1]

can lead: to errors of measurement in situations where the measurement depends on the alignment of two objects such as the scale on a meter and a pointer indicating a reading on that scale. [P1.1]

parallel

is: a term used to describe lines or curves in two dimensions, and planes or surfaces in three dimensions, that have the property that the shortest distance between them is the same everywhere. [M2.1]

parallel (connection)

describes: circuit components joined so as to provide alternative paths between two nodes. [P4.1]

parallel (light)

describes: light that may be represented by parallel rays.

parallel (vectors)

describes: vectors which point in the same direction or in exactly opposite directions. However, the term is ambiguous since it is sometimes restricted to mean the same direction while the complimentary term antiparallel is used to indicate exactly opposite directions. [M2.4]

parallel-axis theorem

states: that if the moment of inertia of a body of mass M about any axis through its centre of mass is I, then its moment of inertia about a parallel axis at a perpendicular distance r from the original axis will be $I + Mr^2$. [P2.7]

parallel LCR circuit

is: an LCR circuit in which the inductance, capacitance and resistance are connected in parallel.

parallelogram

is: a quadrilateral in which opposite sides are parallel. [M2.1]

parallelogram rule (for addition of vectors)

is: a geometric rule in which two vectors are represented by two adjacent sides of a parallelogram, and their vector sum is represented by the diagonal drawn through the point where they intersect. [M2.4, M2.5, P2.2]

states: that if the tail of vector $\boldsymbol{B}$ is placed at the tail of vector $\boldsymbol{A}$ and the parallelogram which they define is completed, then the vector $\boldsymbol{C}$ from their tails to the diagonally opposite vertex of the parallelogram represents the sum of vectors $\boldsymbol{A}$ and $\boldsymbol{B}$. [M2.4, M2.5, P2.2]

is: an alternative to the triangle rule as a geometric way of representing the addition of two vectors. [M2.4, M2.5]

parameter

is: a variable used in an expression that defines another variable. [M1.3, M2.3, M4.3]

is also: a value of a variable used as a label for classification purposes. [M1.3, M2.3, M4.3]

See parametric equations.

parametric differentiation

is: a process based on the chain rule that enables functions defined by parametric equations to be differentiated. If two related variables, x and y are each expressed in terms of a parameter t (so that $x = f(t)$ and $y = g(t)$), then $\dfrac{dy}{dx} = \dfrac{dy}{dt}\bigg/\dfrac{dx}{dt}$.

[M4.3]

parametric equations

of: a given equation (e.g. of the standard equation of a conic section)

are: equations in which each of the variables in the given equation is expressed in terms of one or more new variables known as parameters.

are exemplified: by the parametric equations of a circle:

$x = a\cos\theta$ and $y = a\sin\theta$ where θ is the parameter,

since using the identity $\sin^2\theta + \cos^2\theta = 1$ to eliminate the parameters θ leads to the standard equation of the circle ($x^2 + y^2 = a^2$). [M2.3, M4.3]

parametric function

is: a function defined by parametric equations. [M4.3]

paraxial approximation

is: an approximation which can be applied in ray optics when all the rays are either parallel to or at a small angle to the optical axis.

See also paraxial ray. [P6.3]

paraxial ray

is: a light ray which is either parallel to or at a small angle to the optical axis (usually less than 10°), before and after refraction or reflection. [P6.3]

parent isotope

See parent nucleus.

parent nucleus

is: an unstable isotope that decays to produce a daughter nucleus. [P9.2]

partial derivative

is: a derivative of a function of several (i.e. two or more) variables. For a function of two variables, such as $y = f(x, t)$ we can define

$$\frac{\partial y}{\partial x} = \lim_{\Delta x \to 0}\left(\frac{f(x+\Delta x, t) - f(x,t)}{\Delta x}\right)$$

and $$\frac{\partial y}{\partial t} = \lim_{\Delta t \to 0}\left(\frac{f(x, t+\Delta t) - f(x,t)}{\Delta t}\right)$$

[M6.4, P5.6]

partial differential equation

is: a differential equation involving partial derivatives. [M6.1, M6.4, P5.6]

partial fractions

of: a function of the form $p(x)/q(x)$, where $p(x)$ and $q(x)$ are polynomials and the degree of $q(x)$, is greater than or equal to that of $p(x)$.

are: the functions $f_i(x) = r_i(x)/s_i(x)$, whose sum is $p(x)/q(x)$ where $s_i(x)$ is a polynomial of degree 1 or 2, or a power of such a polynomial, and $r_i(x)$ is a polynomial of lower degree. [M5.5]

are used: in evaluating certain integrals.

See further integration in the Maths handbook.

partial reflection

is: reflection at a surface or interface, such that only part of the light (as measured by its intensity) is reflected, the rest being absorbed or transmitted. [P6.2]

partial sum

for: an infinite series:

$$\sum_{k=1}^{\infty} a_k = a_1 + a_2 + a_3 + a_4 + \dots$$

is: the sum of the first n terms:

$$S_n = \sum_{k=1}^{n} a_k = a_1 + a_2 + a_3 + a_4 + \dots + a_n \qquad [\text{M1.7}]$$

partially polarized

describes: light in which the oscillations of the electric field occur preferentially along some particular axis, but in which its oscillations along other axes are not negligible. [P6.1]

particle

in: classical physics, particularly mechanics

is: an object that can be treated as occupying a single point in space, at any time.   [P2.1, P2.2, P2.4]

is thought of: as having no size, shape or internal motion (such as spin or vibration).   [P2.1, P2.2, P2.4]

is emulated: by the centre of mass of an extended object.   [P2.1, P2.2]

is: the simplest possible example of a (classical) physical system.

more generally, is: (especially in quantum physics) a fundamental constituent of matter, such as an elementary particle or (exceptionally) an atom or molecule.

See also quantum.

particle (fundamental)

See fundamental particle.

particle density function

of: a one-dimensional quantum system consisting of a stream of particles, represented by a spatial wavefunction $\psi(x)$.

is: $P(x) = \psi^*(x)\,\psi(x) = |\,\psi(x)\,|^2$. [P11.1]

represents: the average number density of particles at any point, x. So the number of particles in the region $a \le x \le b$ will be $\int_a^b P(x)\,dx$. [P11.1]

has as its SI unit: m^{-1}. [P11.1]

particle flux

of: a one-dimensional quantum system consisting of a stream of particles represented by the spatial wavefunction $\psi(x) = A\exp(ikx)$, which is an eigenfunction of the momentum operator,

given that: the average number of particles per unit length is the constant $|A|^2$, and their velocity is obtained from the momentum, $v_x = p/m = \hbar k/m$

is: the net number crossing a fixed plane per unit time, i.e. $F = |A|^2\,\hbar k/m$. [P11.1]

has as its SI unit: s^{-1}.

particular solution

is: a solution of a differential equation, which involves no arbitrary constants. [M6.1, P5.5]

pascal, Pa

is: the SI unit of pressure.

is defined: by 1 Pa = 1 N m^{-2}, so it is the pressure that when acting uniformly over a flat surface of area 1 (metre) squared causes a total force of magnitude 1 newton to act in a direction perpendicular to that surface. [P7.2]

Pascal's principle

states: that an externally applied pressure on a confined fluid is transmitted uniformly in all directions to all elements of the fluid and to the containing body. [P7.6]

Paschen series

See series (spectroscopic).

path difference

usually refers: to the difference between the distances travelled by two coherent waves, from their source to the point where they meet and where interference effects may be observed. [P6.1]

path length

is: the distance between given points measured along a specified path.

is given: by $\int_A^B |d\boldsymbol{s}|$ where A and B are the given points, and $d\boldsymbol{s}$ is an element of displacement along the path.

Pauli exclusion principle

states: that no two electrons in an atom can ever occupy the same quantum state. [P8.3]

more generally states: that no two fermions can simultaneously occupy the same quantum state. [P7.1]

peak value

of: a quantity that varies sinusoidally with time, such as $y = A\sin(\omega t + \phi)$

is synonymous with: its amplitude A. (Peak values of sinusoidally varying current and voltage are usually written as I_0 and V_0, respectively.) [P5.4]

pencil of rays

is: a narrow beam of parallel or nearly parallel rays. [P6.2]

pendulum

is: a periodic swinging system, driven by a gravitational restoring force. [P5.1]

has: in the simple (undamped) case, period $T = 2\pi\sqrt{l/g}$ where l is the length of the pendulum, and g is the magnitude of the acceleration due to gravity. [P5.1]

pendulum clock

is: a clock based on the regular oscillations of a swinging pendulum. [P5.3]

penetration depth

in: quantum physics

of: a stream of particles penetrating quantum mechanically into a potential step or potential barrier where the potential energy is greater than the total particle energy

is: the distance *d* at which the probability density function has decreased to 1/e of its initial value. [P11.1]

percentage

of: one number with respect to another

is equal: to the fraction that the first forms of the second, when the denominator is converted to 100. [M1.1]

is expressed: as the numerator of that fraction, followed by the percentage symbol, %. [M1.1]

therefore can be calculated: as the first number divided by the second, multiplied by 100%. [M1.1]

percentage error

is: the fractional error expressed as a percentage. [P1.1, P1.2]

is: obtained by multiplying the fractional error by 100%. [P1.1, P1.2]

perfect square

is: a number or algebraic expression that may be written as the square of another number or algebraic expression. [M1.4]

is exemplified: by $9x^2 + 12x + 4$, which can be written as $(3x + 2)^2$. [M1.4]

perimeter

is: the length of a closed curve, such as the circumference of a circle or the sum of the lengths of the sides of a polygon. [M2.1]

period (of motion)

is in general: the time interval over which a repeating motion or event recurs. [M6.4]

is in particular: the time taken for an oscillating system to complete one full cycle (i.e. one complete oscillation). [P5.1, P5.4, P5.5]

therefore is: the reciprocal of the frequency: $T = 1/f$. [P5.7, P6.1]

is also: 2π times the reciprocal of the angular frequency: $T = 2\pi/\omega$. [M5.1, P5.7, P6.1]

is exemplified: by a particle of mass m executing simple harmonic motion along the x-axis, under the influence of a force $F_x = -k_s x$, where the period is given by

$$T = 2\pi\sqrt{m/k_s}$$ [P5.1]

is also exemplified: by an orbiting particle, where the period is the time taken to complete one orbit. [P2.6]

is also exemplified: by a (periodic) wave, where the period is the time required for one complete cycle of the wave (i.e. one complete oscillation at any fixed point on the path of the wave). [P5.6, P6.1]

periodic function

is: a function $f(x)$, such that $f(x + na) = f(x)$ for all values of x, where n is any integer and a is a constant. The smallest (non-zero) value of a for which this relation holds true is known as the period of the function. [M1.6, M5.2, M6.3]

periodic process

is: a process in which identical events occur at regular intervals of time. [P1.1, P5.1]

See period of motion.

periodic series

is: a series of chemical elements, commonly placed in a horizontal row in a periodic table. Across the row, atomic number increases in steps of one, and there is a variation in chemical properties that is repeated within other corresponding series, in other rows, of the periodic table. [P8.4]

periodic table

is: a tabular listing of the chemical elements, arranged in periodic series so as to emphasize the repetition of certain behavioural characteristics with increasing atomic number. [P8.4]

in modern versions, also shows: the corresponding periodicities of the electronic configurations of the atoms of the elements, which determine the chemical properties of the elements. [P8.4]

periodic wave

is: a repetitive wave characterized by a wavelength and a period. In the case of a periodic wave described by the function $y = f(x, t)$, the wavelength λ is the shortest length such that $f(x + \lambda, t_1) = f(x, t_1)$ for all x, and the period T is the shortest time such that $f(x_1, t + T) = f(x_1, t)$ for all t. [P5.6]

causes: an oscillation at any particular constant value of x [P5.4]

is exemplified: by a sinusoidal wave $y = A \sin[kx - \omega t + \phi]$, where $k = 2\pi/\lambda$ and $\omega = 2\pi/T$. [P5.4]

periodicity

is: the property of regular repetition shown by a periodic function. [M1.6]

permanent magnet

is: a magnet which maintains its magnetism in the absence of any electric current being applied. [P4.2]

permanent magnetism

is: the property of a permanent magnet in exhibiting magnetism. [P4.2]

permeability

of: a material medium

is: a property of the material that determines the magnitude B, of the magnetic field within the material, produced by a given current. [P4.2, P4.5]

appears, for example: in the equation for the magnitude of the magnetic field at a distance r from a long steady electric current I: $B = \mu_0 I/(2\pi r)$ [P4.2]

is equal: to the permeability of free space μ_0 times the relative permeability μ_r of the material.

is equal: in a vacuum, to the permeability of free space, μ_0. [P4.2]

permeability of free space

is: a constant defined so as to enable SI units to be used consistently in equations relating to magnetic fields. Its value arises via the definition of the ampere, and is by definition $4\pi \times 10^{-7}\,\mathrm{T\,m\,A^{-1}}$. [P4.2]

See also relative permeability.

permittivity

of: a material medium

is: a property of the material that determines the magnitude E of the electric field within the material produced by a given charge. [P3.3, P4.5]

appears, for example: in the equation for the magnitude of the electric field at a distance r from a point charge q: $E = |q|/(4\pi\varepsilon r^2)$. [P4.5]

also appears, for example: in the equation for the capacitance of parallel plates of area A separated by a distance d and filled with the material: $C = \varepsilon A/d$. [P4.5]

is equal: if the material is a dielectric, to the permittivity of free space ε_0, times the relative permittivity ε_r of the material. [P3.3, P4.5]

is equal: in a vacuum, to the permittivity of free space, ε_0. [P4.5]

permittivity of free space

is: a fundamental constant with the value $8.854 \times 10^{-12}\,\mathrm{N^{-1}\,m^{-2}\,C^{2}}$ ($= 8.854 \times 10^{-12}\,\mathrm{F\,m^{-1}}$), to four significant figures. [P3.1, P3.3]

often appears: in combination with other constants, e.g. in $1/(4\pi\varepsilon_0)$ which is sometimes known as the electrostatic constant: $1/(4\pi\varepsilon_0) = 8.988 \times 10^{9}\,\mathrm{N\,m^{2}\,C^{-2}}$. [P3.1, P3.3]

perpendicular

describes: a line or plane that is at right angles (90°) to another line or plane. [M1.6, M2.1]

perpendicular bisector

is: a line which intersects a line segment at right angles and divides it into two parts of equal length. [M2.1]

perpendicular height

is: the height of a geometric figure measured in the direction perpendicular to its base. [M2.1]

phase

of: an oscillation described by a periodic function

is: the argument of that function. [P5.1, P5.4, P5.5]

determines: the stage that the oscillator has reached in its cycle. [P5.1, P5.4]

is exemplified: for the oscillation $y = A\sin(\omega t + \phi)$, by the quantity $(\omega t + \phi)$. (The additive term ϕ which is independent of the time t is called the phase constant or the initial phase of the oscillation.) [P5.1, P5.4, P5.5]

may be generalized: to the case of a wave, e.g. the phase of the wave $y = A\sin(kx - \omega t + \phi)$ at position x and time t is $(kx - \omega t + \phi)$. [P5.6]

is: a number, *not* an angle, though it may be given an angular interpretation, in which case it may be referred to as the phase angle. [P5.1, P5.4]

phase angle

See phase.

phase change

See phase transition.

phase constant

is: the value of the phase when $t = 0$ (also known as the initial phase). [P5.1, P5.4, P5.5]

is exemplified: by the constant ϕ that appears in the general solution of the SHM equation when that solution is written in the form $y = y_0 \sin(\omega t + \phi)$. [M6.3, P5.5]

is also exemplified: by the constant ϕ that appears in the equation describing a sinusoidal wave when the equation is written in the form
$y = A \sin(kx - \omega t + \phi)$. [P5.6]

conventionally is quoted: in the range $0 \le \phi < 2\pi$. [P5.1]

is: a number, *not* an angle, though it may be given an angular interpretation. [M1.6, M6.3, M6.4]

See phase.

phase difference

between: two oscillations with the same angular frequency ω such as $A = A_0 \sin(\omega t + \phi_1)$ and $B = B_0 \sin(\omega t + \phi_1)$ (which might be caused at specified points by waves)

is: a measure of the extent to which the two oscillations (or the waves causing them) are out of step. [P5.4, P6.1]

is given: by $\phi = \phi_2 - \phi_1$, but is conventionally restricted to the range $0 \leq \phi < 2\pi$ by subtracting an appropriate integer multiple of 2π from ϕ.

may also be interpreted: as an angle, in which case its value is quoted in radians, or as the equivalent number of degrees. [P5.4, P6.1]

phase lag

between: two oscillations with the same angular frequency ω,
$A = A_0 \sin(\omega t + \phi_1)$ and $B = B_0 \sin(\omega t + \phi_2)$

is: when the phase difference $\phi = \phi_2 - \phi_1$ is in the range $-\pi < \phi < 0$. [P5.4]

Contrast with phase lead.

phase lead

between: two oscillations with the same angular frequency ω,
$A = A_0 \sin(\omega t + \phi_1)$ and $B = B_0 \sin(\omega t + \phi_2)$

is: when the phase difference $\phi = \phi_2 - \phi_1$ is in the range $0 < \phi < \pi$. [P5.4]

Contrast with phase lag.

phase relationship

between: two oscillations with the same angular frequency ω,
$A = A_0 \sin(\omega t + \phi_1)$ and $B = B_0 \sin(\omega t + \phi_2)$

is determined: by their phase difference $\phi = \phi_2 - \phi_1$

if $-\pi < \phi < 0$, it is said that B lags A by $|\phi|$

if $\phi = 0$, it is said that B is in phase with A;

if $0 < \phi < \pi$, it is said that B leads A by ϕ;

if $\phi = \pi$, it is said that B is in anti-phase with A;

For values of ϕ outside the range $-\pi < \phi \leq \pi$, an appropriate integer multiple of 2π should be added to or subtracted from ϕ to bring it within that range. [P5.4]

may also be applied: to waves at a common point (or possibly at separate points) by comparing the oscillations caused by the waves at the relevant point(s).

phase speed

is: the speed at which points of constant phase (e.g. a peak of the wave) move in travelling waves. [P5.6]

phase transition

in: a substance

is: a change in bulk properties which, for pure substances, is often found to occur within a vanishingly small range of temperature. [P7.4]

is exemplified: by the melting of a solid to form a liquid. [P7.1, P7.4]

is also exemplified: by changes in the crystalline structure of solids. [P7.4]

is accompanied: in some phase transitions, including the solid-liquid-vapour ones, by latent heats (but this is not true of *all* phase transitions). [P7.4]

See fusion, sublimation, vaporization.

phases of matter

are: the various 'forms' of matter, specifically solid, liquid or gas. Sometimes additional phases are recognized, such as plasmas. [P7.1, P7.3]

are sometimes referred to: as 'states of matter', but state has a more specific meaning and is best avoided in this general context.

phasor

is essentially: a rotating vector which is used to describe the amplitude and phase of a sinusoidal oscillation, (which might be the oscillation caused at a specified point by a sinusoidal wave). The 'magnitude' of the phasor is called its amplitude and is equal to the amplitude of the associated oscillation. The 'direction' of the phasor is determined at any time t by the angle between the phasor and an arbitrarily chosen fixed axis, this angle is called the phase of the phasor and is equal to the phase of the associated oscillation. If the value of the phase at time $t = 0$ is equal to the phase constant ϕ of the oscillation, and the rate of change of the phase is determined by the angular frequency ω of the oscillation, then the oscillation itself will be represented by the projection of the phasor onto the chosen fixed axis. [P5.1, P5.4]

is used: to find the result of superposing two or more simple harmonic oscillations acting together, either in the same direction or in different directions. This is achieved by representing each oscillation by a phasor and then adding the phasors in a similar manner to vectors to find the resultant phasor, which represents the superposed oscillations. [P5.1, P5.4]

phasor model

is: a way of representing oscillatory motion in general, and simple harmonic motion in particular, that is especially useful when considering the result of combining two or more oscillations at a point. [P5.1]

See phasor.

photoelectric effect

is: the phenomenon whereby electrons are ejected from metals which are illuminated by electromagnetic radiation of suitable frequency (usually ultraviolet radiation). [P10.1]

occurs: when each ejected electron completely absorbs the energy of a single photon.

cannot be explained: by the classical wave model of electromagnetic radiation. [P10.1]

was explained: by Albert Einstein (1879-1955) (see Einstein's photoelectric equation) by assuming that the interaction energy of electromagnetic radiation occurs in discrete quanta, given by the Planck-Einstein formula:

$$E = hf$$

where h is Planck's constant and f is the frequency of the electromagnetic radiation. [P10.1]

photoelectron

is: an electron that has been ejected from an atom (or a material) by a photon.
[P8.3, P10.1]

photoelectron spectroscopy

is: a type of spectroscopy that examines the energies of the photoelectrons produced by bombarding an atom (or a material) with radiation of a fixed frequency. [P8.3]

provides: a measure of the threshold energies (i.e. binding energies) of the electrons in the atom (or the material). [P8.3]

photoelectron spectrum

is: a plot of photoelectron current against threshold energy that reveals the binding energies of atomic electrons. [P8.3]

photographic film

is: the flexible plastic strip which carries the light sensitive emulsion for recording optical images in a camera. [P6.4]

photoionization

is: ionization, or removal of one or more electrons from an atom, by absorption of light, often ultraviolet radiation or even shorter wavelength radiation.
[P10.1]

photomultiplier

is: a sensitive device used to detect light down to the level of single photons. [P10.1]

can produce: a large pulse of electrons, and hence a current pulse, for each photon absorbed. The size of the current pulse can be made proportional to the energy of the photon, and with suitable electronic equipment, individual photons can be counted and distinguished by energy. [P6.4, P10.1]

photon

is: a quantum of electromagnetic radiation. [P10.1, P10.2]

has: a discrete amount of energy, given by the Planck-Einstein equation $E = hf$ where f is the frequency of the radiation, and h is Planck's constant. [P10.1, P10.2]

has: a discrete amount of momentum, given in magnitude by $p = E/c = h/\lambda$ (where c is the speed of light in a vacuum) and with a direction that is the same as the photon's direction of motion. [P10.1, P10.2]

as a concept, is: at the heart of the quantum theory of electromagnetic radiation. [P8.2]

physical

means: pertaining to physics.

physical optics

is: that part of optics in which it is not valid to treat the propagation of light in terms of rays and it is necessary to take account of the wave-like aspect of light. [P6.1]

physics

is: a high and noble calling for good people with fine minds.

is also: the branch of science concerned with the behaviour of space, time, matter and radiation. [P1.1]

pi, π

is: the mathematical constant obtained by dividing the circumference of any circle by its diameter.

[M1.6]

is: an irrational number. [M1.6]

is given: to eight decimal places by $\pi = 3.141\,582\,65$. [M1.6]

piezoelectric

describes: some materials, such as quartz, which react to an imposed electric field by changing their size or shape. If an oscillating field is applied to the material then high Q-factor mechanical oscillations result. [P5.3]

pinhole camera

is: a camera with no optically refracting components, and in which focusing is achieved by the use of a very small aperture. [P6.4]

pitch

sometimes is used: as a synonym for frequency. [P5.7]

more properly is: a subjective quality of a musical note or sound that may be used to assign it a position in an appropriately defined scale. [P5.7]

Planck's constant

is: the fundamental constant h that has the value $h = 6.6262 \times 10^{-34}\,\mathrm{J\,s}$ (to five significant figures). [P10.1, P10.2]

appears: in practically every equation of quantum physics, but *never* in the equations of classical physics. [P8.2, P10.1, P10.2]

Planck's equation

may be written: $E = hf$

where h is Planck's constant.   [P10.1, P10.2]

relates: the energy E of a single photon to the frequency f of monochromatic light composed of such photons.   [P10.1]

is also known: as Planck's law, Planck's formula or (in a more specific context) the Planck-Einstein formula.   [P10.1]

Planck's function

describes: the spectral brightness at wavelength λ of black-body radiation from a source at temperature T. [P7.3, P10.1]

is given by: $R_\lambda = \dfrac{2hc^2}{\lambda^5[\exp(hc/\lambda kT)-1]}$ where h is Planck's constant, c is the speed of light in a vacuum and k is Boltzmann's constant. [P7.3]

is based: on the quantized interactions of electromagnetic waves in a cavity with the atoms in the walls, where the atoms are treated as oscillators with states of distinct energy. [P10.1]

Planck-Einstein formula

for: a quantum system making a transition between a state of (initial) energy E_i and a state of (final) energy E_f

relates: the frequency f of the electromagnetic radiation emitted or absorbed by the system to the magnitude of the energy change $\Delta E = |E_i - E_f|$. [P8.2, P10.1, P10.2, P11.3]

may be written: $|E_i - E_f| = \Delta E = hf$, where h is Planck's constant. [P8.2, P10.2, P11.3]

results from: the combination of Planck's equation and the conservation of energy.

plane (geometric)

is: a surface such that a straight line that joins any two points on the surface lies in the surface. [M2.1]

can be represented: by the general equation $ax + by + cz = d$ where a, b, c and d are constants. [M2.2]

plane angle

is: an angle measured in a plane.

has as its SI unit: the radian (rad).

plane mirror

is: a flat reflecting surface in which the largest irregularities are (ideally) much smaller than the wavelength of light. [P6.1, P6.2]

plane of polarization

for: a linearly polarized electromagnetic wave

is: the plane containing the electric field vector and the direction of propagation. [P6.1]

plane of rotation

of: a particle

is: the plane in which the rotation is confined. [P2.8]

more generally is: for a body rotating about a well-defined axis of rotation, any plane perpendicular to the axis of rotation. [P2.8]

plane polarized

See linearly polarized.

plane wave

is: a wave in two or three dimensions characterized by a constant, uniform wave vector. [P5.6]

has: wavefronts which are straight lines or planes, in two or three dimensions, respectively. [P5.6, P6.1]

plane wavefront

is: the flat wavefront of a plane wave. [P6.1]

plano-concave lens

is: a lens having one concave surface and one flat surface. [P6.3]

plano-convex lens

is: a lens having one convex surface and one flat surface. [P6.3]

plasma

is: matter consisting of partially or fully ionized atoms and free electrons with overall charge neutrality, coexisting in a gas-like phase or state. [P9.3]

is usually distinguished: by cooperative particle behaviour and the screening of (reducing the effects of) any applied electric or magnetic fields. [P9.3]

occurs: as the temperature of matter is increased above 10^5 K. [P8.2]

can be found: around and within stars. [P8.2]

also has been produced: with some difficulty, in the laboratory. [P8.2]

plasma confinement

is: containment of a plasma (typically of deuterium or tritium or a mixture of these), often at sufficiently high temperature and density that nuclear fusion can take place within it. [P9.3]

plasma state

See plasma.

plastic region

is: the part of the loading curve, (the graph of stress against strain) of a material over which it exhibits plasticity. [P7.6]

is also called: the ductile region. [P7.6]

plasticity

is: the property of a solid body to undergo a permanent change in shape or size when subjected to a stress larger than the yield point. [P7.6]

plotting graphs

is: the process of drawing an accurate graph, as opposed to sketching. [M1.3]

Contrast with sketching graphs.

plum-pudding model

was: an early model of the atom, proposed by J. J. Thomson (1856-1940), following his discovery of the electron. [P8.1]

supposed: that a large (possibly very large) number of negatively charged electrons move in concentric circular orbits within a compensating cloud of positive charge. [P8.1]

point

is: a geometrical object that occupies a position but has no size or extension. [M2.1]

may be specified: relative to a given coordinate system by an appropriate set of position coordinates or by an appropriate position vector.

point discharge

is: the neutralization of charge on a conductor around any sharp point or edge. [P3.3]

arises: because electrons and ions in the surrounding air are accelerated by the enhanced electric field close to the point. [P3.3]

point image

is: an image of a point object. [P6.3]

can be treated: as having zero size. [P6.3]

point object

is: an idealized object without size or extension which can be treated as a source of light (i.e. from which light rays diverge). [P6.2, P6.3]

point of incidence

is: the point of contact of an incident ray with a surface or interface. [P6.2]

point of inflection

is: a point on a graph where the direction of curvature changes from downwards to upwards, or vice versa. [M1.3]

more technically is: a point on the graph of a function at which the second derivative of the function changes sign. (This implies that the second derivative is zero at a point of inflection, but the converse is not necessarily true.) At such a point, a tangent to the graph crosses the graph itself.

may or may not have: the first derivative of the function vanishing. When this additional condition is satisfied, the point of inflection is said to be a horizontal point of inflection, and is a particular kind of stationary point. [M1.3, M4.4, P6.2]

point source

is: a source of light of (ideally) zero size. [P6.1]

point-gradient form

of: the equation of a straight line

is: $y - y_0 = m(x - x_0)$

where the straight line passes through the point (x_0, y_0), and has gradient m. [M1.3, M2.2]

poise, P

is: a non-SI unit of viscosity.

is defined: by $1\,\mathrm{P} = 0.1\,\mathrm{Pa\,s}$ (i.e. 0.1 pascal second). [P7.6]

polar angle

See polar coordinates.

polar axis

See polar coordinates.

polar coordinates

are: coordinates in which the position of a point in a plane is determined by its distance from a chosen point called the origin and the angle (called the polar angle) between a straight line joining the point to the origin and a chosen fixed line (called the polar axis) emanating from the origin. [M2.2, P2.3]

polar form (of a complex number)

represents: the complex number as $z = r\,[\cos(\theta) + i\sin(\theta)]$, where r and θ are real. r is known as the modulus of z and is usually written as $|z|$, while θ is known as the argument of z and is usually written as $\arg(z)$. (Adding an integer multiple of 2π to θ leaves the value of z unchanged, so the argument of a given complex number has infinitely many possible values. However the unique value that satisfies the restriction $-\pi < \theta \le \pi$ is called the principal value of the argument, and it is this value that is conventionally quoted when specifying a complex number in polar form.) [M3.2, P5.5]

Compare and contrast with Cartesian form and exponential form, and see complex numbers in the Maths handbook for the relationship between these forms.

polar representation (of a complex number)

See polar form (of a complex number).

polarity

of: a voltage or potential difference between two points

is: the specification of which point is at the higher potential. [P4.4]

is determined: for induced voltages by Lenz's law. [P4.4]

is determined: for the open circuit voltage of an electric cell by the relative locations of its electrode materials in the electrochemical series. [P4.5]

polarization (in a cell)

is: the concentration of ions and/or bubbles of gas around an electrode in an electric cell. [P4.5]

causes: the cell's open circuit voltage (e.m.f.) and current to fall from their initial values. [P4.5]

requires: the inclusion of chemical depolarizers in most commercial electric cells. [P4.5]

polarization (of electromagnetic radiation)

describes: the direction of oscillation of the electric field of an electromagnetic wave. At every point this direction must lie in the plane that is perpendicular to the direction of propagation of the wave, but it may be oriented in various ways within that (transverse) plane. If the same direction may be associated with the oscillation at every point the radiation is said to be linearly polarized. If the direction varies randomly and unpredictably then the radiation is said to be unpolarized. Other states of polarization are also possible, but are generally more complicated. [P6.1]

polarizing filter

is: a filter that transmits only light of a given linear polarization. [P6.1]

polaroid

is: a commercially produced plastic material capable of acting as a polarizing filter. [P6.1]

pole (of a lens)

is: the point at which the curved boundary of the lens or mirror surface intersects the optical axis.

is also called: the vertex. [P6.3]

pole (of a magnet)

See magnetic pole.

pole (of a parabola)

is synonymous: with vertex. [P6.3]

polygon

is: a geometric figure consisting of straight lines and enclosing a single area. [M2.1]

polynomial equation

of: degree n [M1.4]

is: an equation of the form

$$a_0 + a_1 x + a_2 x^2 + \ldots + a_{n-1} x^{n-1} + a_n x^n = 0$$

where n is a positive integer, and $a_n \neq 0$. (The $n + 1$ constants $a_0, a_1, a_2, \ldots + a_{n-2}, a_{n-1}$ and a_n are called the coefficients of the polynomial.) [M1.4]

polynomial expression

of: degree n [M1.4]

is: an expression of the form

$$a_0 + a_1 x + a_2 x^2 + \ldots + a_{n-1} x^{n-1} + a_n x^n$$

where n is a positive integer, and $a_n \neq 0$. [M1.4]

polynomial function

of: degree n

is: any function of the form

$$f(x) = a_0 + a_1 x + a_2 x^2 + \ldots + a_{n-2} x^{n-2} + a_{n-1} x^{n-1} + a_n x^n$$

where n is a positive integer, and $a_n \neq 0$. [M1.3, M1.4]

is exemplified: by $f(x) = x^5 + 3x^3 - x + 2$.

population

in: statistics

is: a collection of items about which information is sought. [P1.1]

Porro prisms

are: erecting prisms. [P6.4]

commonly are used: in binoculars. [P6.4]

position

of: a point in space

in: three dimensions

is: the property that enables the point to be located by means of an appropriate set of position coordinates, or by an appropriate position vector relative to a coordinate system. [M4.1]

is also used to refer: to the position coordinates or the position vector, as in a particle at position (x, y, z), or at position $\boldsymbol{r}$.

can be specified: in linear motion by a single coordinate such as $x(t)$ and this is then referred to as 'the position'. [M4.1, M5.1]

position coordinates

specify: the location of any point in space. [P2.1, P2.2]

uniquely determine: the location of any point in an n-dimensional space, if there are n (independent) coordinates. [P2.1, P2.2]

usually are presented: in the form of an ordered multiple e.g. an ordered pair (x, y) [P2.1, P2.2]

also are: the components of the position vector of that point, so we may write (in two-dimensions) $\boldsymbol{r} = (x, y)$. [P2.1, P2.2]

position of equilibrium

of: a system in stable equilibrium

is: the position taken up naturally by the system, in which no resultant forces act. When the system is displaced from this position the restoring forces are directed so as to return the system to this equilibrium position. [P5.1]

position vector

of: a point in space (relative to a specified coordinate system)

is: the vector which connects the origin of the coordinate system to the point. [M2.5, P2.1, P2.7]

is: a special class of displacement (i.e. displacement from the origin of the specified coordinate system.) [M2.5, P2.1, P2.7]

has magnitude: equal to the distance from the origin to the point. [M2.5, P2.1, P2.7]

has direction: along the line from the origin to the point. [M2.5, P2.1, P2.7]

has components: equal to the position coordinates of the point, so (in two-dimensions) $\boldsymbol{r} = (x, y)$. [P2.2]

position-time graph

is: a graph of the position of an object against time. The convention is to plot the position vertically and the time horizontally. The gradient of the tangent to the position-time graph at any particular time is the instantaneous velocity at that time. [M4.1,P2.1]

positive lens

is: a lens having a positive optical power. [P6.3]

See also convex lens or converging lens. [P6.3]

positron

is: the antiparticle of the electron. [P9.2]

has: the same mass as the electron but opposite (and therefore positive) charge. The magnitude of the charge is the same as that of the electron. [P9.2]

postulate

is: a statement assumed to be true for the purpose of formulating an argument.

is exemplified: by the postulates of Einstein's special theory of relativity.

potential

See electric potential, gravitational potential and equipotential surface.

potential barrier

is: a region of space where a particle's potential energy is significantly higher than in the surrounding space. [P10.4, P11.1]

potential difference, p.d.

See electric potential difference.

potential divider

See voltage divider.

potential energy

of: a body

is: energy (i.e. the capacity to do work) that it has by virtue of its position, shape or internal configuration.

is exemplified: by gravitational potential energy, strain potential energy and electrostatic potential energy. [P2.4, P11.1]

potential energy function

is: a scalar function of position which gives the potential energy of a particle in space. [P10.4]

potential step

is: a region where a particle's potential energy suddenly increases or decreases. [P11.1]

potential well

is: a region of space where a particle's potential energy is significantly lower than in the surrounding space. [P10.4]

power (mathematical)

is: a superscript following a number or expression that indicates repeated multiplication (if the exponent is a positive integer) or some related operation in other cases. [M1.5]

is exemplified: by the square of a quantity, as in $x^2 = x \times x$, where x is said to be raised to the power 2. [M1.1]

is exemplified: by the square root of a number $\sqrt{x} = x^{1/2}$, which is said to be raised to the power 1/2. [M1.1]

is exemplified: by the reciprocal of a number $1/x = x^{-1}$, which is said to be raised to the power -1. [M1.1]

See arithmetic and algebra in the Maths handbook.

power (physical)

is: the rate at which energy is transferred or converted. [P4.1]

is defined: as the rate of doing work (i.e. the rate of transferring energy from one form to another). [M2.6]

therefore can be written: as $P = dW/dt$. [P2.4]

is exemplified: by the power delivered by a constant force $\boldsymbol{F}$, when its point of application moves with constant velocity $\boldsymbol{v}$, which is given by $P = \boldsymbol{F} \cdot \boldsymbol{v}$. [P2.4]

is exemplified: by the power consumed by an electrical component across which there is a potential difference V and in which there is a current I, which is given by $P = IV$. If the electrical component is an ohmic resistor, R, then $P = IV = I^2R = V^2R$. [P4.1]

has as its SI unit: the watt (W); $1\,\mathrm{W} = 1\,\mathrm{J\,s^{-1}}$. [P2.4, P4.1]

See conservation of energy.

power absorption curve

is: a graph showing the mean power transferred per cycle to an oscillator by a driving force as a function of the driving frequency.

power factor

for: a driven oscillator

varies: with the oscillator's frequency. [P5.3]

is: the factor by which the power absorption of the oscillator is reduced from its maximum value on resonance. [P5.3]

is given: by the square of the sine of the angle by which the displacement lags the driving force. [P5.3]

power law

is: any expression relating two quantities, x and y that may be written in the form $y = kx^n$, where k and n are constants. [M1.1, M1.5, P1.3]

power series

is: a series of the form

$P_n(x) = a_0 + a_1(x-a) + a_2(x-a)^2 + a_3(x-a)^3 + \dots a_n(x-a)^n$ [M1.7, M4.5]

power supply

is: a battery or voltage generator which is capable of maintaining its voltage when current is drawn from it.

powers of ten

are: numbers of the form 10^n, where n is usually an integer. [M1.2]

sometimes refers: to the power n itself. [M1.2]

powers of ten notation

is: a notation in which a number is written as the product of an integer power of ten and a number (normally between 0 and 10). [P1.1]

is exemplified: by 73 874, which is written as 7.3874×10^4. [P1.1]

is also known: as scientific notation. [P1.1]

precession

of: an axis of rotation

is: the rotation of the axis of rotation, produced by the application of a torque which is perpendicular to the axis of rotation. [P2.8]

precision

is: a measure of the extent to which a particular measurement from a set of similar measurements differs from other members of the set. [P1.1]

is also: a measure of the extent to which a measurement (or value) is free of random error. [P1.1]

linguistically is: perverse. The greater the precision, the smaller is its numerical value. A clearer way of expressing it is to say that a quantity is 'precise to within plus-or-minus so-much'. [P1.1]

can be quantified: as (typically) plus or minus two standard errors of the mean, but conventions differ. [P1.1]

Compare with accuracy.

pressure

is: a macroscopic property of a system, defined as the magnitude of the perpendicular force per unit area exerted by the system on any plane area. [P7.2]

has as its SI unit: the pascal (Pa), where $1\,\text{Pa} = 1\,\text{N}\,\text{m}^{-2}$. [P7.2]

primary coil

in: a transformer or mutual induction circuit

is: the part of the circuit which is connected directly to the input from some external source. [P4.4]

primitive

See indefinite integral.

principal maxima

in: the interference pattern of a diffraction grating

are: the most prominent intensity maxima. [P6.1]

principal molar specific heats

are: the specific heats C_P and C_V at constant pressure and at constant volume, respectively. [P7.4]

See also ratio of specific heats.

principal quantum number

for: an electron energy level

in: an atom

is: the quantum number *n* which is used to label the electron energy level according to the shell that contains the electrons. [P8.3, P8.4]

can have: one of the integer values 1, 2, 3, ... [P8.3, P8.4]

is essentially equivalent: for the hydrogen atom, to Bohr's quantum number. [P8.2]

principal rays

in: a ray diagram

for: a lens or mirror

are: the defining rays which can be used to find the relative positions of object and image. [P6.3]

are classified: in two types. One type travels parallel to the optical axis and then passes through (or appears to pass through) the first or second focal points of the lens or the focal point of the mirror. The other type passes undeviated through the centre of the lens or reflects from the pole of the mirror with equal angles of incidence and reflection. [P6.3]

principal value (of the argument)

is: a value of the argument of a complex number which lies within a specified range. The range usually chosen is $-\pi < \arg(z) \leq \pi$. [M3.2, P5.5]

principle of conservation of charge

See conservation of charge.

principle of conservation of mechanical energy

See conservation of mechanical energy.

principle of entropy increase

states: that in any process, the entropy of the Universe never decreases. [P7.4]

more precisely, states: that $\Delta S_{\rm universe} \geq 0$, where the equality holds for reversible processes and the inequality for irreversible processes. [P7.4]

principle of rectilinear propagation

states: that light travels in straight lines in a uniform medium. [P6.2]

is: a basic principle of geometric optics. [P6.2]

principle of reversibility

in: optics

states: that the result of reversing the direction of a light ray is another valid light ray. [P6.2]

is: a basic principle of geometric optics. [P6.2]

principle of superposition

states, in general: that the total of several separate but similar effects (for example, magnetic fields due to various sources) is the sum of the individual effects. [P4.2]

applies only: when the equations describing the effects are linear. [P5.1, P5.5, P6.1]

states, for example: that the gravitational (or electric or magnetic) field strength at any point due to a distribution of masses (or charges or magnetic poles) is found by adding the contributions of the individual masses (or charges or magnetic poles) at that point. [P3.1]

also states, for example: that if two or more waves meet in a region of space, then at each instant of time the net disturbance at any point is given by the sum of the disturbances created by each of the waves individually. [P5.1, P5.6, P5.7, P6.1]

and in a different context, states as well: that in a circuit made up of linear components and containing several voltage generators, the resulting current in, or voltage across, any linear component will be the algebraic sum of those currents or voltages produced in or across that linear component when each of the voltage generators is taken in turn, with all other voltage generators replaced by short circuits. [P4.1]

principle of virtual work

is: a procedure in which an imagined displacement of a system and the calculation of the work done leads to a result which is independent of the displacement and thus represents a valid statement about the system itself. [P7.6]

prism

is: a three-dimensional geometrical form with two parallel faces that are identical in size and shape and which has a constant cross section parallel to those faces. If one of the parallel faces is treated as the base, the volume of the prism is given by the product of the area of that face and the perpendicular height. [M2.1]

in optics, is: a piece of (good quality) glass in the shape of a triangular prism (i.e. a solid body whose cross section at any point along one axis is a triangle of uniform size). Such prisms may be used for total internal reflection, as in binoculars, or for the dispersion of light to reveal the different colours (wavelengths) contained in a single beam. [P6.2, P6.3]

prism angle

is: the angle between the refracting faces of a prism. [P6.3]

probability

is: a quantitative measure of the relative likelihood of a particular outcome resulting from a specified procedure.

may be: normalized, so that the sum of the probabilities of all possible outcomes is 1.

is exemplified: by the probability of obtaining a six with one roll of a fair die being 1/6.

probability density

for: a one-dimensional quantum system, consisting of a particle with potential energy $U(x)$ in a state described by a wavefunction $\Psi(x, t)$

is: $P(x, t) = \Psi^*(x, t)\Psi(x, t) = |\Psi(x, t)|^2$. [M5.4, P10.3, P10.4, P11.1, P11.2]

determines: according to the Born probability hypothesis, the probability at time t of finding the particle in the small region of the x-axis between x and $x + \Delta x$. This probability is proportional to $P(x, t)\Delta x$, and will be equal to $P(x, t)\Delta x$ if the wavefunction has been normalized. [M5.4, P10.3, P10.4, P11.1, P11.2]

is independent: of time for stationary states and can then be written as $P(x) = |\psi(x)|^2$, where $\psi(x)$ is the spatial part of the wavefunction $\Psi(x, t)$. [M5.4, P10.3, P10.4, P11.1, P11.2]

probable error

in: a single quantity subject to n independent errors $\pm e_1$, $\pm e_2$, … $\pm e_n$.

is: the quantity $E = \sqrt{e_1^2 + e_2^2 + e_3^2 + \ldots + e_n^2}$ [P1.2]

produced

describes: a straight line segment AB when it is extended beyond A or B. [M2.1]

product

See operation.

product formulae

are: a class of trigonometric identities. [M1.6]

See trigonometric functions in the Maths handbook.

product identities

are: a class of hyperbolic function identities. [M4.6]

See hyperbolic functions in the Maths handbook.

product rule (of differentiation)

is: $\dfrac{d}{dx}\left[f(x)g(x)\right] = \dfrac{df}{dx}g(x) + f(x)\dfrac{dg}{dx}.$ [M4.2]

projectile

is: an object that is launched into the air near the Earth's surface and whose subsequent motion is determined by the influence of gravity (and, possibly air resistance). [P2.2]

has motion: which (in the absence of air resistance) is characterized, in the absence of other forces, by a uniform horizontal velocity component and a uniform vertical acceleration component. [P2.2]

projection

of: a vector $\boldsymbol{b}$ onto a vector $\boldsymbol{a}$.

is: the (scalar) component of the vector $\boldsymbol{b}$ in the direction of $\boldsymbol{a}$. [M2.6, P5.1]

is given: by $\dfrac{\boldsymbol{a}\cdot\boldsymbol{b}}{|\boldsymbol{a}|}$. [M2.6]

See scalar component.

propagation

means: the act of travelling from place to place.

proper integral

is: a definite integral in which the upper and lower limits are both finite, and the integrand does not become infinite anywhere in the range of integration.

proportional

See directly proportional, inversely proportional, proportionality.

proportionality

is possessed: by two quantities if a change by a factor in one of them implies a change by the same factor in the other. If the quantity y is proportional to x, their relationship is written as $y \propto x$. [P1.1]

proportionality constant

See constant of proportionality.

proton

is: the nucleus of the lightest kind of hydrogen atom and a fundamental constituent of all other nuclei, their number being represented by the atomic number Z. [P3.3, P8.1]

has: a positive charge $+e \approx 1.602 \times 10^{-19}\,\mathrm{C}$ where the charge on the electron is $-e$ [P3.3, P8.1]

has: a mass equal to $1.673 \times 10^{-27}\,\mathrm{kg}$, which is approximately 1836 times the mass of an electron and represents a relative atomic mass of 1.007, slightly less than that of the neutron which it resembles in some ways (for instance, the typical nuclear size scale of $10^{-15}\,\mathrm{m}$ may be taken to roughly represent the 'diameter' of both particles). [P3.3, P8.1]

pulse

See solitary wave.

pupil

is: the variable aperture in the iris through which light enters the eye. [P6.4]

***PVT*-surface**

for: a given amount (usually expressed in moles) of any substance whose equilibrium states are determined by any two of the variables pressure, volume and temperature.

is: a continuous two-dimensional surface formed by plotting the pressure, volume and temperature of every equilibrium state of the substance on three perpendicular axes. Each point on the surface thus represents a possible equilibrium state, and the whole surface may be regarded as a representation of the equation of state of the relevant amount of that substance. [P7.2, P7.3, P7.4]

for an ideal gas is: a graphical representation of the equation of state of an ideal gas ($PV = nRT$) for a fixed value of n. [P7.2, P7.3, P7.4]

is also referred to: as the equilibrium surface, though this term may also be applied to more general systems for which P, V, and T are not appropriate thermodynamic coordinates. [P7.2, P7.3, P7.4]

often is drawn: in two-dimensional projections in which P is plotted against V, P against T, or V, against T. [P7.2, P7.3, P7.4]

pyrometer

is: a device for analysing the light (or more generally the electromagnetic spectrum) emitted by a hot object. [P7.2]

can be used: as a thermometer, since the spectrum is a well-characterized function of temperature. Indeed the International Practical Temperature Scale 1990 known as IPTS-90 recommends its use above 961.78 °C. [P7.2]

Pythagoras's theorem

states: that the square of the hypotenuse in a right-angled triangle is equal to the sum of the squares of the other two sides. [M1.6, M2.1, P2.1]

may be written: $a^2 + b^2 = c^2$. [M1.6, M2.1, P2.1]

Q-factor (quality factor)

See quality factor.

Q-value

is: the amount of kinetic energy released as a result of a nuclear reaction. [P9.1]

is: for a nuclear decay, the kinetic energy shared by the decay products. [P9.1]

always is: for a spontaneous reaction, greater than zero: $Q \geq 0$. [P9.1]

quadrant

is: a quarter of a circle or disc, being a region bounded by a circular arc and two diameters that intersect at right angles. [M2.1]

is also: a quarter of a (two-dimensional) Cartesian coordinate system, being a region bounded by two axes that intersect at right angles.

quadratic equation

is: a polynomial equation of degree 2, i.e. an equation of the form $ax^2 + bx + c = 0$, where $a \neq 0$. [M1.3, M1.4]

quadratic expression

is: an expression of the form $ax^2 + bx + c$, where $a \neq 0$. [M1.4]

quadratic function

is: a function of the form $f(x) = ax^2 + bx + c$, where $a \neq 0$. [M1.3, M1.4]

quadrilateral

is: a four-sided polygon. [M2.1]

quality factor (Q-factor)

for: an oscillator

is: a 'figure of merit' describing the quality of the oscillator. [P5.2]

is: the factor by which the power absorption of a driven oscillator on resonance exceeds that for the oscillator when the frequency of the driving force is well away from the resonance frequency. [P5.3]

is equal: to the ratio of the resonance frequency to the resonance bandwidth between the two half-power points. [P5.3]

is also given: by 2π times the magnitude of the reciprocal of the fractional energy loss over one period of oscillation, i.e. $Q = 2\pi E(t)/|(\Delta E)_T|$. [P5.2]

quanta

is: the plural of quantum.

quantization

See quantized.

quantization of charge

is the observation: that all experimentally isolated charges are (positive or negative) integer multiples of the charge e, where $e = 1.602 \times 10^{-19}$ C (to four significant figures). [P3.3]

quantized quantity

describes: a quantity which has only certain separated or discrete values, as opposed to a continuous range of values. [P10.3]

appears: often in quantum physics but not in classical physics (except for the allowed frequencies of standing waves – from which the idea of quantum physics evolved). [P8.2]

is exemplified: in the Bohr model for atomic hydrogen, by the atomic electron having only certain values for the magnitude of its angular momentum about the nucleus (Bohr quantization condition), which leads also to quantized energy levels for the atomic electron's bound states. [P8.2, P8.3]

is also exemplified: when electromagnetic radiation interacts with matter, by the energy transfers being quantized in terms of photons (quantum theory of electromagnetic radiation). [P8.2]

quantum

is: a term that can be applied both to matter and to electromagnetic radiation in order to avoid referring to either as 'particles' or 'waves'. These latter terms can be used only in certain circumstances ('particles' for interactions, 'waves' for propagation), whereas the term 'quantum' refers to both types of behaviour. [P10.1, P10.3]

often referred to: as a particle. [P10.1, P10.3]

See also photon.

quantum field theory

is: the branch of quantum theory that concerns systems with an infinite number of degrees of freedom, and may be contrasted with quantum mechanics which concerns systems with a finite number of degrees of freedom.

is used: mainly in the study of elementary particles.

is characterized: by consistency with Einstein's special theory of relativity.

quantum harmonic oscillator

is: a quantum mechanical system in which a particle of mass m moves (in one dimension) under the influence of a potential energy function $U(x) = k_s x^2/2$ [P11.2]

has: energy levels $E_n = (n + 1/2)hf$, where $n = 0, 1, 2, 3, \ldots$, and h is Planck's constant. [P11.2]

has: spatial wavefunctions $\psi(x) = A_n f_n(x) \exp(-\alpha x^2/2)$ where $n = 0, 1, 2, 3, \ldots$,

A_n is a constant, $f_n(x)$ is a particular polynomial function of x of degree n with n nodes, and $\alpha = (2\pi/h)$ [P11.2]

has: zero point energy $E_0 = hf/2$ when $n = 0$. [P11.2]

exhibits: classical behaviour as n approaches infinity. [P11.2]

quantum mechanical exchange effects

are: phenomena in quantum mechanics arising from the requirement that observable properties of systems containing several identical particles should be unchanged by the interchange of the coordinates of those particles. (Such effects have no direct analogues in classical physics.)

quantum mechanics

is: a wide-ranging theory that describes the behaviour of mechanical systems (such as a particle moving under the influence of a given potential energy function) in situations where the laws and methods of classical mechanics may be inapplicable. [M6.4, P7.1, P8.3, P10.3]

more formally is: the branch of quantum theory that concerns systems with a finite number of degrees of freedom, and may be contrasted with quantum field theory which concerns systems with an infinite number of degrees of freedom.

may be formulated: in a number of equivalent ways, one such formulation being Erwin Schrödinger's wave mechanics. [M6.4, P7.1, P8.3, P10.3]

was founded: mainly by European physicists between 1925-1927. [M6.4, P7.1, P8.3, P10.3]

is used: mainly in the study of microscopic systems such as molecules, atoms and nuclei. [M6.4, P7.1, P8.3, P10.3]

is characterized: by the existence of a (de Broglie) wave description of matter and by the ensuing Heisenberg uncertainty principle and the impossibility of simultaneously determining the position and momentum of a particle with arbitrarily high precision, thus denying the possibility that an electron in an atom moves in a well defined observable orbit.

is also characterized: by the occurrence of quantized quantities; by the use of probability (as in the Born probability interpretation of the wavefunction); and by inconsistency with Einstein's special theory of relativity.

See quantum and Schrödinger equation.

quantum model (of the atom)

See Schrödinger model.

quantum number

for: a confined particle

is: a quantity whose possible values characterize the possible eigenfunctions (wavefunctions) of the particle. [P8.3]

is exemplified: for a particle confined in one dimension between parallel plates, by the **one** quantum number n (which can have the value 1 or 2 or 3, etc.) which is required to specify each of the particle's possible energy eigenfunctions (spatial wavefunctions). [P11.2]

is exemplified: for a particle that is confined in three dimensions in a cube, by the **three** quantum numbers n_1, n_2, n_3 (n_1, n_2 and n_3 can each be equal to 1 or 2 or 3, etc.) which are required to specify each of the particle's possible energy eigenfunctions (spatial wavefunctions). [P11.2]

most usually is: a number (or one of a set of such numbers) specifying a particular energy eigenfunction (spatial wavefunction) and the corresponding energy eigenvalue (energy level) of the confined particle. [P10.3, P10.4]

is exemplified: for electrons in an atom, by the principal quantum number n the orbital angular momentum quantum number l, the orbital magnetic quantum number m_l and the spin magnetic quantum number m_s. [P8.3, P11.3]

quantum physics

is: the broad area of physics that concerns the theoretical and experimental study of phenomena such as the photoelectric effect, Compton scattering, electron diffraction and the spectra of atoms, which cannot be adequately described on the basis of classical physics. [P10.1, P10.2]

applies: to objects of all sizes, but its consequences are more commonly observable at an atomic scale. [P10.2]

has had great success: in describing the behaviour of nuclei, atoms, molecules and the properties of solids, using quantum mechanics; and in describing the behaviour of elementary particles, using quantum field theory. [P10.1, P10.2]

quantum state

of: a system

in: quantum mechanics (or, more generally, quantum physics)

is: the most complete description of the properties of a system allowed by its wavefunction. It may include the values that various observables (such as momentum and energy) will be found to have if measured, or it may be confined to statements about the relative probability of various possible outcomes of a measurement. [M6.4, P7.1, P8.3, P8.4, P10.3, P10.4]

is specified: in sufficiently simple cases, by the values of a set of quantum numbers. [M6.4, P7.1, P8.3, P8.4, P10.4]

See stationary state.

quantum theory

is: the theoretical part of quantum physics. It encompasses quantum mechanics and quantum field theory.

is also: used to indicate the early pre-quantum mechanics stage of quantum physics.

quantum theory of electromagnetic radiation

holds: that when electromagnetic radiation is emitted or absorbed by matter, the energy transfers are in terms of the emission or absorption of photons. They are *not* continuous: arbitrarily small energy transfers are *not* possible. [P8.2]

holds: that the energy of a photon is given by $E = hf$, where f is the frequency of the associated radiation and h is Planck's constant. [P8.2]

more generally is: a wide ranging and very mathematical branch of quantum theory.

quantum tunnelling

is: the process by which a particle tunnels through a potential barrier to the other side, even though the presence of the particle within the potential barrier (where its potential energy would exceed its total energy) is forbidden by classical physics. [P10.2, P10.4]

is made possible: by the quantum nature of matter. [P10.2]

is also called: barrier penetration. [P10.4]

quark

See elementary particle.

quartic equation

is: any fourth-degree polynomial equation that may be written in the form:

$$ax^4 + bx^3 + cx^2 + dx + e = 0$$

where a, b, c, d, and e are constants, and $a \neq 0$. [M1.4]

quartic function

is: a polynomial function of degree 4. [M1.3]

quartz crystal oscillator

is: an electrical oscillator and mechanical oscillator combined. [P5.3]

is sustained: by the piezoelectric properties of a quartz crystal. [P5.3]

works: when an electric field deforms the crystal, so that the energy of the oscillation is stored in the crystal as mechanical energy, and the crystal, in recovering, produces an electric field and therefore a current, whose energy now is stored in the rest of the circuit as electrical energy, and so on around again. [P5.3]

in other words, is like: an electrical oscillator, with the capacitor mainly replaced by the quartz crystal.

quasistatic process

in: thermodynamics

is: a process in which the state of a system changes sufficiently slowly that it is always infinitesimally close to an equilibrium state. [P7.3, P7.4]

therefore can be shown: as a pathway on the equilibrium (PVT)-surface of a system. [P7.3, P7.4]

but never can be achieved: fully in practice, because it would take an infinite length of time. [P7.3, P7.4]

quotient

See operation.

quotient of two complex numbers

for: $Z_1 = a_1 + ib_1$ and $Z_2 = a_2 + ib_2$

is: $\dfrac{Z_1}{Z_2} = \dfrac{a_1a_2 + b_1b_2 + i(a_2b_1 + a_1b_2)}{a_2^2 - b_2^2}$ [M3.1]

quotient rule (of differentiation)

states that: $\dfrac{d}{dx}\left[\dfrac{f(x)}{g(x)}\right] = \dfrac{f'(x)g(x) - f(x)g'(x)}{[g(x)]^2}$ [M4.2]

r.m.s.

is: an abbreviation for root-mean-square. [P5.4]

radial

means: pertaining to the direction measured outwards or inwards, directly away from or towards a centre or origin.

radial coordinate

of: a point in a system of polar coordinates

is: the distance from the origin to the point. [M2.2]

radial probability density

is: the factor $4\pi r^2|R_{nl}(r)|^2$, that arises in calculating the probability density $|\psi(r, \theta, \phi)|^2$, where $R_{nl}(r)$ is the radial part of the spatial wavefunction $\psi(r, \theta, \phi)$ in Schrödinger's model of the hydrogen atom. [P11.3]

represents: the probability per unit increment of r of finding the electron at distance r from the nucleus.

radian, rad

is: a dimensionless derived unit of plane angle. [M1.6, M2.1]

is defined: by requiring that, for any circle, the arc subtended at the circumference by an angle of 1 radian at the centre has a length equal to that of the circle's radius; so there are 2π radians in one complete revolution of 360° and 1 radian ≈ 57.3°. [M1.6, M2.1]

See degree.

radiation (α-, β-, γ-)

is: a general term for the particles (e.g. α-particles and β-particles) and electromagnetic radiation (e.g. γ-rays) emitted during nuclear reactions, particularly radioactive decay.

radiation (electromagnetic)

See electromagnetic radiation.

radiation (general)

refers: to anything travelling in a stream, especially subatomic particles or electromagnetic waves.

See radiation (α-, β-, γ-) and electromagnetic radiation.

radiation (thermal)

is: one of three ways (the other two being conduction and convection) in which heat can be transferred. [P7.3]

operates: not only in transparent materials (gases, liquids and solids), but also in a vacuum. [P7.3]

works: through emission and absorption of energy carried by electromagnetic radiation. [P7.3]

can be understood: very precisely in microscopic terms, provided that the surface emitting the radiation can be treated as that of an idealized black-body. (The next best approximation is to characterize the surface by a constant emissivity $\varepsilon \leq 1$.) The total power emitted per unit area of a black-body at temperature T is described by Stefan's law ($R = \sigma T^4$), and its spectral brightness is described by Planck's function. [P7.3]

goes: both ways. When a hot body and a cold body exchange heat by radiation, *both* bodies emit and *both* bodies absorb, so the net heat flow is a difference. In some applications where there is a large temperature difference, the heat emitted by the cold body is small enough that it can be safely neglected. [P7.3]

radiation pressure

is: pressure exerted on a surface reflecting or absorbing electromagnetic radiation as a consequence of the momentum carried by that radiation. [P10.1]

radiation weighting factor, RWF

is: a measure of the ability of ionizing radiation to ionize the molecules of living tissue. X-rays are defined to have RWF = 1 and other radiations have their RWF determined relative to X-rays. [P9.3]

See dose equivalent.

radio waves

are: electromagnetic waves with wavelengths greater than approximately $0.03\,\mathrm{m}$.

See electromagnetic spectrum.

radioactive decay

is: the spontaneous decay of an unstable nucleus (usually of one of the heavier elements) into a lighter nucleus by the emission of α-particles or β-particles or γ-radiation. [P9.1, P9.2]

radioactive decay equation

See radioactive decay law.

radioactive decay law

is: the law which governs the number of nuclei $N(t)$ of a radioactive isotope that will remain in a sample after a given time t has elapsed. [P1.3, P9.2]

is: exponential: $N(t) = N_0\,e^{-\lambda t}$, where N_0 is the initial number of nuclei and λ is the decay constant. [P1.3, P9.2]

arises: as a solution to the first-order differential equation $dN/dt = -\lambda N$. [M6.2]

radioactive nucleus

is: a nucleus which is unstable and which therefore spontaneously decays.
[P9.1]

radioactivity

See radioactive decay.

radiocarbon dating

is: a method of dating (finding the age of) a sample that contains carbon absorbed from the atmosphere. The age is obtained by finding the relative amounts of the radioactive ${}^{14}_{6}C$ isotope and the stable ${}^{12}_{6}C$ isotope. [P9.2]

is used mainly: in archaeology and for studies of relatively recent geological events (less than 50 000 years ago). It can give the age of wood, shell, bone and other forms of organic material. [P9.2]

is also known: as carbon dating. [P9.2]

radioisotope

is: an isotope which is unstable and which therefore undergoes radioactive decay. [P9.2]

radionuclide

is: a nuclide which is unstable and which therefore undergoes radioactive decay. [P9.2]

radius

is: the distance from the centre of a circle to a point on its circumference, or the distance from the centre of a sphere to a point on its surface. [M2.1, M2.3]

is also: the distance (which will vary with orientation) from the centre of an ellipse to a point on its perimeter. [M2.3]

radius of curvature

for: a spherical surface

is: the radius of the sphere of which the surface forms a part. [P2.6, P6.3]

can be: according to a commonly adopted sign convention, positive or negative for a convex or concave surface, respectively. (See Cartesian sign convention.) [P2.6, P6.3]

radius of gyration

of: a body of mass M

about: a particular axis of rotation

is: the distance k from the axis of rotation that a particle of (the same) mass M would have to be, in order for its moment of inertia I about the axis to be the same as that of the real body. [P2.7]

therefore is defined: by $I = Mk^2$. [P2.7]

radius vector

of: a point

in: a polar coordinate system (including spherical polar coordinates)

is: a directed line segment, from the origin to the point. (Its magnitude is the radial coordinate of the point.) [M2.2]

random error

in: a measurement

is: the kind of error that causes the results to be distributed around a mean value and so reduces the precision. [P1.1, P1.2]

arises: from many causes, including non-systematic instrumental errors such as limitations in the scale on which the measurement is based. [P1.1, P1.2]

can be reduced: (within limits) by averaging repeated measurements. [P1.1, P1.2]

limits: the precision of a measurement.

Contrast with systematic error which determines accuracy.

random motion

can characterize: the motion of one particle over a very long time, or many particles over an arbitrary time. [P7.5]

is defined: by the absence of any preferred direction or speed. In the case of the motion of one particle, this means that at some time the particle will be found to be moving in any pre-specified direction with any pre-specified speed. [P7.5]

range

is: the distance between the point from which a projectile is launched and the point at which it lands. If the two points are at the same vertical height, the range is sometimes referred to as the horizontal range. [P2.2]

range of integration

for: a definite integral

is: the range of values bounded by the lower and upper limits of integration. [M5.2]

rarefaction

in: a medium

is: a region where the pressure and hence the density of the medium are lower than average. [P5.7]

rate of change

is: the derivative of a function with respect to its independent variable. [M4.1, M4.2]

usually refers: to situations where the independent variable is time, but is not entirely restricted to such cases. [M4.1, M4.2]

ratio

of: two quantities

is: one quantity divided by the other quantity.

is also: known as quotient.

ratio of specific heats

for: a substance

is: the ratio of the principal specific heats, $\gamma = c_P/c_V$. [P7.4]

is equivalently: the ratio of the molar specific heats $\gamma = C_P/C_V$. [P7.4]

is exemplified: for a monatomic ideal gas, by $\gamma = 5/3$ [P7.4]

is also exemplified: for a diatomic ideal gas, by $\gamma = 7/3$ [P7.4]

rational number

is: a number which can be expressed as a fraction. [M1.2, M3.1]

more precisely is: a number which can be expressed in the form m/n where m and n are integers. [M1.5]

rationalization

is: the algebraic procedure whereby a differential equation is manipulated to remove all fractional powers of derivatives. [M6.1]

is more generally: any procedure that removes fractional powers from the denominator of an algebraic or numerical fraction.

rationalizing a (complex) quotient

is: the process of converting a complex quotient (such as $(3 + 2i)/(1 + 4i)$) to the form $x + iy$ where x and y are real numbers. [M3.1]

involves: multiplying the numerator and the denominator of the quotient by the complex conjugate of the denominator.

See complex numbers in the Maths handbook.

ray

is: that part of a straight line that extends from a given point in one direction only. [M2.1]

is also used: as an abbreviation for light ray.

ray approximation

is: the approximation to the wave model of light in which diffraction effects may be ignored and light treated as though it travels along rays. [P6.2]

provides the basis: for geometrical optics.

ray diagram

in: geometrical optics

is: a diagram which is used to find the relative positions of object and image for a lens or mirror, using the principal rays. [P6.3]

Rayleigh criterion

is: an arbitrary criterion establishing the condition in which the optical images of two point-like objects can be said to be resolved by the optical system that created them [P6.4]

requires: that the central diffraction maximum of one image should fall on or beyond the first diffraction minimum of the other. [P6.4]

implies: for a circular aperture of diameter d, that the angular separation of the two objects, as measured (in radians) at the aperture, should be at least (1.22 radian)λ/d, where λ is the wavelength of the radiation used. [P6.4]

reactance

of: a reactive circuit component in an a.c. circuit

is: the impedance of the circuit component. [P5.4]

has the symbol: X. [P5.4]

has as its SI unit: the ohm (Ω). [P5.4]

generally depends: on the angular frequency of the alternating current

is exemplified: for a capacitor, by the reactance $X_{\rm C} = 1/(\omega C)$. [P5.4]

is exemplified: for an inductor, by the reactance $X_L = \omega L$. [P5.4]

reaction

is: a process in which an entity or a group of entities is transformed to produce one or more different entities.

is exemplified: by a chemical reaction.

reaction force

of: a solid surface

against: an oppressing object

is: in equilibrium on a horizontal surface, equal and opposite to the weight of the object (or to the sum of the weight plus any additional forces pressing the object into the solid). [P2.3]

reactive

describes: electrical components in an a.c. circuit whose impedance depends upon the supply frequency. [P5.4]

is exemplified: by capacitors and inductors. [P5.4]

See reactance.

reactor

is: a device designed to contain a reaction.

See nuclear fission reactor and nuclear fusion reactor.

real axis

is: the axis in a complex plane (or Argand diagram) along which the real part of a complex number is measured. [M3.1]

normally is: the horizontal axis. [M3.1]

real depth

of: an object below an interface between transparent media, when the object is viewed by refraction from above the interface

is: the distance from the interface to the object. [P6.2]

See apparent depth.

real gas

is: a gas that actually exists, in contrast to an ideal gas, which does not. [P7.2]

generally is: a complicated system. [P7.3]

but usually can be modelled: at low pressure, by the equation of state of an ideal gas $PV = nRT$, provided that there are no phase changes. [P7.3]

often is modelled: by equations of state which allow for the undoubted facts that atoms or molecules in a gas interact and have volume. [P7.3]

real image

is formed: where the light rays from a point object converge to a point, after reflection at a mirror or refraction at a lens. [P6.2, P6.3]

can be formed: on a screen. [P6.2, P6.3]

real line

is: the set of all real numbers. [M3.1]

is also: the infinite line representing such numbers. [M3.1]

is the same: as the real axis in an Argand diagram. [M3.1]

real number

is: an ordinary number, such as 3.44 or −198.0. [M1.4]

can be expressed: as a decimal number (possibly with an infinite number of decimal places). [M1.2, M3.1]

can represent: a measurable physical quantity, when used in conjunction with appropriate units. [M1.2, M3.1]

real part

of: a complex number $x + iy$ (where x and y are real numbers)

is: the term x. [M1.4, M3.1, P5.5]

often is denoted: by $\mathrm{Re}(z)$. [M3.1, P5.5]

rearrangement (of an equation)

results: from performing a valid algebraic manipulation. [M1.1]

provides: a different, but equivalent, way, of expressing the initial relationship. [M1.1]

reciprocal

of: a given number or expression

is: the result of dividing 1 by the given number or expression. [M1.1]

is exemplified: by the reciprocal of x, which is $1/x$ or x^{-1}. [M1.1]

is exemplified: by the reciprocal of $1/x$ which is x. [M1.1]

is exemplified: by the reciprocal of a fraction y/x which is x/y. [M1.1]

reciprocal function

of: a function $f(x)$

is: a function of the form $R(x) = 1/f(x)$. [M1.3]

is exemplified: by the reciprocal trigonometric functions.

reciprocal hyperbolic functions

are: the cosech, sech and coth functions. [M4.6]

are: reciprocals of the basic hyperbolic functions: sinh, cosh and tanh. [M4.6]

See hyperbolic functions in the Maths handbook.

reciprocal rule (of differentiation)

states that: $\dfrac{d}{dx}\left(\dfrac{1}{F(x)}\right) = -\dfrac{F'(x)}{[F(x)]^2}$ [M4.2]

reciprocal trigonometric functions

are: the cosecant, secant and cotangent functions. [M1.6]

are: the reciprocals of the standard trigonometric functions: sine, cosine and tangent. [M1.6]

often are referred to: simply as trigonometric functions. [M1.6]

See trigonometric functions in the Maths handbook for further details.

reciprocal trigonometric ratios

are: the cosecant, secant and cotangent. [M1.6]

are: the reciprocals of the standard trigonometric ratios: sine, cosine and tangent. [M1.6]

often are referred to: simply as trigonometric ratios. [M1.6]

See trigonometric functions in the Maths handbook.

rectangle

is: a parallelogram in which all interior angles are right angles. [M2.1]

rectangular block

is: a prism in which the base is a rectangle and the angle between any two adjacent edges is 90°. [M2.1]

rectangular hyperbola

is: a hyperbola with orthogonal asymptotes. [M2.3]

can be represented: by the equation $xy = c^2$, where c is a constant. [M2.3]

See conic sections in the Maths handbook.

rectilinear propagation

is: travel in straight lines.

is exemplified: by the travel of light in a uniform medium under conditions where diffraction is insignificant. [P6.2]

reduction formula

for: an integral which involves a power of x (or of some function of x)

is: an equation which relates the integral to another integral of the same form but involving a lower power of x (or of the function of x). [M5.5]

See further integration in the Maths handbook.

reflected ray

is: a light ray leaving a surface or interface following the reflection of an incident ray. [P6.1, P6.2]

reflection

is: a process in which an entity or agency (e.g. a ray of light) encountering a surface or interface returns through its original medium after the encounter rather than being absorbed at the interface or transmitted (refracted) into the new medium. [P6.2]

See law of reflection.

reflection coefficient

in: quantum physics

for: a stream of particles

encountering: a potential step or potential barrier

can be determined: from quantum mechanics. [P11.1]

is defined as:

$$R = \frac{\text{flux of reflected particles}}{\text{flux of incident particles}}$$ [P11.1]

reflection diffraction grating

is: a form of diffraction grating in which the diffracted beams are produced by reflection from a surface that has been ruled with many closely spaced, narrow parallel lines. [P6.1]

reflectivity

is: a measure of the efficiency with which reflection takes place at a surface or interface.   [P6.2]

reflex angle

is: an angle between 180° and 360°. [M2.1]

refracted ray

is: a ray formed from an incident ray by transmission either across an interface at which the refractive index changes abruptly, or through a region of varying refractive index. [P6.1, P6.2]

refraction

is: the process in which the direction of a light ray changes either at the boundary between two transparent materials of different refractive index or through a region of varying refractive index. [P6.2]

more generally is: the process by which a wave's direction of propagation is changed as it travels through varying materials. The bending is a direct consequence of the different speeds of the wave in the different materials - dispersion. [P5.7, P6.1]

See law of refraction.

refractive index

of: a transparent material

is: the ratio of the speed of light in a vacuum to the speed of light in the material. [P6.1]

generally depends: on the frequency of the light.

usually is symbolized: by μ. [P6.1, P6.2]

regula falsi

is: a numerical procedure for locating the root of an equation. [M1.4]

regular polygon

is: a polygon in which each of the sides is of equal length and each of the interior angles is of the same size. [M2.1]

relative abundance

refers to: relative numbers of atoms of the various isotopes of an element, that are found in the analysis of a sample of matter. [P8.1]

often means specifically: the relative abundances of isotopes in naturally occurring samples on Earth. [P8.1]

relative atomic mass

of: an atom

is given: by

$$A_{\rm r} = \frac{\text{mass of atom}}{1\,\text{u}} = \frac{12 \times \text{mass of atom}}{\text{mass of one } ^{12}\text{C atom}}$$

where 1 u stands for one atomic mass unit. (Relative atomic masses of other particles may be defined in a similar way.) [P7.1, P8.1]

formerly was known: as 'atomic weight'. [P8.1]

is numerically equal: to the mass in grams of one mole of the substance. So it can be determined by comparing the masses of appropriately prepared macroscopic samples of matter. [P7.1, P7.2]

for a naturally occurring element, is obtained: by multiplying the relative atomic mass of each of its isotopes by the corresponding relative abundance and adding together the resulting products. [P8.1]

relative maximum

See local maximum.

relative minimum

See local minimum.

relative molecular mass

is given: by

$$\frac{\text{mass of molecule}}{1\,\text{u}} = \frac{12 \times \text{mass of molecule}}{\text{mass of one } ^{12}\text{C atom}}$$

where 1 u represents one atomic mass unit. [P8.1]

numerically is equal: to the mass in grams of one mole of the substance. [P7.2]

formerly was known: as 'molecular weight'. [P8.1]

relative permeability

of: a material

is: the dimensionless ratio μ/μ_0 of its permeability μ to the permeability of free space μ_0.

is therefore: the factor by which the magnetic field strength due to an arbitrary current distribution is increased from its value in vacuum, by the presence of the material. [P4.4, P4.5]

relative permittivity

of: a material

is: the dimensionless ratio $\varepsilon_r = \varepsilon/\varepsilon_0$ of the permittivity ε of the material to the permittivity of free space ε_0. [P3.3, P4.5]

is therefore: the factor by which the electric field strength due to an arbitrary charge distribution is reduced in the medium compared with its value in free space. [P3.3]

relative velocity

of: an object relative to a point from which its displacement is $\boldsymbol{s}$

is: the rate of change of the displacement with respect to time: $d\boldsymbol{s}/dt$. [P2.1]

has: a magnitude known as the 'relative speed' of the object with respect to the reference point.

relativistic momentum

of: a particle of mass m travelling with velocity $\boldsymbol{v}$, (which may be close to the velocity of light)

is: according to Einstein's special theory of relativity,

$$\boldsymbol{p} = \frac{m\boldsymbol{v}}{\sqrt{1 - \dfrac{v^2}{c^2}}}$$ where c is the speed of light in a vacuum. [P2.5]

agrees: with the definition of linear momentum in Newtonian mechanics ($\boldsymbol{p} = m\boldsymbol{v}$) for low speeds (when $|\boldsymbol{v}| << c$), but differs markedly at high speeds.

ensures: that the principle of conservation of momentum is valid at all speeds (up to c). [P2.5]

relativity

See Einstein’s special theory of relativity.

repeated root

is: a root of a polynomial equation which appears more than once in the factorized form of the polynomial. [M1.4]

is exemplified: by the repeated root a in $(x - a)^2(x - b) = 0$. [M1.4]

reprocessing

is: the recovery of materials that are either valuable or particularly hazardous from the spent fuel rods of a nuclear fission reactor. [P9.3]

resistance

is: the ratio of the voltage difference between the ends of a conductor to the current in that conductor: $R = V/I$ [P4.1, P5.5]

determines: the power dissipated in the conductor, $P = IV = I^2R = V^2/R$. [P4.1]

has as its SI unit: the ohm (Ω) where $1\,\Omega = 1\,\mathrm{V\,A^{-1}}$. [P4.1]

more generally refers: to any dissipative force. [P5.2]

resistance thermometer

is: a device for measuring temperature, based on the variation with temperature of electrical resistance in a wire (often a platinum wire). The resistance is usually monitored with the aid of a bridge circuit. [P7.2]

can be used: over a wide range of temperatures. [P7.2]

resistive heating

See Joule heating.

resistivity

of: a material

is: an intrinsic electrical property of the material. [P4.1]

permits: computation of the resistance, R of a sample of the material of specified shape and size. For a sample of length l, cross-sectional area A and resistivity ρ: $R = \rho l/A$ [P4.1]

has as its SI unit: the Ω m [P4.1]

resistor

is: a device for restricting the flow of charge in an electric circuit.

resolution (of a vector)

is: the process of splitting the vector into its component vectors along an appropriately chosen set of directions. [M2.1, M2.4]

See also orthogonal resolution.

resolution

is: a measure of performance of an instrument (e.g. an optical instrument) in its ability to produce or distinguish two images of two objects which are, or appear to be, very close together. [P6.4]

See also angular resolving power and Rayleigh criterion.

resolve

means: to be able to distinguish as separate two narrowly separated points or objects, according to some appropriate criterion. [P6.4]

See resolution and Rayleigh criterion.

resolving power

See angular resolving power.

resonance

is: the condition in which a driven oscillator responds with maximum amplitude or velocity to a periodic driving force. [P5.3, P5.4, P5.5, M6.3]

occurs: for lightly damped systems, when the frequency of the driving force is close to the natural frequency of the oscillator. [P5.3, P5.4, P5.5, M6.3]

resonance absorption bandwidth

of: a driven oscillator

is: the frequency difference between the two half-power points on the power absorption curve of the oscillator. [P5.3]

resonance angular frequency

of: an oscillator

is: the angular frequency at which resonance occurs. [P5.3]

resonance frequency

of: an oscillator

is: the frequency at which resonance occurs. [P5.3, P5.5]

rest energy

of: a particle of rest mass m_0

is: the energy $E_0 = m_0c^2$ that the particle would have by virtue of its mass alone, even if free and at rest, according to Einstein's mass-energy equation. [P9.1]

is also called: rest mass energy. [P9.1]

rest mass

of: a particle

is: the mass, m_0, of the particle as measured when it is at rest relative to the observer. [P9.1]

rest mass energy

See rest energy.

restoring force

is: a force which is always directed towards a single equilibrium position. [P2.4, P5.1]

is exemplified: by the force that tends to return the end of a spring to its unextended position. [P2.4]

resultant (vector)

is: the vector that results from combining two (or more) vectors together using the operations of vector addition and scaling. [M2.4, M2.5, P2.2]

is exemplified: by the resultant force of a set of forces $\boldsymbol{F} = \boldsymbol{F}_1 + \boldsymbol{F}_2 + \dots$; the resultant torque of a set of torques $\boldsymbol{\Gamma} = \boldsymbol{\Gamma}_1 + \boldsymbol{\Gamma}_2 + \dots$; the resultant moment of a set of moments, etc. [P2.3, P2.7]

resultant force

See resultant (vector).

resultant moment

See resultant (vector).

resultant torque

See resultant (vector).

retina

is: the light sensitive surface at the back of the eye, made up of two types of cell, the rods and the cones. [P6.4]

reversed image

is: the kind of image which is seen in a plane mirror: right and left appear to be interchanged but top and bottom do not. [P6.2]

can be understood: by supposing that the mirror occupies the (x, y)-plane of a right-handed Cartesian coordinate system, and then recognizing that a point object with coordinates (X, Y, Z) will correspond to a point image with coordinates $(X, Y, -Z)$. This implies that the reversed image of a right-handed coordinate system will be a left-handed coordinate system. [P6.2]

reversible

describes: a process which allows the system undergoing it and the environment to be returned to their original states after the process has taken place. According to the principle of entropy increase, the entropy of the Universe (i.e. system + environment) is unchanged by a reversible process. [P7.4]

revolution

is: the turning motion of a body about an axis which does not necessarily (especially in astronomy) pass through the centre of mass of the body.

is exemplified: by the revolution of the planets about the Sun.

Compare and contrast with rotation.

rhombus

is: a parallelogram in which all sides are equal. [M2.1]

right angle

is: an angle of 90° (or, equivalently, $\pi/2$ radians). [M1.6, M2.1]

corresponds: to a rotation through one quarter of a complete revolution. [M1.6, M2.1]

right-angled triangle

is: a triangle in which one of the three (interior) angles is a right angle.
[M1.6, M2.1]

right-hand grip rule

is: a rule for determining the direction of the magnetic field associated with a current.

states: if you point the extended thumb of your right hand in the direction of the current, then the fingers of your right hand curl around your thumb in the same sense that the magnetic field lines curl around the current. [P4.2]

is also: a rule for determining the sense of the rotation associated with an angular velocity $\boldsymbol{\omega}$, an angular momentum $\boldsymbol{L}$, or a torque $\boldsymbol{\Gamma}$.

right-hand rule

is: a rule for working out the direction of a vector product such as $\boldsymbol{a} \times \boldsymbol{b}$.

states: if you align the straightened fingers of your right hand with the vector $\boldsymbol{a}$ and twist your wrist so that when you close your palm your fingers come into alignment with the vector $\boldsymbol{b}$, then the direction of your extended right thumb shows the sense in which $\boldsymbol{a} \times \boldsymbol{b}$ is perpendicular to $\boldsymbol{a}$ and $\boldsymbol{b}$. [M2.7, P4.3]

more briefly states: the direction of $\boldsymbol{a} \times \boldsymbol{b}$ is the direction of your extended right thumb, when the fingers of your right hand sweep from $\boldsymbol{a}$ to $\boldsymbol{b}$.

See corkscrew rule and right-hand screw rule.

See also vector product in the Maths handbook.

right-hand screw rule

is: a rule for working out the direction of a vector product such as $\boldsymbol{a} \times \boldsymbol{b}$. [M2.7, P2.8]

states: that the vector $\boldsymbol{a} \times \boldsymbol{b}$ points in the direction in which a right-handed screw will advance when the slot in its head is turned from the direction of $\boldsymbol{a}$ to the direction of $\boldsymbol{b}$. [M2.7, P2.8]

See the right-hand rule and the corkscrew rule.

right-handed (Cartesian) coordinate system

is: a three-dimensional Cartesian coordinate system (consisting of three mutually perpendicular coordinate axes which meet at a point called the origin) in which an observer located at the origin and looking along the *z*-axis in the direction of increasing *z* finds that a right-handed screw motion through 90° (i.e. a 90° clockwise rotation) is needed to bring the *x*-axis into the position previously occupied by the *y*-axis. [P2.7, P6.2]

Contrast with left-handed coordinate system.

rigid body

is: a body of fixed shape. When revolving, all parts of a rigid body have the same axis of rotation and the same angular speed about this axis. [P2.3, P2.8]

ringing time

is: the time required for a damped oscillator with a high Q-factor (i.e. only a lightly damped oscillator) to reduce its energy by a factor of e^{-1}. [P5.2]

is equal: to $Q/2\pi$ [P5.2]

rise

is: a term arising in the informal definition gradient = rise/run

represents: the difference in vertical coordinate value (usually denoted by Δy) between two points on a straight line. (The run represents the corresponding change in horizontal coordinate value (often denoted Δx)). [P1.3]

rods

are: one of two types of light sensor present in the retina, the other type being cones. [P6.4]

are: the more sensitive and provide vision at low light levels, but do not provide colour vision. [P6.4]

root

of: an equation

is: a value of the independent variable that makes the equation true, i.e. a solution of the equation. [M1.1, M4.1, M4.4]

root-mean-square (r.m.s.) current

of: a given alternating current

is: the steady d.c. current which, when flowing through a resistor, causes energy to be dissipated at the same rate as the given alternating current. [P5.4]

is given: for a sinusoidally varying current $I(t) = I_0 \sin(\omega t + \phi)$ by $I_{\rm rms} = I_0/\sqrt{2}$. (Similarly, the root-mean-square voltage is given by $V_{\rm rms} = V_0/\sqrt{2}$.) [P5.4]

See root-mean-square value.

root-mean-square (r.m.s) speed

for: a speed distribution of gas molecules

is: the square root of the mean of the squares of the speeds. [P7.5]

is obtained: by dividing the sum of the squares of the speeds by the total number of molecules and then taking the square root. [P7.5]

See root-mean-square value.

root-mean-square value (r.m.s.)

(1) of: n values, x_1, x_2, x_3, … x_n

is: $$x_{\text{rms}} = \sqrt{\frac{x_1^2 + x_2^2 + \ldots + x_n^2}{n}} = \left(\frac{1}{n}\sum_{i=1}^{n} x_i^2\right)^{1/2}$$

(2) of: a continuously varying quantity $f(x)$, over the interval $a \le x \le b$ (often a period of a periodic function).

is: $$f_{\text{rms}} = \left\{\frac{1}{(b-a)}\int_a^b [f(x)]^2\,dx\right\}^{1/2}$$

root-mean-square (r.m.s.) voltage

See root-mean-square (r.m.s.) current.

roots of unity

are: the n complex numbers that satisfy the equation $z^n = 1$. [M3.2]

rotation

is: the turning motion of a body about an axis, normally (especially in astronomy) about an axis through its centre of mass.

is exemplified: by the rotation of the Earth about its axis.

Compare and contrast with revolution.

rotational equilibrium

of: a system

is: the condition in which the total angular momentum of the system is constant.

requires: that the resultant external torque acting on the system is zero. [P2.7]

implies: for a rigid body, that the angular acceleration of the body is zero (though it does not necessarily imply that the angular velocity is zero). [P2.7]

is a necessary condition: for static equilibrium in which there is no motion.

See also translational equilibrium.

rotational kinetic energy

is: the kinetic energy which a body possesses by virtue of its rotation. [P2.7]

is given: for a body with moment of inertia I about some axis, rotating with angular speed ω about that axis, by $\frac{1}{2}I\omega^2$. [P2.7]

rounding

See rounding-down, rounding-up.

rounding-down

takes place: when the number of figures in a value is reduced and the last of the remaining figures is unchanged from its original value. [M1.2, P1.1]

takes place only: if that last figure would have been followed by 0, 1, 2, 3 or 4. [M1.2, P1.1]

rounding errors

are: errors that arise as a result of rounding. [M1.2]

rounding-up

takes place: when the number of figures in a value is reduced, and the last of the remaining figures is increased by one from its original value. [M1.2, P1.1]

takes place only: if that last figure would have been followed by 5, 6, 7, 8 or 9. [M1.2, P1.1]

run

is: a term arising in the informal definition gradient = rise/run.

represents: the difference in horizontal coordinate value (usually denoted Δx) between two points on a straight line. (The rise represents the corresponding change in vertical coordinate value (often denoted Δy)). [P1.3]

Rydberg atoms

are: atoms with large values of the principal quantum number n (say $n > 20$). [P8.2]

can have: a large radius r compared with the Bohr radius a_0. [P8.2]

have: energy levels very close to the ionization level and so are very easily ionized. [P8.2]

Rydberg constant

is: the physical constant R (a convenient combination of fundamental constants) that appears in the expressions for the wavelengths of the spectral lines in the Bohr model for the hydrogen atom. [P8.2]

has: the value $R = 1.097 \times 10^7\,\mathrm{m}^{-1}$ (to four significant figures). [P8.2]

is defined: by

$$R = \frac{m_{\rm e}e^4}{8\varepsilon_0^2 h^3 c} \quad [\text{P8.2}]$$

permits: use of spectroscopic measurements of wavelengths, which are amongst the most precise measurements in science, to find the best values for the fundamental constants. [P8.2]

strictly: should be written as R_∞ since, as written, it is derived from the Bohr model of hydrogen using a stationary nucleus around which the electrons revolve. This approximation is equivalent to treating the nucleus as having a very large mass (ideally infinite) compared to the electron. In reality, both electron and nucleus revolve around their common centre of mass.

s-p-d-f notation

is: the notation which is used to indicate the subshell that electrons occupy in an atom according to the value of the orbital angular momentum quantum number l
The letter s denotes l = 0, p denotes l = 1, d denotes l = 2, f denotes l = 3.
[P8.3]

sample

in: statistics

is: that part of a population from which data is taken, usually in the hope that it will be representative of the population as a whole. [P1.1]

saturated bond

between: atoms

in: a molecule, or solid

is: a bond to which no further atoms may be added. [P11.4]

saturated vapour

is: a vapour in equilibrium with its liquid (or solid) phase.

responds to: any isothermal compression or expansion by condensing or evaporating, thus changing the quantity of vapour while maintaining the original pressure. [P7.4]

saturated vapour pressure

is: the pressure of a saturated vapour. [P7.4]

is represented: as a function of temperature by the vaporization curve. [P7.4]

scalar

describes: a quantity, which can be completely specified by a single number together with an appropriate unit of measurement. [M2.4, M2.5, P2.2]

is exemplified: by mass, temperature and electric potential.

scalar components (of a vector)

in: the $\boldsymbol{i}$ (or x), $\boldsymbol{j}$ (or y) and $\boldsymbol{k}$ (or z) directions

if: the vector $\boldsymbol{v}$ is represented in the form $v_x\boldsymbol{i} + v_y\boldsymbol{j} + v_z\boldsymbol{k}$ or the form (v_x, v_y, v_z)

are: the scalars v_x, v_y, and v_z, respectively. [M2.5]

should not be confused with: component vectors.

scalar field

throughout: some region of space

is: a quantity which can be specified fully by a number and an appropriate unit at each point within that region. [P3.1]

therefore is: a field $\phi(\boldsymbol{r})$ which associates a definite value of the scalar quantity ϕ with each point specified by position vector $\boldsymbol{r}$ (in short, a scalar valued function of $\boldsymbol{r}$.). [P3.1]

scalar product

of: two vectors $\boldsymbol{a} = (a_x, a_y, a_z)$ and $\boldsymbol{b} = (b_x, b_y, b_z)$

is: a scalar quantity denoted by $\boldsymbol{a} \cdot \boldsymbol{b}$. [M2.6]

is defined: by $\boldsymbol{a} \cdot \boldsymbol{b} = |\boldsymbol{a}||\boldsymbol{b}|\cos\theta$, where $|\boldsymbol{a}|$ and $|\boldsymbol{b}|$ are the magnitudes of the vectors, and θ is the angle from the direction of $\boldsymbol{a}$ to the direction of $\boldsymbol{b}$. [M2.6, P2.4]

can be computed: in terms of scalar components, using

$$\boldsymbol{a} \cdot \boldsymbol{b} = a_xb_x + a_yb_y + a_zb_z$$ [M2.6, P2.2, P2.4]

has the property: that $\boldsymbol{a} \cdot \boldsymbol{b} = \boldsymbol{b} \cdot \boldsymbol{a}$

also is known as: the dot product.

See scalar product in the Maths handbook for further details.

scalar quantity

is: a quantity that may be represented by a scalar. [M2.4]

as a term, is used interchangeably: with the term scalar. [M2.4]

scalar triple product

is: a product involving three vectors which may be written in any of the equivalent forms

$$\boldsymbol{a} \cdot (\boldsymbol{b} \times \boldsymbol{c}) = \boldsymbol{b} \cdot (\boldsymbol{c} \times \boldsymbol{a}) = \boldsymbol{c} \cdot (\boldsymbol{a} \times \boldsymbol{b})$$ [M2.7]

See scalar product in the Maths handbook.

scalene triangle

is: a triangle in which no two sides have the same length. [M2.1]

scaling (of a geometric figure)

of: a geometric figure

is: the process of multiplying the length of each side of the geometric figure by the same number, to produce a new figure which has the same shape as the original but a different size. [M2.1]

scaling (of a vector)

is: the process of multiplying a vector, $\boldsymbol{a}$ by a scalar, α, to produce another vector $\alpha\boldsymbol{a}$. The scaled vector $\alpha\boldsymbol{a}$ points in the same direction as $\boldsymbol{a}$ if $\alpha > 0$, and in the opposite direction if $\alpha < 0$. The magnitude of $\alpha\boldsymbol{a}$ is given by $|\alpha||\boldsymbol{a}|$.
[M2.4, P2.2]

scanning tunnelling microscope, STM

is: an instrument which uses quantum tunnelling to measure the vertical displacement of a probe tip with a dimension of a few nanometers as it is moved parallel the surface of a conducting material, by monitoring (and maintaining) the tunnelling current between the surface and the probe. [P7.1]

measures: the profile of the surface with an approximate resolution of 10^{-10} m. [P7.1]

can be used: to build up three-dimensional representations of the atomic structure on the surface of the material. [P7.1]

scattering experiments

are: a wide and important class of experiments. [P8.1]

entail: bodies being investigated by using them as 'targets' in collisions with other bodies, often referred to as 'projectiles'. [P8.1]

normally cause: alteration in the paths of the projectiles, which then are said to have been 'scattered' by the target. [P8.1]

normally use: simple projectiles (such as electrons) and involve observing the way in which they are scattered by complicated targets. This strategy has permitted much progress in physics. [P8.1]

Schrödinger equation

is: an ambiguous term that might mean either the time-dependent Schrödinger equation or the time-independent Schrödinger equation according to context.

See the relevant entry for further details.

Schrödinger model

is: a detailed mathematical model of the atom based on quantum mechanics. [P8.3, P11.3]

was formulated: by Erwin Schrödinger (1887-1961) and others around 1925/26. [P8.3, P11.3]

specifies: that many of the physical quantities normally associated with atomic electrons are quantized, and that severe restrictions are placed on others. [P8.3, P11.3]

implies: for example, that it is impossible to determine the position and momentum of an electron simultaneously with arbitrarily high precision (see Heisenberg uncertainty principle), so the idea that the electron follows a classical (Newtonian) orbit has to be abandoned. Instead, the quantum state of the electron is specified by four quantum numbers which correspond to a particular wavefunction or orbital. [P8.3, P11.3]

is also called: the quantum model (of the atom). [P8.3]

scientific notation

is: a standard way of representing numbers and numerical quantities. [M1.2, Ml.5, P1.1]

consists: of a decimal number with one digit before the decimal point, multiplied by a power of ten, and followed by appropriate units. The total number of digits is the number of significant figures. [M1.2, Ml.5, P1.1]

is exemplified: by the speed of light in a vacuum to four significant figures: $2.998 \times 10^8\,\mathrm{m\,s^{-1}}$. [M1.2, Ml.5, P1.1]

is also known: as standard form, standard index form, floating point notation and powers of ten notation. [M1.2, Ml.5, P1.1]

search coil

is: a small coil, that may be used to measure the strength of a magnetic field. [P4.4]

operates: on the basis of electromagnetic induction. Quickly turning the coil within a steady field, or removing it from the field, gives rise to a pulse of current. The total charge that flows in this pulse is proportional to the change in flux linkage, so its measurement by means of a suitably calibrated ballistic galvanometer (or fluxmeter) reveals the magnetic field strength. [P4.4]

secant, sec

See trigonometric function.

sech

See hyperbolic function.

second, s

is: the SI unit of time, one of the seven base units. [P1.1]

is defined: as the duration of 9 192 631 770 periods of the radiation corresponding to the transition between two designated energy levels (hyperfine levels of the ground state) of caesium-133. [P1.1]

See caesium atomic clock.

second derivative

is: the derivative of a derivative. [M4.3]

is symbolized: by $f''(x)$ or $\dfrac{d^2y}{dx^2}$ or some similar symbol. [M4.3]

See higher derivative for further details.

second derivative test

is: a test to determine the location and nature of a local extremum of a given function $f(x)$. [M4.4]

involves: (a) finding the points at which $f'(x) = 0$, (b) investigating the behaviour of the sign of $f''(x)$ at those points. If $f'(a) = 0$, and $f''(a) < 0$ there is a local maximum at $x = a$. If $f'(a) = 0$, and $f''(a) > 0$ there is a local minimum at $x = a$. If $f'(a) = 0$, and $f''(a) = 0$ then further investigation is required. [M4.4]

See stationary points and graph sketching in the Maths handbook.

second focal point

is also called: the image focus or second focus. [P6.3]

See focal length.

second focus

is also called: the image focus or second focal point. [P6.3]

See focal length.

second law of thermodynamics

describes: all manner of physical processes in such a way as to predict the direction in which they will proceed spontaneously.

can be stated: in various ways, all of which are interrelated:

- No process is possible whose sole result is the transfer of heat from a colder to a hotter body.
- No process is possible in which the sole result is the transfer of heat from a body and its complete conversion into work.
- No process is possible that would lead to a net decrease in the entropy of the Universe, $\Delta S_{\rm universe} \geq 0$.
- Any spontaneous process is irreversible and leads to an increase in the entropy of the Universe.

See also principle of entropy increase. [P7.4]

second of arc, ″

is: a unit of plane angle. [M1.6]

is equal: to 1/60 of a minute of arc (arcmin). [M1.6]

is abbreviated: arcsec. [M1.6]

is exemplified: by 20″ = 20 arcsec = 1 arcmin/3. [M1.6]

second-order differential equation

is: a differential equation containing a second-order derivative of the dependent variable (e.g. d^2y/dx^2), but no higher derivative. [P5.4, P5.5]

secondary coil

in: a transformer or mutual induction circuit

is: the part of the circuit in which there is an induced voltage due to changes in the primary coil. [P4.4]

usually is thought of: as the output from the transformer. [P4.4]

secondary wavelets

See Huygens' principle.

sector

of: a circle

is: the region bounded by a circular arc and the straight line segments that join the centre of the circle to the end points of that arc.   [M2.1]

segment

of: a circle

is: the region bounded by a circular arc and the chord that joins the end points of that arc. [M2.1]

self inductance

See coefficient of self inductance.

self-induction

is: the production of an induced voltage in a circuit due to a changing current within the circuit itself. [P4.4]

opposes: the change that causes it. [P4.4]

See also coefficient of self inductance, inductor, Lenz's law. [P4.4]

semicircle

is: half a circle. [M2.1]

is more precisely: a segment of a circle, such that the chord joining its end points is a diameter of the circle. [M2.1]

semiconductor

is: a material containing a relatively small but significant number of mobile charged particles. [P4.1, P11.4]

has: a resistivity between that of good conductors (i.e. metals) and insulators, most typically in the range 10^{-2} to $10^{2}\,\Omega\,\mathrm{m}$. [P4.1, P11.4]

has typically: in terms of band theory of solids, at absolute zero, an empty conduction band at a gap 1 eV, or less above a full valence band. [P11.4]

is exemplified: by silicon and germanium, which are used for the construction of electronic devices. [P4.1]

See p-type semiconductor and n-type semiconductor.

semi-major axis (of an ellipse)

is: half of the major axis of the ellipse.

See ellipse.

semi-minor axis (of an ellipse)

is: half of the minor axis of the ellipse.

See ellipse.

sense

defines: for a force, which of the two possible directions in which the force acts along its line of action.

defines: for a torque, which of the two possible orientations the torque has along the axis of rotation.

sense of rotation

defines: one of the two possible directions of rotation around an axis of rotation. [P2.7, P4.3]

separable

describes: an ordinary differential equation which can be written in the form $dy/dx = f(x)g(y)$ and which can be solved (at least implicitly) by the separation of variables.

also describes: a solution of a partial differential equation which can be written as the product of two functions, each of which is itself a function of a different independent variable. [M6.4]

separable differential equation

See separable.

separation constant

of: a partial differential equation which has a separable solution, and which can be rearranged to produce an equation whose left-hand and right-hand sides involve different independent variables

is: a constant that can be equated to either side of the final equation described above, since the two sides of the equation are independent yet equal, so they must both be equal to the same constant. [M6.4]

is exemplified: by the constant E that arises when the one-dimensional time-dependent Schrödinger equation, with time-independent potential energy $U(x)$ and separable stationary state solution $\Psi(x, t) = \psi(x)\,\phi(t)$, is rewritten to yield two ordinary differential equations (one of them the time-independent Schrödinger equation) for the spatial and temporal parts of the wavefunction. [M6.4]

separation of variables

is: a method of solving any differential equation which can be written in the form $dy/dx = f(x)g(y)$.

entails: rearranging the equation and integrating both sides to obtain $\int g(y)\,dy = \int f(x)\,dx$ which may (in favourable cases) be evaluated and rearranged to give y as a function of x. [M6.2]

sequence

is: an ordered set of numbers. [M1.7]

series (connection)

describes: electrical components connected end to end, as the links of a chain, so that the current through each is the same. [P4.1, P5.5]

series (mathematical)

is: the sum of a sequence of numbers. The sequence may be either finite or infinite, and the series is said to be finite or infinite accordingly. [M1.7]

series (spectroscopic)

in: a characteristic emission spectrum or absorption line spectrum

is: the set of spectral lines which arise when electrons make transitions from initial quantum states characterized by initial principal quantum numbers $n_{\rm i}$ to a specific final state characterized by a specific final principal quantum number $n_{\rm f}$.

is exemplified: for the spectrum of atomic hydrogen, by the Lyman series for $n_{\rm f} = 1$, the Balmer series for $n_{\rm f} = 2$, the Paschen series for $n_{\rm f} = 3$, etc.

series expansion

of: a given function (possibly over a restricted domain)

is: a power series which is equivalent to the given function. [M1.7]

series LCR circuit

is: an LCR circuit in which the resistor, capacitor and inductor are connected in series.

series limit

for: a spectroscopic series

is: the shortest possible wavelength in the series. Successive members of the series become closer and closer together in wavelength, converging to the series limit. [P8.2]

can be computed: in an emission line spectrum by setting $n_{\rm i} = n_\infty$, i.e. when the initial energy level corresponds to $E = 0$ and the electron in its initial state is no longer bound to the atom at all. [P8.2]

See spectroscopic series.

set

is: a collection of entities (often, though not necessarily, numbers) that are defined by some characteristic which they all have in common, making them members or elements of the set, and which distinguishes them from entities that are not members of the set. [M1.2]

is exemplified: by the positive whole numbers. [M1.2]

is denoted: by listing the entities inside braces which signifies that they are elements (members) of the set. For example the set of non-negative whole numbers can be denoted by $\{1, 2, 3, \ldots\}$. [M1.2]

has its membership indicated: by the symbol $\in$, which means 'is a member of (a particular set)'. [M1.2]

set of complex numbers

is: the set of all numbers of the form $a + i\,b$, where a and b are real numbers and i is an algebraic quantity satisfying the rule $i^2 = -1$. [M3.1]

shear modulus

of: a material

is: an elastic modulus, conventionally denoted G. [P7.6]

is defined: as the ratio of the applied shear stress σ_S to the resulting shear strain ε_S:

$$G = \frac{\sigma_S}{\varepsilon_S} \quad [P7.6]$$

has as its SI unit: $N\,m^{-2}$ or Pa (i.e. pascal). [P7.6]

shear strain

in the simplest case, is: a measure of the deformation of a material in which two parallel surfaces separated by a perpendicular distance y undergo a relative displacement, parallel to their original planes, of magnitude Δx. [P7.6]

is given: by the ratio of the parallel relative displacement to the perpendicular distance between the surfaces, so $\varepsilon_S = \Delta x/y$. [P7.6]

shear stress

is: a stress σ_S resulting from the application of a force to a surface, in a direction parallel to that surface. [P7.6]

is given: by the ratio of the magnitude of the force to the area of the surface over which it acts, so $\sigma_S = F_{\|}/A$. [P7.6]

shell

is: a grouping of electrons within an atom, in which the electrons have the same principal quantum number n. [P8.3, P8.4]

therefore describes: electrons which, to a zeroth approximation, have the same energy. [P8.3, P8.4]

SHM equation

is: a differential equation of the form

$$\frac{d^2y}{dt^2} + \omega^2 y = 0. \quad [\text{P5.3, M6.3}]$$

describes: the motion of any object that is undergoing (undamped, unforced) simple harmonic motion. The parameter ω determines the period of the oscillations, which is equal to $2\pi/\omega$. [M6.3]

See simple harmonic motion.

short circuit

is: a path of very low (effectively zero) resistance within a circuit. [P4.1]

usually is: unwanted, accidental. [P4.1]

sometimes is: catastrophic, when it forms directly across the terminals of a power supply. [P4.1]

short sight

See myopia.

shunt resistor

is: a resistor connected in parallel with some other circuit component. [P4.1]

commonly is: a resistor connected in parallel with an ammeter to reduce its current sensitivity. [P4.1]

shutter speed

is: the time for which the aperture of a camera remains open. (Note that it is a time not a speed.) [P6.4]

SI units

are: an internationally agreed system of units based on the metre, kilogram, second, ampere, kelvin, mole and candela. [P1.1]

stands for: Système International d'Unités. [P1.1]

are used: almost universally by the scientific community. [P1.1]

See Tables 1 to 5 in Section 0 of the Maths handbook.

siemens, S

is: the SI unit of conductance.

is defined: by $1\,\mathrm{S} = 1\,\Omega^{-1}$ (i.e. one reciprocal ohm or inverse ohm).

is used: in the measurement of conductivity, for which the SI unit is the siemens per metre ($\mathrm{S\,m^{-1}}$). [P4.1]

sievert, Sv

is: the SI unit of dose equivalent of ionizing radiation.

is defined by: 1 Sv = 1 J kg (i.e. 1 joule per kilogram). Dose equivalents measured in Sv are related to absorbed doses measured in gray (Gy) via a radiation weighting factor. The dose equivalent in sievert equals the absorbed dose in gray times the radiation weighting factor. [P9.3]

sign convention

is: an agreed means of attributing positive and negative signs to the quantities that arise in various calculations.

is exemplified: by the Cartesian sign convention of geometrical optics.
[P6.3]

significant figures

are: the meaningful digits in a number. [M1.2, P1.1]

indicate: its precision. [M1.2, P1.1]

do not include: zeros to the left of the first non-zero digit, as in 0.00876. [M1.2, P1.1]

may or may not include: zeros at the end of a number, particularly a whole number, as in 9400. These are ambiguous. [M1.2, P1.1]

are totally unambiguous: in scientific notation, which avoids the need to write down any zeros that are not significant either to the right or to the left of the significant figures. For example, 9.4×10^3 has two significant figures, while 9.400×10^3 implies that both zeros are significant. [M1.2, P1.1]

silicon p-n junction photodiode

is: a semiconducting device that enables the intensity of a light beam to control or generate a current in an electric circuit. [P10.1]

similar

describes: two geometric figures which are identical in shape, irrespective of their size. [M2.1]

similar triangles

are: triangles that are identical in shape, irrespective of their size. [P1.6]

have: the same interior angles. [P1.6]

also have: corresponding sides that are in the same ratio to each other. [M1.6]

simple harmonic motion (SHM)

of: a particle of mass m moving in the x-direction about the equilibrium position $x = 0$ under the influence of a restoring force $F_x = -kx$, that is always directed towards $x = 0$ and which is proportional to the displacement x from that point

is: an oscillatory form of linear motion in which the displacement of the particle at time t from an equilibrium position is given by

$$x(t) = A\sin(\omega_0 t + \phi)$$

where the amplitude A and phase constant ϕ are arbitrary constants determined by the initial conditions, and the angular frequency ω_0 is a constant determined by the force constant k and the mass m as given by $\omega_0 = \sqrt{k/m}$. [M5.1, P5.4, P5.5]

can be described: by a differential equation (called the SHM equation) of the form:

$$\frac{d^2x}{dt^2} + \omega_0^2 x = 0. \quad \text{[M6.3, P5.5]}$$

simple harmonic oscillations

See simple harmonic motion.

simple harmonic oscillator

is: any oscillatory system that exhibits oscillations which can be described by an equation of the form

$$\frac{d^2x}{dt^2} + \omega_0^2 x = 0.$$

with solutions of the form $x(t) = A\sin(\omega_0 t + \phi)$

is exemplified: by a mechanical oscillator exhibiting simple harmonic motion.

is also exemplified: by an electrical circuit in which an inductor of inductance L is connected across a charged capacitor of capacitance C, with the result that the charge q on the capacitor satisfies the differential equation

$$\frac{d^2q}{dt^2} + \omega_0^2 q = 0 \text{ where } \omega_0 = \sqrt{\frac{1}{LC}}$$

and where the charge then is given at time t by $q(t) = q_0\sin(\omega_0 t + \phi)$, with q_0 and ϕ arbitrary constants.

simple pendulum

is: a pendulum consisting of a single mass suspended by a light thread which is very long compared to the size of the suspended mass. [P5.1]

exhibits: simple harmonic oscillations in the angle between the thread and the vertical, provided that angle is always small. The period of the oscillation is $T = 2\pi\sqrt{l/g}$ where l is the length of the thread, and g is the magnitude of the acceleration due to gravity.

simplify

is: the process of writing an algebraic expression in a equivalent but simpler form. [M1.1]

more specifically, means: to express in a shorter form, especially by using brackets and extracting common factors. [M1.1]

simultaneous

means: at the same time.

more specifically means: at the same time, as measured in a given frame of reference (an important proviso in Einstein's special theory of relativity).

simultaneous linear equations

are: a number of equations, which are linear in each of the independent variables and which are required to be true simultaneously. [M1.4]

sine, sin

See trigonometric function.

sine rule

for: a triangle

is: a set of independent relations between the sines of angles in the triangle and the lengths of sides opposite the angles:

$$\frac{a}{\sin(\hat{\mathrm{A}})} = \frac{b}{\sin(\hat{\mathrm{B}})} = \frac{c}{\sin(\hat{\mathrm{C}})} \quad [\mathrm{M1.6}]$$

See trigonometric functions in the Maths handbook for further details.

single-valued function

describes: a function which can have only a single value at each point in space at a given time. [M1.3, P10.4]

is exemplified: by the wavefunction for a particle, which must be a single-valued function since it relates to the probability of finding the particle at the point. [M1.3, P10.4]

See multi-valued function. [M1.3]

singular solution

is: a particular solution of a non-linear differential equation, which cannot be obtained from the general solution by the usual assignment of particular values to the essential constants. [M6.1]

singularity

of: a function $f(x)$ which can be written in the form $g(x)/(x - p)^n$ in the neighbourhood of $x = p$, where $g(x)$ is finite and non-zero at $x = p$,

is: the point $x = p$ (at which the singularity is of order n.) [M5.2]

sinh

See hyperbolic function.

sintered

describes: a material formed by heating a mixture of its ingredients to promote atomic diffusion (and hence bonding) but without causing melting.

sinusoidal

describes: any function that has a graph of the same 'wavy' shape as that of a sine or cosine function. [M1.6]

also describes: the graph itself. [M1.6]

is exemplified: by any function of the form $A\sin(kx+\phi)$ or $B\cos(kx+\phi)$ or $G\cos(kx)+H\sin(kx)$, where A, B, G, H, k and ϕ are all constants. [M1.6]

sinusoidal wave

is: a periodic wave described (in one spatial dimension) by a function of two variables of the form $y(x, t) = A\sin[k(x - \upsilon t) + \phi]$, where $y(x, t)$ represents the disturbance caused by the wave (e.g. a transverse displacement) at position x and time t and the constants A, k, υ and ϕ are the amplitude, angular wavenumber, propagation speed and phase constant respectively. [M6.4, P5.6]

may be generalized: to two or three dimensions, and may be represented mathematically in a variety of different ways e.g. using complex numbers,

$$y(x, t) = \mathrm{Re}\left[A\mathrm{e}^{i(kx - \omega t + \phi)}\right], \text{ where } \omega = k\upsilon. \quad \text{[M6.4, P5.6]}$$

can be represented: by the cosine function as well. By writing $\phi = \theta + \pi/2$, and using an appropriate trigonometric identity it is possible to rewrite the 'sine wave' given above as the 'cosine wave' $y(x, t) = A\cos[k(x - \upsilon t) + \theta]$. [M6.4, P5.6]

sketching graphs

is: the process of drawing a rough graph, which shows the qualitative features of the function, but does not attempt to achieve accuracy. [M1.3]

Contrast with plotting graphs.

skew

describes: straight lines which are not parallel but which do not meet at any point. [M2.2]

skewed

describes: a distribution of values which is asymmetric rather than a symmetric (e.g. normal) distribution.

sliding friction

is: a force of friction which acts on a solid surface in contact with another surface when the two are in relative motion. [P2.3, P7.6]

has a direction: which opposes the relative motion that causes it. [P2.3, P7.6]

has a magnitude: which is directly proportional to the magnitude R of the reaction force acting on the surface of interest from the other surface, so that $F_{\rm slide} = \mu_{\rm slide}R$, where $\mu_{\rm slide}$ is a constant, called the coefficient of sliding friction, that is characteristic of the surfaces involved (including their state of lubrication). [P2.3, P7.6]

also known as: dynamic friction.

Compare with static friction, which is generally greater in any given situation.

slope

See gradient.

smooth function

is: a function whose graph does not contain any sharp kinks or sudden discontinuous jumps. [M4.4]

Snell's law

states: that when a light ray passes from one material of refractive index μ_1 to another material of refractive index μ_2 it undergoes refraction, and the angle of incidence θ_1 and angle of refraction θ_2 are related by:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\mu_2}{\mu_1} = \text{constant}.$$ [P5.7, P6.1, P6.2]

is sometimes expressed: in terms of the respective speeds of light in the two materials v_1 and v_2, in which case

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$$ [P6.1]

as a term, normally is used: as a synonym for the law of refraction, and is applicable to sound as well as light. [P5.7]

solar cell

is: a device that uses electromagnetic radiation (usually from the Sun) to generate an electric current. [P10.1]

See silicon p-n junction photodiode.

solenoid

is: an extended current-carrying coil. [P4.2]

has the shape: of a helix. [P4.2]

generates: a uniform magnetic field throughout much of the volume within the solenoid. [P4.2]

solid of revolution

is: a mathematical solid which can be obtained by rotating a suitable curve about a specified line or axis. [M5.4]

solid phase

is: the general form of matter which is characterized by having a definite volume and shape at fixed temperature and pressure, when in equilibrium. [P7.1]

solitary wave

is: an isolated (i.e. non-periodic) disturbance that satisfies an appropriate wave equation. [P5.6]

often is referred to: as a pulse. [P5.6]

soluble

in: mathematics

describes: an equation (or system of equations) which can be solved. [M1.4]

solution (chemical)

is: a material (usually, but not necessarily, a liquid) in which one substance is homogeneously mixed with another, and which can only be separated into those original substances by transforming one or both of them through a process such as freezing or boiling, or by means of an appropriate chemical reaction.

solution (mathematical)

of: an equation

is: a value, or an expression for the dependent variable in terms of the independent variable(s), such that when substituted into the equation the resulting expression is an identity. [M1.4, M6.1]

solving the equations

means: finding the solution(s) of the equations. [M1.4, M6.1]

sound

is: the phenomenon associated with the propagation of longitudinal pressure waves (sound waves) through a medium. [P5.7]

sound energy

is: energy transported by sound waves, and associated with the coordinated vibrations of the molecules of the medium through which the sound travels, as opposed to the random vibrations of molecular thermal motion. [P5.7]

is also called: acoustic energy. [P5.7]

sound wave

is: a longitudinal wave consisting of alternate compressions and rarefactions of the medium through which the sound is travelling. [P5.7]

may transport: acoustic energy (i.e. sound energy) from place to place. [P5.7]

south magnetic pole

is: the magnetic pole of a compass needle which, when allowed to move freely under the influence of the Earth's magnetic field, points in a southerly direction. (This means that the Earth's south geographic pole is close to a north magnetic pole!) [P4.2]

is: the magnetic pole towards which magnetic field lines converge. [P4.2]

is called: in some texts, the south-seeking pole. [P4.2]

See magnetic pole. [P4.2]

space

is: the set of all possible positions.

more abstractly is: a set with properties similar to those of 'real' space (e.g. the *PVT* 'space' that contains the equilibrium surface of a fixed quantity of gas).

spatial

means: pertaining to space.

spatial coherence

of: waves

is: their characteristic of maintaining coherence over some region of space. [P6.1]

usually is: limited by the nature of the source.

spatial part of the wavefunction

See spatial wavefunction and contrast with temporal wavefunction.

spatial wavefunction

is: that part of a separable solution to the time-dependent Schrödinger equation that depends only on spatial coordinates and is therefore independent of time. [P6.4, P10.3, P10.4]

is exemplified: in one dimension by the factor $\psi(x)$ that appears in the stationary state wavefunction

$$\Psi(x, t) = \psi(x)\,\phi(t)$$ [M6.4, P10.3, P10.4]

is therefore: a solution of the time-independent Schrödinger equation and consequently is an eigenfunction of the energy operator. [P10.4]

specific activity

is: the activity per unit mass of a radioactive sample. [P9.2]

specific heat

is also known: as 'specific heat capacity' or 'kilogram specific heat'. [P7.4, P7.5, P11.4]

is: the heat required per unit mass of a substance per unit rise in temperature. [P7.4, P7.5, P11.4]

more succinctly, is: the heat capacity per unit mass. [P7.4, P7.5]

is given: by $c = \Delta Q/m\Delta T$, where ΔQ is the heat required to raise the temperature of a sample of mass m by an amount ΔT. (Strictly speaking the specific heat should be defined as the limit of this ratio as ΔT becomes vanishingly small, since the specific heat depends on the state of the sample and will generally have a value that depends on temperature.) [P7.4, P7.5]

also depends: on the constraints applied during heating: see principal specific heats. [P7.4, P7.5]

is the subject: of the Einstein model and the Debye model, and a good deal of other theoretical work. [P11.4]

has as its SI unit: $\mathrm{J\,kg^{-1}\,K^{-1}}$. [P7.4, P7.5]

See also molar specific heat.

specific latent heat

is: the amount of heat absorbed or emitted per unit mass by a substance during an isothermal phase transition. [P7.4]

has as its SI unit: $\mathrm{J\,kg^{-1}}$. [P7.4]

See also latent heat; molar latent heat.

spectral brightness

is: the power emitted per unit area per unit wavelength range by a radiating surface. [P7.3]

varies: with wavelength. [P7.3]

generally depends: on the temperature and nature of the emitting surface. [P7.3]

is described: in its variation with temperature T and wavelength λ, for a black-body, by Planck's function. [P7.3]

is also called: spectral emittance. [P7.3]

spectral emittance

See spectral brightness.

spectral lamp

is: a light source with which the emission spectrum of a substance may be studied. [P8.2]

is only useful: for substances which may be vaporized by moderate heating, since it works by vaporizing the substance and then exciting the atoms by means of collisions with an electron beam (i.e. an electric current). [P8.2]

spectral lines

See line spectrum.

spectrometer

is: an optical instrument for separating light into its constituent wavelengths and measuring these wavelengths. [P6.4]

usually contains: a collimator, which produces a narrow parallel rectangular beam of light from a slit, and a telescope, which allows this parallel beam to be observed. [P8.2]

also contains: between the collimator and the telescope, a dispersion device, which makes the various constituent wavelengths in the beam travel in different directions and thus appear at different angles when viewed through the telescope. [P8.2]

usually contains: as the dispersion device, a diffraction grating (or a triangular glass prism.) [P8.2]

permits determination: of the wavelength, λ, using the grating relation, $n\lambda = d\sin\theta_n$, by measuring the angle θ_n through which the light of wavelength λ is diffracted in order n by a grating of known grating spacing d. [P8.2]

spectroscopic series

See series (spectroscopic).

spectroscopy

is: the branch of science which is concerned with the production, measurement, analysis and interpretation of spectra. [P8.2]

spectrum

of: electromagnetic radiation (usually from a specified source)

is: the distribution of spectral brightness (or some similar quantity) with respect to the wavelength or frequency (or possibly the corresponding photon energy) of the radiation. [P8.2]

may be displayed: as a graph, or as a photographic image of a dispersed band of light, or as a mathematical function (see black-body spectrum and Planck's function).

may be classified: as a continuous spectrum if it includes non-zero contributions across a wide and unbroken range of wavelengths; as a line spectrum if certain narrowly defined wavelength ranges are particularly prominent; or as a band spectrum if certain moderately broad ranges of wavelength are dominant.

may also be classified: as an emission spectrum if the observed radiation was emitted by the source, or as an absorption spectrum if the observed radiation is that which remains after radiation with a continuous spectrum has passed through the specified source.

speed

is: the magnitude of velocity. [M2.4, M4.1, P2.1, P2.2, P7.5]

is therefore: a positive quantity. [M2.4, M4.1, P2.1, P2.2, P7.5]

has as its SI unit: $m\,s^{-1}$. [M2.4, M4.1, P2.1, P2.2, P7.5]

speed (of a film)

is: the sensitivity to light of a photographic film or emulsion. [P6.4]

speed of light

or of: any electromagnetic radiation

in: a vacuum

is: a fundamental physical constant with the value $3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$, to three significant figures. [P6.1]

more precisely, is now defined: to be exactly $2.997\,924\,58 \times 10^{8}\,\mathrm{m\,s^{-1}}$. [P6.1]

speed of propagation

of: a wave

is: the speed at which it moves in the direction of propagation. [M6.4, P5.6, P5.7]

is equal: for a simple non-dispersive wave, to the phase speed. [M6.4, P5.6, P5.7]

is equal: for a periodic wave, to the product of the wavelength and the frequency of the wave. [P5.7]

is equal: to the group speed, where there is dispersion (i.e. where the frequency is dependent on wavelength) and the wave may be a superposition of several different components with different frequencies and hence different phase speeds. [M6.4, P5.6, P5.7]

sphere

is: a surface in three dimensions, every point of which is a fixed distance (the radius) from a fixed point (the centre). [M2.1]

spherical

in: geometry

means: pertaining to a sphere. [M2.1]

spherical aberration

in: a lens or a mirror

causes: distortion in the image produced by the lens or mirror, due to the variation of focal length with radial distance from the optical axis for rays incident on the lens or mirror. [P6.4]

spherical lens

is: a lens with two spherical surfaces. [P6.3]

spherical mirror

is: a mirror with a curved reflecting surface having a single radius of curvature. [P6.3]

spherical mirror equation

is: a general equation relating the object position u, the image position v and the focal length f for spherical mirrors in the paraxial approximation:

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \quad \text{(Cartesian sign convention)}$$ [P6.3]

Compare with thin lens equation.

spherical polar coordinates

are: coordinates (r, θ, ϕ) in which the position of a point is determined by: its distance r from a chosen point, called the origin; the angle θ between the line from the point to the origin and a chosen plane containing the origin; and the angle ϕ measured in the chosen plane, from a chosen line through the origin to the projection of the line from the origin to the point. [P11.3]

are normally restricted: so that $0 \le \theta < 2\pi$ and $-\pi/2 \le \phi \le \pi/2$, but other (equivalent) restrictions are also used.

spherical symmetry

is: a condition in which all relevant properties depend (or may depend) on the distance from some fixed point, but not on direction.

is exemplified: by a spherical body whose density depends only on the distance *r* from the centre of the sphere. [P3.2]

spherical wave

is: a wave which has radially expanding spherical wavefronts of the kind that come from a point source. [P6.1]

spherical wavefront

is: a wavefront of a spherical wave. [P6.1]

spin (angular momentum)

is: an intrinsic property of fundamental particles such as protons, neutrons and electrons. [P8.3, P9.2]

is similar: in quantum theory, to orbital angular momentum, so is often referred to as intrinsic angular momentum or spin angular momentum. [P8.3, P9.2]

is represented: in quantum mechanics, by the vector observable $\boldsymbol{S}$ of magnitude S and with S^2 having the eigenvalues $S^2 = s(s+1)\hbar^2$ where s is the spin angular momentum quantum number.

See also electron spin.

spin angular momentum quantum number

is: the quantum number s that determines the magnitude of the spin angular momentum of a particle. [P8.3]

has: a unique, positive, integer or half-integer value for each particle (e.g. $s = 1/2$ for the electron). [P8.3]

determines: the magnitude of the square of the spin angular momentum of the particle as $S^2 = s(s+1)\hbar^2$.

spin magnetic quantum number

is: the quantum number m_s which describes the component of the spin angular momentum of a particle along an arbitrarily chosen z-axis (usually the direction of an imposed magnetic field). [P8.3]

may have: any of the values $-s$, $-s + 1$, $-s + 2$, … $s - 1$, s, where s is the spin angular momentum quantum number, implying that the z-component of the spin angular momentum vector may take on any value $S_z = m_s\hbar$ (for the electron m_s can have the values +1/2 or −1/2, so the z-component of the spin angular momentum of an electron can have the value $+\hbar/2$ or $-\hbar/2$). [P8.3]

spiral

is: the locus of a point that moves repeatedly around a fixed origin while its distance from that origin progressively increases.

splitting the numerator

is: a technique that enables integrals of the form

$$\int \frac{px+q}{ax^2+bx+c}\,dx \text{ or } \int \frac{px+q}{\sqrt{ax^2+bx+c}}\,dx$$

to be written in terms of two simpler integrals.

works: by writing the numerator, $px + q$, as a multiple of the derivative of $ax^2 + bx + c$, plus a constant. [M5.5]

See further integration in the Maths handbook.

spontaneous fission

is: a process in which an atomic nucleus, usually one with a large mass number, spontaneously undergoes nuclear fission (i.e. breaks up to form (typically) two less massive nuclei and a number of neutrons). [P9.3]

generally occurs: only in artificially-created nuclei. [P9.3]

spring constant

for: a spring obeying Hooke's law

is: the coefficient which relates the change in length of the spring to the tension or compression needed to stretch or compress the spring. [P2.3]

is equivalently: the coefficient k_s which determines the restoring force that the spring exerts. When the spring is extended by an amount x along the x-axis from its natural (unextended) state it exerts a restoring force $F_x = -k_s x$. [P2.4, P5.1]

square

is: a rectangle in which all four sides are of equal length. [M2.1]

square (of a number)

is: the product of the number multiplied by itself. [M1.1]

square roots

of: any number p

are: the two numbers s such that $s^2 = p$ (and $p^{1/2} = s$). [M1.1]

are exemplified: by the square roots of 9, which are 3 and −3. [M1.1]

are: real numbers if p is real and positive. Otherwise they are complex numbers.

may be indicated: by the symbol $\sqrt{\ }$, although usually this symbol is reserved for the positive square root (for example, usually $\sqrt{9} = 3$, not −3). [M1.1]

SQUID

is: a superconducting quantum interference device. [P11.1]

is used: to measure very weak magnetic fields.

stability line

on: a plot of the number of neutrons N ($N = A - Z$) in nuclei against number of protons Z

is: the line joining the points which represent stable nuclei. For light nuclei, $N \approx Z$, and for heavier nuclei $N > Z$. [P9.2]

stable

describes: nuclear and sub-nuclear particles that do not decay (or, at least, that are so long-lived that their decay has never been observed). [P9.1]

stable equilibrium

of: a system

describes: a state of equilibrium in which any small disturbance of the system results in a tendency for the system to return to its initial equilibrium state. [P5.1]

standards

are: realizable methods of determining fixed values of physical quantities to high precision and high accuracy. [P1.1]

play: a vital part in determining the precision and accuracy with which units of measurement may be established and maintained. [P1.1]

underpin: the precision and accuracy of any experimental measurement that uses units. [P1.1]

standard atmosphere, atm

is: a non-SI unit of pressure

is defined: by $1\,\text{atm} = 1.013\,25 \times 10^5\,\text{N}\,\text{m}^{-2}$. [P7.2]

standard deviation

is: a quantity related to the spread in repeated measurements $x_1, x_2, x_3, x_4, x_5, \ldots x_n$ of a particular quantity x. The greater the spread, the greater the standard deviation. [P1.2]

more formally, is defined: as $\sigma_n = \sqrt{\dfrac{d_1^2 + d_2^2 + \cdots + d_n^2}{n}}$ where $d_i = x_i - \langle x \rangle$ is the deviation of the i^{th} measurement, and $\langle x \rangle$ is the mean of the n measurements. [P1.2]

implies: when n is large and the distribution of measured values is a normal distribution, that about 68% of the readings will lie within $\pm\sigma_n$ of the mean value, 95% within $\pm 2\sigma_n$ and 99.7% within $\pm 3\sigma_n$. Equivalently, the likelihood that any particular measurement will lie within $\pm\sigma_n$ of the mean value is about 68%, $\pm 2\sigma_n$ is 95%, etc. [P1.2]

See statistics in the Maths handbook.

standard equations

are: the most commonly encountered equations representing the various conic sections in terms of Cartesian coordinates. [M2.3]

See conic sections in the Maths handbook.

standard error of the mean

of: n repeated measurements x_1, x_2, x_3, x_4, x_5, … x_n of a quantity x

when: the measurements form a normally distributed population.

is: a measure of how close the mean of the measurements is likely to be to the 'true' value of x, in the absence of systematic errors. [P1.2]

is given: by

$$s_m = \frac{\sigma_n}{\sqrt{n-1}}$$

In the absence of systematic error, the mean, $\langle x \rangle$, of a large number of (normally distributed) measurements of a quantity x has a 68% chance of lying within $\pm s_m$ of the 'true' value, a 95% chance of lying within $\pm 2s_m$ and a 99.7% chance of lying within $\pm 3s_m$. [P1.2]

therefore provides: a direct measure of the precision of an experimental value: the precision can be taken to be $\pm 2s_m$ regardless of its accuracy. Nevertheless, in common laboratory practice, the precision usually is taken to be $\pm 2\sigma_n$, which is numerically larger and therefore *less* precise. [P1.1]

See statistics in the Maths handbook.

standard form

(1) is used synonymously: with standard equations. [M2.3]

(2) is used synonymously: with scientific notation.

standard integrals

are: the 'well known' integrals of a number of standard functions, including polynomial functions, logarithmic and exponential functions, and trigonometric functions. [M5.2]

See Table 15 in Section 5 of the Maths handbook.

standard temperature and pressure, s.t.p.

is: a temperature of 273.15 K (= 0.00 °C) and a pressure of 1.01×10^5 Pa (= 1.00 atm). [P7.4]

standing wave

is: a wave which does not propagate (sometimes called a stationary wave). [M6.4, P5.6]

may be regarded: as a superposition of waves of equal amplitude and wavelength moving in opposite directions. [M6.4, P5.6]

is exemplified by: the wave

$$\begin{aligned} y(x,t) &= A\sin(kx - \omega t) + A\sin(kx + \omega t) \\ &= 2A\sin(kx)\sin(\omega t) \end{aligned}$$ [M6.4, P5.6]

has: nodes (i.e. points at which the disturbance caused by the wave is permanently zero) at points separated by half the wavelength of the superposed travelling waves.

standing wave mode

is: a mode of oscillation of a confined system in which the endpoints are nodes and the behaviour between those nodes can be described by a standing wave of a single wavelength. [P10.3]

has: a wavelength equal to an integer multiple of twice the distance between the endpoints. [P10.3]

persists: without change (except for decay), if excited individually. [P10.3]

is represented: by an eigenfunction of the equation for wave propagation when the boundary conditions are zero amplitude at each end. [P10.3]

state

is: used to refer to the condition of a system. Its exact meaning varies according to circumstance, but it generally implies a sufficiently detailed account of the condition of a system to distinguish it from any other condition that would behave differently in the circumstances under discussion. The nature of the required account is indicated by an appropriate qualifier as in mechanical state, thermodynamic state, quantum state, bound state, equilibrium state, stationary state, etc.

is specified: in classical physics by the values of various observable physical quantities (e.g. pressure, volume and temperature for an equilibrium state of a fixed quantity of ideal gas).

is specified: in quantum mechanics by a wavefunction that determines the probability that measurements of observables will yield specified eigenvalues of the operator corresponding to the observable.

static equilibrium

describes: a situation in which a mechanical system remains at rest, with no resultant force or torque acting. [P2.3]

requires: translational equilibrium and rotational equilibrium, as necessary (but not sufficient) conditions. [P2.3]

static friction

is: a force of friction which acts on a solid surface in contact with another surface when there is an applied external force tending to cause sliding of one surface across the other, but no actual relative motion. [P2.3]

has a direction: which opposes the relative motion that would arise in its absence. [P2.3, P5.2]

has a magnitude: which is proportional to the magnitude R of the reaction force acting on the surface of interest from the other surface, so that $F_{\rm static} = \mu_{\rm static} R$, where $\mu_{\rm static}$ is a constant, called the coefficient of static friction, characteristic of the surfaces involved (including their state of lubrication). [P2.3, P5.2]

exists: only so long as there is no actual sliding motion between the two surfaces. [P7.6]

Compare with sliding friction, which is generally less in any given situation.

statics

is: the study of systems which are in static equilibrium. [P2.3]

stationary

describes: a function $f(x)$ at any point where the tangent to its graph is horizontal. [P6.2]

therefore describes: a function $f(x)$ at any point where its derivative is zero. [M4.4]

stationary (function)

refers: to a function $f(x)$ at its stationary point, where $\dfrac{df}{dx} = 0$. [M4.4]

stationary orbit

of: an electron in the Bohr model of the atom

is: an orbit in which the electron, although accelerating, does not emit electromagnetic radiation as required by classical physics. [P11.3]

was postulated: by Niels Bohr (1885-1962) to explain the stability of the hydrogen atom. [P11.3]

stationary point

is: a point $(a, f(a))$ on the graph of the function $f(x)$ at which the tangent to the graph is horizontal and the function therefore is stationary. [M4.4, P6.2]

therefore is: a point at which the function's derivative $f'(x) = 0$. [M4.4, P6.2]

is exemplified: by a local maximum or local minimum or point of inflection (with horizontal tangent). [M4.4, P6.2]

stationary state

of: a quantum mechanical system

is: a state described by a wavefunction in which the spatial and temporal parts are separable, so in one dimension, $\Psi(x, t) = \psi(x)\,\phi(t)$, where $\psi(x)$ is a solution of the time-independent Schrödinger equation corresponding to a unique energy eigenvalue. [P10.3, P10.4]

therefore has: a probability density function $P(x,t) = |\,\Psi(x,t)\,|^2$ which is independent of time and so may be written as $P(x) = |\,\psi(x)\,|^2$ [P10.4]

is: stable. A system prepared in one of its stationary states will remain in this state, if isolated. [P10.3]

is: the quantum mechanical equivalent of one of the standing wave modes of a classical oscillatory system. [P10.3]

stationary wave

See standing wave.

statistical mechanics

is: a powerful and wide-ranging branch of physics that is concerned with the behaviour of systems of such a nature and involving sufficiently many degrees of freedom that mathematical methods developed in the field of statistics are of use in their study.

predicts: amongst other things, and in appropriate circumstances, the likely distribution of energy amongst the particles of a system. [P7.5]

statistics

is: the branch of mathematics which is concerned with analysis of quantitative data. [P1.1]

steady state (motion)

describes: the behaviour of a system once any transient behaviour has decayed away.

often refers specifically: to the motion produced in a driven oscillator once the transient motion has decayed away. [P5.3, P5.5]

Stefan's constant

is: a useful constant that appears in Stefan's law and which is equal to a particular combination of fundamental constants:

$$\sigma = 2\pi^5 k^4/(15h^3c^3) = 5.6697 \times 10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}.$$ [P7.3]

Stefan's law

states: that the total power radiated per unit area by a black-body at temperature T is given by $R = \sigma T^4$ where σ is Stefan's constant. [P7.3]

can be derived: from Planck's function, by integrating the expression that it provides for the spectral brightness of a black-body over all possible wavelengths. [P7.3]

step-down transformer

is: a transformer whose output voltage on the secondary coil is less than the input voltage on the primary coil, as a result of the transformer turns ratio being less than unity. [P4.4]

step-up transformer

is: a transformer whose output voltage on the secondary coil is greater than the input voltage on the primary coil, as a result of the transformer turns ratio being greater than unity. [P4.4]

stepped-index fibre

is: an optical fibre in which the refractive index changes abruptly at some distance from the axis of the fibre and in which total internal reflection at this interface is used to confine light rays within the fibre and away from the surface of the fibre. [P6.2]

Stern-Gerlach experiment

is: a classic experiment in which a beam of (silver) atoms travelling through a non-uniform magnetic field is split into two sub-beams. [P8.3]

demonstrates: quantization of orientation in a magnetic field. (The results were eventually interpreted in terms of the spin magnetic quantum number.) [P8.3]

stimulated emission

is: the process in which an incoming photon stimulates an atom in an excited state to radiate another photon of the same frequency, phase and direction.

is: the process underlying the operation of a laser. [P5.3, P10.1]

Stokes' law

is: an empirical law of limited validity

states: that the magnitude of the force due to viscosity, on a spherical body moving through a fluid is directly proportional to the product of the relative speed v, the coefficient of viscosity of the fluid η, and the radius of the sphere r.

So $F = 6\pi\eta r v$. [P7.6]

stops

are: preset aperture adjustments on a lens, changing the f-number of the lens. [P6.4]

storage cell

is: a cell (such as a lead-acid accumulator) whose open circuit voltage (e.m.f.) results from a chemical reaction that can be reversed by passing an electric current through the cell. [P4.5]

straight line

is: the path of shortest distance between two points. [M2.1]

See equation of a straight line.

straight line segment

is: the part of a straight line passing through two given points that lies between the two points. [M2.1]

strain

is: a dimensionless quantity which measures the fractional distortion in a material produced by an applied stress. [P7.6]

See also tensile strain, shear strain and volume strain.

strain energy

is: an abbreviation for strain potential energy. [P2.4]

strain potential energy

is: the potential energy possessed by an object by virtue of its deformation from its equilibrium shape. [P2.4, P5.2]

is exemplified: by a spring obeying Hooke's law, with spring constant, k_s, extended or compressed by displacement x which has strain potential energy $E_{pot} = \frac{1}{2}k_s x^2$. [P2.4, P5.2]

stress

is: a force acting uniformly through or across an area of a material, divided by the area over which it acts.   [P7.6]

See also tensile stress, shear stress and volume stress.

strong interaction

is: the strongest of the fundamental interactions between elementary particles. [P9.1, P9.2]

has: a short range, roughly equivalent to a typical nuclear diameter

is responsible: for the strong interaction between nucleons that binds together the neutrons and protons in nuclei. [P9.1, P9.2]

is often called: the strong nuclear force. [P9.2]

strong interaction between nucleons

See strong interaction.

strong nuclear force

See strong interaction.

subatomic particle

is: a general term for particles with diameters that are less than the typical atomic size scale of 10^{-10} m. (Such diameters may be rather loosely defined.) [P8.1]

is exemplified: by the proton, neutron and electron. [P8.1]

subcritical

describes: a nuclear chain reaction which fails to be self-sustaining because, on average, less than one neutron released in each fission of a nucleus goes on to produce fission in a further nucleus.   [P9.3]

Contrast with critical.

subject (of an equation or formula)

is: the single variable which is expressed in terms of others. [M1.1]

is exemplified: in the equation $F = ma$, by F. [M1.1]

sublimation

is: a phase change in which a solid is converted directly into a gas (or vapour), or vice versa, without passing through a liquid phase. [P7.4]

See also latent heat, sublimation curve.

sublimation curve

on: a *P*-*T* diagram

is: the curve that separates the solid phase from the vapour (gas) phase. [P7.4]

subscript

is: a symbol or number which is written beneath another symbol. [M1.7]

is used: to identify particular members of a sequence. [M1.7]

is exemplified: for the sequence, x_1, x_2 and x_3, by the numerals 1, 2 and 3. [M1.7]

subset

describes: all the elements of a set A when they are also elements of a larger set B. [M1.2]

is denoted: by $A \subset B$. [M1.2]

subshell

is: a grouping of electrons within a shell (i.e. having the same principal quantum number n), which also have the same orbital angular momentum quantum number l. [P8.3, P8.4]

therefore describes: electrons which, to a first approximation, have the same energy. [P8.3, P8.4]

subsidiary maxima

in: the interference pattern

from: a diffraction grating

are: the less prominent intensity maxima which are found between the principal maxima. [P6.1]

subsonic

means: travelling at a speed that is slower than the speed of sound. [P5.7]

substitution

is: a method of solving, or trying to solve, simultaneous equations. [M1.4]

subtended angle

of: two points A and B, at a third point C not on the line passing through A and B,

is: the angle $A\hat{C}B$ at C. [M2.1]

successive ionization energies

are: the energies required to remove successively each of the electrons from an atom or ion, beginning with the least tightly bound electron and proceeding to the most tightly bound. [P8.3]

sum

See operation.

sum (of vectors)

is: the vector which results from the vector addition of two or more vectors. [M2.4]

sum formulae

are: a class of trigonometric identities. [M1.6]

See trigonometric functions in the Maths handbook.

sum identities

are: a class of hyperbolic function identities. [M4.6]

See hyperbolic functions in the Maths handbook.

sum of a series

See convergent series.

sum rule for differentiation

is: $\dfrac{d}{dx}\big(f(x)+g(x)\big)=\dfrac{df(x)}{dx}+\dfrac{dg(x)}{dx}$ [M4.2]

sum rule for integration

is: $\int \left(f(x) + g(x) \right) dx = \int f(x)\, dx + \int g(x)\, dx$ [M5.2]

summation over addition rule

is: $\sum_{i=1}^{N}(x_i + y_i) = \sum_{i=1}^{N} x_i + \sum_{i=1}^{N} y_i$ [M1.7]

summation symbol, $\sum$

is: the symbol which is used to denote the operation of performing a sum. [M1.7]

$$\sum_{k=1}^{n} a_k = a_1 + a_2 + a_3 + \ldots + a_n$$

where $k = 1$ indicates the lower limit of the summation, the integer n above the summation symbol indicates the upper limit of the summation, and k is the summation variable that ranges over the integer values between the lower and upper limits. [M1.7]

summation variable

See summation symbol.

superconductivity

is: the sudden disappearance of electrical resistance that occurs in some materials below a characteristic critical temperature. [P8.4]

normally occurs: below 25 K but in 1986 a new class of material was discovered that exhibit superconductivity well above 25 K. These new materials are known as high-temperature superconductors and most of them are compounds that contain lanthanides and transition elements. [P8.4]

superconductor

is: a material whose resistivity drops to zero when its temperature falls below a critical transition temperature T_c. [P4.1, P11.1]

supercritical

describes: the condition in which a nuclear chain reaction proceeds at an ever-increasing rate, with an explosive release of energy, because more than one neutron released in each fission of a nucleus goes on to produce fission in further nuclei. [P9.3]

See also critical.

superelastic collision

is: a collision in which the total kinetic energy is increased (usually by the release of some stored potential energy during the collision). [P2.5]

superposition

is: the addition of oscillations or waves in which the superposition principle is applied. [P5.1]

is also: the result of such an addition.

superposition principle

See principle of superposition.

superscript

is: a symbol or number written above another symbol. [M1.7]

is used: identically to a subscript, but generally is employed in situations where the two need to be distinguished. [M1.7]

is exemplified: by n in the binomial coefficient, ${}^nC_r$. [M1.7]

supersonic

describes: anything travelling at a speed greater than the speed of sound.
[P5.7]

supplementary angles

are: two angles whose sum is 180°. [M2.1]

surface

is: the boundary of a real or imagined body.

more formally is: a connected and restricted set of points in (a possibly abstract) space such that by imposing a suitable system of coordinates on the surface, the location of any one of its points may be fixed relative to any other of its points with fewer coordinates than would be needed to locate a general point in the space.

is exemplified: by the surface of a sphere, the points of which can be located with respect to one another by means of two coordinates (e.g. latitude and longitude) even though points in general require three coordinates for their unique specification.

generally implies: the existence of a relationship between the coordinates of the space in which the surface is located, such as the equation of state of an ideal gas which specifies its two-dimensional equilibrium surface in three-dimensional *PVT* space.

surface energy

is: the energy per unit area of surface arising from the difference between molecular forces at the surface of a material and those within the bulk of the material.

surface gravity

is: the gravitational field ***g***, (or, equivalently, the acceleration due to gravity) at the surface of the Earth or any other massive body. [P3.2]

is given: for the Earth, in magnitude, by

$$g = GM_{\mathrm{E}} \big/ R_{\mathrm{E}}^2$$

where G is Newton's universal gravitational constant, M_{E} is the mass of the Earth and R_{E} the radius of the Earth. [P3.2]

surface integral

of: a function $f(x, y, z)$ defined at all points on a surface $\boldsymbol{S}$

is: the limit of the sum of terms of the form $f(X, Y, Z)\Delta\boldsymbol{S}$, where $\Delta\boldsymbol{S}$ is an element of area of the surface $\boldsymbol{S}$ and $f(X, Y, Z)$ is the value of $f(x, y, z)$ at some point within that element.

is exemplified: by the integral $\int_S \boldsymbol{V}\cdot d\boldsymbol{S}$ where $\boldsymbol{V}$ represents a vector field defined on $\boldsymbol{S}$ and $d\boldsymbol{S}$ is a vector element of integration with magnitude dS directed along an outward pointing normal to $\boldsymbol{S}$ at every point. [M2.6]

See also flux of a vector field.

surface of revolution

is: the surface obtained by rotating a curve (or part of a curve) about a given line or axis. [M5.4]

surface tension

in: the surface of a liquid

is: the property tending to minimize the area of the surface.

numerically is equal: to the energy per unit area needed to increase the surface area under isothermal conditions, or the force magnitude acting per unit length on the surface. [P7.6]

suspensory ligaments

are: the ring of ligaments which tie the lens of the eye to the surrounding ciliary muscles. [P6.4]

symmetric function

means: even function. [M1.6, M5.2]

symmetry

is: any one of the classes of operations that leave the essential features of a system unchanged.

is exemplified: by the rotational symmetry of a sphere about any axis through its centre. [P2.5]

symmetry argument

is: an argument that relies on the belief that a system would be unchanged in its essential features under certain actions, such as the exchange of two identical particles, or rotation about a specified axis.

symmetry relations

are: a class of trigonometric identities. [M1.6]

See trigonometric functions in the Maths handbook.

system

is: a general term referring to that portion of the Universe which is to be identified as the subject of a study or investigation. The rest of the Universe is said to constitute the environment of the system. [P7.3, P7.4]

is used: with various qualifiers according to circumstance, as in thermodynamic system, mechanical system, quantum system, etc.

See state.

systematic error

in: a measurement

is: the kind of error that systematically shifts all readings in the same direction away from the true value and consequently also shifts the mean and so reduces the accuracy. [P1.1, P1.2]

is: hard to detect. Either the experiment is designed to anticipate it and to cancel it out, or it biases the measured value. If this happens, only disagreement of the measured value with the results of a different kind of experiment will bring it to light. [P1.1, P1.2]

limits: the accuracy of a measurement.

Contrast with random error which determines precision.

table of values

is: a systematic way of displaying the value of a function corresponding to various values of its independent variable. [M1.3]

often provides: the basis for a graph. [M1.3]

tangent

at: a given point on a curve

is: a straight line that touches the given curve at the given point and which has the same gradient as the curve at that point. The gradient of the tangent to a point on a curved graph defines the gradient of the graph at that point. [M1.5, M2.1, M2.2, M2.3, M4.1, M4.2]

tangent, tan

See trigonometric function.

tanh

See hyperbolic function.

Taylor expansion or series for $f(x)$ near $x = 0$

for: values of x in some specified domain

is: a series (quite possibly an infinite series) of the form

$$f(0) + f'(0)\frac{x}{1!} + f''(0)\frac{x^2}{2!} + f^{(3)}(0)\frac{x^3}{3!} + f^{(4)}(0)\frac{x^4}{4!} + \ldots$$

where the sum of the series is the value of $f(x)$. [M4.5]

Taylor expansion or series for $f(x)$ near $x = a$

for: values of x in some specified domain

is: a series (quite possibly an infinite series) of the form

$$f(a) + f'(a)\frac{(x-a)}{1!} + f''(a)\frac{(x-a)^2}{2!}$$
$$+ f^{(3)}(a)\frac{(x-a)^3}{3!} + f^{(4)}(a)\frac{(x-a)^4}{4!} + \dots$$

where the sum of the series is the value of $f(x)$. [M4.5]

Taylor polynomial of degree *n* for *f*(*x*) near *x* = 0

is: a polynomial of the form

$$f(x) = f(0) + f'(0)\frac{x}{1!} + f''(0)\frac{x^2}{2!} + f^{(3)}(0)\frac{x^3}{3!}$$
$$+ f^{(4)}(0)\frac{x^4}{4!} + \ldots + f^{(n)}(0)\frac{x^n}{n!}$$

provided that the derivatives $f(0)$, $f'(0)$, … ,$f^{(n)}(0)$ all exist. [M4.5]

is: a Taylor series for $f(x)$ near $x = 0$ truncated to $n + 1$ terms.

Taylor polynomial of degree *n* for *f*(*x*) near *x* = *a*

is: a polynomial of the form

$$f(a)+f'(a)\frac{(x-a)}{1!}+f''(a)\frac{(x-a)^2}{2!}+f^{(3)}(a)\frac{(x-a)^3}{3!}$$
$$+f^{(4)}(a)\frac{(x-a)^4}{4!}+\ldots+f^{(n)}(a)\frac{(x-a)^n}{n!}$$

provided that the derivatives, $f^{(m)}(a)$ (for $0 \le m \le n$), all exist. [M4.5]

is: a Taylor series for $f(x)$ near $x = a$ truncated to $n + 1$ terms.

telescope

is: a device which allows observation of a parallel beam of light from a distant object or as produced by a collimator, with high angular magnification. [P6.4, P8.2]

is exemplified: by the final observation stage of a spectrometer. [P6.4, P8.2]

temperature

of: a thermodynamic system

is: the property which indicates whether there is thermal equilibrium. Two objects in thermal equilibrium with each other are said to have the same temperature. [P7.2]

is: a function of state of the system. [P7.3]

is related: to the internal energy U of the system. For an ideal gas of point particles this relationship takes the form $U = 3nRT/2$ implying that the temperature is proportional to the average translational kinetic energy of the particles that make up the gas. However, in other systems the relationship may be more complicated. [P7.3]

when increasing, generally corresponds: to increasing internal energy of the system. But it is not necessarily true that an increase in internal energy corresponds to an increase in temperature. [P7.3]

temperature coefficient of resistance

of: a material (in a given state)

is: the mean fractional change of resistance per unit temperature rise between 0 °C and 100 °C:

$$\alpha = \frac{R_{100} - R_0}{100\,^\circ\mathrm{C} \times R_0}$$ [P4.1]

generally is: positive for a metal. [P4.1]

often is: negative for a semiconductor. [P4.1]

See temperature coefficient of resistivity.

temperature coefficient of resistivity

of: a material (in a given state)

is: the mean fractional change of resistivity per unit temperature rise between 0 °C and 100 °C:

$$\alpha = \frac{\rho_{100} - \rho_0}{100\,°\mathrm{C} \times \rho_0}$$

is defined more generally: over any suitable temperature range, by applying the linear relation

$$\rho = \rho_0 [1 + \alpha(T - T_0)]$$

where ρ is the resistivity at temperature T and ρ_0 is the resistivity at temperature T_0. [P11.4]

generally is: positive for a metal, due to the increase in lattice vibrations with increasing temperature. [P11.4]

often is: negative for a semiconductor, due to increase in the number of mobile charged particles with increasing temperature. [P11.4]

temperature gradient

is: the rate of change of temperature with position along an axis or across some region, dT/dx. [P7.3]

is exemplified: by the temperature gradient along a metal rod, one end of which is maintained at a relatively high temperature while the other end is at a relatively low temperature.

temperature scale

relates: a particular physical property to the corresponding temperature. [P7.2]

ideally is: fundamental (such as the ideal gas absolute temperature scale or the thermodynamic Kelvin temperature scale) and/or internationally agreed (such as IPTS-90). [P7.2]

is also exemplified: by centigrade temperature scales and the Celsius scale. [P7.2]

temporal

means: pertaining to time.

temporal coherence

of: waves

is: their characteristic of maintaining coherence over some period of time. [P6.1]

usually is: limited by the nature of the source.

temporal part of the wavefunction

See temporal wavefunction and contrast with spatial wavefunction. [M6.4, P10.3, P10.4]

temporal wavefunction

is: that part of a separable solution to the time-dependent Schrödinger equation that depends only on time. [M6.4]

is exemplified: in one dimension by the factor $\phi(t) = \exp(-iEt/\hbar)$ that appears in the stationary state wavefunction $\Psi(x, t) = \psi(x)\phi(t)$. [M6.4, P10.3, P10.4]

tensile force

is: a force which acts to stretch a material and therefore to produce tensile strain. [P7.6]

tensile strain

is: the strain σ_T within a material caused by the application of a tensile force. [P7.6]

is given: by the increase in length Δl of the material divided by the original undistorted length l, so $\varepsilon_T = \Delta l/l$. [P7.6]

tensile stress

is: the stress σ_T resulting from a tensile force acting over a surface in a material. [P7.6]

is given: by the ratio of the perpendicular component of the tensile force to the cross-sectional area over which it acts, so $\sigma_T = F_\perp/A$. [P7.6]

tension

is: that property of a stretched elastic body that tends to restore the body to its natural length. [P2.3]

is also: the force which such a stretched body will apply to an attached object. [P2.3]

term

See expression.

terminal

is: a structure, typically a metal plate or wire, through which electric current may be supplied.

terminal potential difference

is: the potential difference between the terminals of a voltage generator. [P4.1]

will vary: for a non-ideal voltage generator, according to the resistance of the rest of the circuit. [P4.1]

See open circuit voltage.

terminal velocity

is: the final velocity reached by a body falling in a viscous medium, when the weight, the viscous force and the buoyancy force give zero resultant force.
[M4.2, P7.6]

terrestrial telescope

is: a telescope whose final image is erect. [P6.4]

tesla, T

is: the SI unit of magnetic field strength.

is defined: by $1\,\mathrm{T} = 1\,\mathrm{N\,C^{-1}\,m^{-1}\,s}$. So, a uniform magnetic field has a strength B of 1 tesla, if a particle with a charge of 1 coulomb moving with a speed of 1 metre per second in a direction perpendicular to that field experiences a magnetic force of 1 newton. Alternatively (and equivalently), a uniform magnetic field has a strength B of 1 T if a wire carrying a current of 1 A in a direction perpendicular to the field experiences a force of 1 newton per metre length of wire, so $1\,\mathrm{T} = 1\,\mathrm{N\,m^{-1}\,A^{-1}}$. [P4.2, P4.3]

is exemplified: by the magnetic field near a typical bar magnet, which has a strength of about $10^{-1}\,\mathrm{T}$.

test charge

is: an (imaginary) electrically charged body, whose nature is such that it may be used to determine the electric field at a point (by experiencing a measurable force due to the field) without causing any significant disturbance to the field. [P3.1, P3.3]

test mass

is: an (imaginary) body, whose nature is such that it may be used to determine the gravitational field at a point (by experiencing a measurable force due to the field) without causing any significant disturbance to the field. [P3.1, P3.3]

theorem

is: a mathematical proposition that may be proved, or which it is hoped will be proved.

theory

is: a connected and coherent set of (scientific) concepts and relationships which is (ideally) capable of making predictions that can be tested by experiment or observation.

thermal

means: pertaining to temperature.

thermal conduction

See conduction (of heat).

thermal conductivity

See conduction (of heat).

thermal conductivity coefficient

See coefficient of thermal conductivity.

thermal contact

is: the condition in which heat can be transferred between two bodies, or between a system and its environment. [P7.2, P7.3]

thermal equilibrium

of: a system

means: that no net transfer of heat is taking place. [P7.2, P7.3]

justifies: the introduction of temperature and thermometry. We say that if two bodies (one of which might be a thermometer) are in thermal equilibrium then they are at the same temperature. [P7.2, P7.3]

can be recognized: by the constancy of its thermal properties and the uniformity of its temperature.. [P7.2, P7.3]

thermal expansion (or contraction)

is: expansion (or contraction) due to temperature changes.

See also thermal expansivity.

thermal expansivity

is: the ability of a material to change its volume in response to a change in temperature and thus exhibit the phenomenon of thermal expansion.

arises: in a solid, from the thermal agitation of atoms subject to a potential energy function that is not symmetric about its minimum. [P11.4]

thermal kinetic energy

is: the kinetic energy associated with the random thermal motion at a given temperature.

thermal neutrons

are: neutrons with a kinetic energy of approximately 0.04 eV – i.e. the energy that they would have in thermal equilibrium with their surroundings at room temperature (i.e. at about 300 K). [P9.3]

thermal reservoir

ideally is: a part of the environment of a system that absorbs or supplies any required amount of heat without undergoing a change of temperature. [P7.3, P7.4]

thermistor

is: a thermally sensitive resistor.   [P4.1]

thermocouple

is: a circuit in which two different metals are brought into contact at two distinct junctions. [P7.2]

can be used: as a thermometer. [P7.2]

works: by the electrical potential difference created when the junctions are at different temperatures. [P7.2]

is widely used: because it is small, cheap and reliable. [P7.2]

may be used: over a wide range of temperatures, by selecting appropriate pairs of metals. [P7.2]

thermodynamic coordinates

are: the macroscopic properties of a system that may be used to specify its state, or more particularly its equilibrium state.

are exemplified: by pressure P, volume V, temperature T, and internal energy U: quantities that are functions of state. [P7.3]

thermodynamic equilibrium

See thermal equilibrium.

thermodynamic Kelvin temperature scale

is: a temperature scale based on heat flow under carefully controlled conditions.

is also: perhaps the most fundamental of all temperature scales. [P7.2]

rarely is used: in practice, since it is essentially identical to the far more practical ideal gas absolute temperature scale over a very wide range of temperatures. [P7.2]

is defined: by the thermometric relation

$$T = \left(\frac{Q}{Q_{\text{triple}}}\right) \times 273.16\,\text{K}$$

where Q is the quantity of heat that flows in or out of a system at temperature T in a reversible isothermal process that links one adiabat to another, and Q_{triple} is the quantity of heat that flows in or out if the system in a reversible isothermal process at the triple-point temperature (defined to be 273.16 K) that returns the system from the second adiabat to the first. [P7.2]

thermodynamics

is: the study of temperature and heat, and the interrelations of those quantities with matter and energy in general. [P7.1, P7.2, P7.3]

thermometer

is: a device for measuring temperature on a specified temperature scale. [P7.2]

thermometric property

is: a property of matter which depends on temperature. [P7.2]

is selected: for reasons of sensitivity, convenience, or tradition. [P7.2]

is used: as a means of relating temperature differences to a generally recognized temperature scale such as the Celsius scale. [P7.2]

thermometric relation

is: an equation which relates the value of some thermometric property between given fixed points, to the temperature on a particular temperature scale. [P7.2]

Thévenin resistance

of: any circuit between two terminals

is: the resistance R_{Th} of the single resistor in an equivalent circuit described by Thévenin's theorem. [P4.1]

is equal: to the net resistance between the two terminals when all voltage generators between the terminals are replaced by short circuits. [P4.1]

Thévenin voltage

of: any circuit between two terminals

is: the voltage V_{Th} of the ideal voltage generator in an equivalent circuit described by Thévenin's theorem. [P4.1]

is equal: to the open circuit voltage between the two terminals. [P4.1]

Thévenin's theorem

states: that for the purpose of calculating the current and voltage in a load resistor, *any* two-terminal network of voltage generators and resistors can be replaced by an equivalent circuit consisting of a single ideal voltage generator in series with a single resistor. [P4.1]

thin lens

is: a lens whose thickness is much less than the object distance and image distance and the radius of curvature of each of its surfaces, and so can be neglected. [P6.3]

thin lens equation

is: an equation which relates the object position u, the image position v and the focal length f of a thin lens:

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$ (Cartesian sign convention). [P6.3]

Compare with spherical mirror equation.

third law pair

is: a pair of forces of equal magnitude that act in opposite directions on two interacting bodies or entities and which are necessarily 'equal and opposite' by virtue of Newton's third law of motion. [P2.3]

Thomson's *e*/*m* experiment

is: a classic experiment in which J. J. Thomson (1856-1940) determined the charge-to-mass ratio of the electron by subjecting cathode rays (i.e. streams of high speed electrons) to mutually perpendicular electric and magnetic fields. [P8.1]

three-dimensional

describes: an object or situation which requires the use of a coordinate system with *three* independent axes for its adequate description. [P2.1, P2.2]

threshold energy

is: a general term used to indicate the minimum amount of energy required to achieve a certain condition (e.g. the minimum amount of energy that will just unbind a certain bound state).

threshold frequency

for: a particular material

is: a frequency of electromagnetic radiation f_t below which the radiation cannot eject electrons from the material. [P10.1]

corresponds: to photons whose energy is just large enough to overcome the work function ϕ of the material and eject photoelectrons of zero kinetic energy. [P10.1]

is given: from Einstein's photoelectric equation, by $hf_t = \phi$. [P10.1]

is: a characteristic of each material and its surface preparation. [P10.1]

tides

are: the motion of ocean water on the Earth's surface produced by changes, across the Earth's diameter, in the gravitational fields due to the Moon and to the Sun. [P3.2]

time

is: one of the fundamental dimensional quantities of mechanics (along with mass and length).

allows: events occurring at the same place to be distinguished from one another.

has as its SI unit: the second (s), one of the seven base units.   [P1.1]

time constant

in: exponential decay

is: the time τ required for a decaying quantity to reduce to e^{-1} of its original value. [P5.2]

therefore is: the reciprocal of the decay constant α

$$A(t) = A_0\,e^{-\alpha t} = A_0\,e^{-t/\tau}$$ [P5.2]

time-dependent Schrödinger equation

of: a system

is: the fundamental partial differential equation of quantum mechanics whose solutions are the wavefunctions that describe the possible (quantum) states of the system. [M6.4, P10.4]

has: a specific form that depends on the problem in hand.

is exemplified: for a particle of mass m moving in one dimension with potential energy $U(x)$ by

$$i\hbar\frac{\partial\Psi(x,t)}{\partial t} = \frac{-\hbar^2}{2m}\frac{\partial^2\Psi(x,t)}{\partial x^2} + U(x)\,\Psi(x,t)$$

time-independent Schrödinger equation

of: a system

is: a differential equation, derived from the time-dependent Schrödinger equation for the system in the case where the wavefunction is separable, whose solutions (called spatial wavefunctions) depend only on spatial variables (i.e. not time) and are the energy eigenfunctions of the system. [M6.4, P10.4]

therefore can be written: as an eigenvalue equation of the total energy operator (the Hamiltonian operator) with eigenvalues that correspond to the possible values of the total energy of the system. [M6.4, P10.4, P11.1]

has: a specific form that depends on the problem in hand.

is exemplified: for a particle of mass m moving in one dimension with potential energy $U(x)$ by

$$\frac{-\hbar^2}{2m}\frac{d^2\psi(x)}{dx^2} + U(x)\,\psi(x) = E\psi(x)$$ [M6.4, P10.4, P11.1]

toroid

See torus.

toroidal solenoid

is: a solenoid which is curved into a circle by bringing its ends together.
[P4.2]

torque

is: the moment of a force about a given point. [M2.7, P2.7, P2.8]

is given: as $\boldsymbol{\Gamma} = \boldsymbol{r} \times \boldsymbol{F}$. [M2.7, P2.7, P2.8]

torr

is: a non-SI unit of pressure equal to 133.322 pascal. [P7.2]

very nearly is: the pressure exerted by a column of mercury 1 mm high. [P7.2]

torsional

means: pertaining to a twisting motion.

torus

is: a shape similar to that of a bagel or ring-shaped dough-nut. [P4.2]

is also called: a toroid. [P4.2]

total force

See resultant force.

total internal reflection

of: a wave

travelling: from one medium, to another medium in which its speed is greater (i.e. for which the refractive index is smaller)

occurs: when the angle of incidence exceeds the critical angle. The interface acts like a mirror, the wave is reflected back into the first medium and no refraction occurs. [P5.7, P6.2]

trajectory

is: the path through space followed by a moving body, especially a projectile. [P2.2]

transformer

is: a device that can change (transform) an a.c. voltage, from one value to another, with high power transfer efficiency. [P4.4]

consists: of two coils wound on a common core, with the primary coil connected to an a.c. input. [P4.4]

works: because mutual induction produces an induced voltage in the secondary coil. Depending on the transformer turns ratio, the induced voltage on the secondary coil may be stepped up or down compared with the voltage on the primary coil. [P4.4]

transient

describes: short lived behaviour that a system displays in response to a sudden change or disturbance. [P5.5]

transient current

refers: to the initial current in an electrical circuit, following some kind of disturbance, before the steady state becomes established. [P4.5]

transient motion

refers: to the initial motion produced in a driven oscillator, soon after the driving force has been applied and before the steady state motion has become established as the dominant motion. [P5.3]

transition

is: a process in which the state of a quantum system is abruptly changed. Usually this involves transferring energy from the system (emission) or to the system (absorption), often by emitting or absorbing photons of electromagnetic radiation. [P8.3, P10.3]

transition elements

are: the chemical elements that span a region of the periodic table in which a d subshell of atoms in their ground state is being progressively filled. [P8.4]

consist mainly: of the three series; Sc to Zn (3d filling), Y to Cd (4d filling), and Lu to Hg (5d filling). [P8.4]

transition temperature

is: the temperature T_c below which a material becomes a superconductor.
[P4.1]

translation

of: a rigid body

is: a form of motion in which there is no rotation of the body with respect to itself, so that every part moves parallel to every other part. [P2.3, P2.7]

translational equilibrium

of: a system

is: the condition in which the total linear momentum of the system is constant.

requires: that the resultant external force acting on the system is zero. [P2.3, P2.7]

implies: for a body of fixed mass, that the acceleration of the body is zero, so that it remains in uniform (linear) motion. [P2.3, P2.7]

is a necessary condition: for static equilibrium in which there is no motion.

See also rotational equilibrium.

translational kinetic energy

is: the energy that a body has by virtue of the motion of its centre of mass. [P2.4]

is given: by $E_{\text{tran}} = \frac{1}{2}mv^2$ or equivalently by $E_{\text{tran}} = p^2/(2m)$, where the mass of the body is m and its speed is v. [P2.5]

is: for a collection of bodies (or particles), the sum of the individual translational kinetic energies. [P2.4]

is conserved: in elastic collisions. [P2.4]

transmission

is: a process in which an entity or agency (e.g. a ray of light) encountering a surface or interface between media, enters the new medium and continues to travel in that medium rather than being absorbed at the interface or reflected back into the original medium. [P6.2]

transmission coefficient

for: a stream of particles encountering a potential step or potential barrier

is defined: by

$$T = \frac{\text{flux of transmitted particles}}{\text{flux of incident particles}}. \quad [\text{P11.1}]$$

transmission diffraction grating

is: a form of diffraction grating in which the diffracted beams are produced by transmission through a transparent surface which has been ruled with many closely spaced, narrow parallel lines. [P6.1]

transparent

describes: a medium that transmits light.

transport process

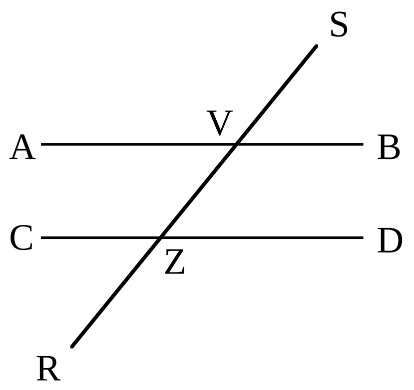
in: a bulk macroscopic system

is: any physical phenomenon which involves the movement of matter or energy from one place to another by transfer of particles.

is exemplified: in a gas, by diffusion, viscosity and thermal conduction. [P7.5]

transversal

is: a line RS crossing a pair of parallel lines AB and CD and intersecting them at points V and Z respectively (see Figure). [M2.1]



has: angles RZC and RVA equal (corresponding angles). [M2.1]

also has: angles RZC and DZS equal (alternate angles). [M2.1]

transverse

means: at right angles to.

transverse magnification

is: the ratio of the transverse dimensions of an optical image to those of the object from which the image is derived. [P6.4]

transverse wave

is: a wave in which the 'disturbance' that constitutes the wave is perpendicular (i.e. transverse) to the direction of propagation of the wave. [M6.4, P5.6, P6.1, P11.1]

Contrast with longitudinal wave.

trapezium

is: a quadrilateral in which two opposite sides are parallel. [M2.1]

travelling wave

given: a physical quantity that may be measured throughout some region and which possesses a well defined equilibrium value at each point in that region,

is: a disturbance from equilibrium in that quantity, moving from place to place. [M6.4, P5.6]

See periodic wave and solitary wave, and contrast with standing wave. See also sinusoidal wave.

triangle

is: a polygon with three sides.

is called: an isosceles triangle if two sides are of equal length. [M2.1]

is called: an equilateral triangle if three sides are of equal length. (See regular polygon.) [M2.1]

triangle rule (for vector addition)

is: a geometric rule in which two vectors are represented by two sides of a triangle and their vector sum is represented by the third side. [M2.4, M2.5, P2.2]

states: that if the tail of vector $\boldsymbol{B}$ is placed at the head of vector $\boldsymbol{A}$ then the vector $\boldsymbol{C}$ from the tail of vector $\boldsymbol{A}$ to the head of vector $\boldsymbol{B}$ represents the sum of vectors $\boldsymbol{A}$ and $\boldsymbol{B}$. [M2.4, M2.5, P2.2]

Compare with parallelogram rule.

triatomic ideal gas

is: an ideal gas that may be used to model a real gas with three atoms per molecule at low density. [P7.4]

trigonometric functions

are: functions which are equivalent to the trigonometric ratios (sine, cosine, tangent) for arguments in the range 0 to $\pi/2$, but are defined for all real values. (The tangent function is undefined for values of the argument which are odd integer multiples of $\pi/2$.) [M1.6]

often are taken: to include the reciprocal trigonometric functions (cosecant, secant, cotangent). (The cotangent function is undefined for values of the argument which are even integer multiples of $\pi/2$.) [M1.6]

are all: periodic functions. [M1.6]

strictly consist; of two distinct classes of functions, those whose domain is the set of real numbers, and those whose domain is the set of angles, but this distinction is deliberately blurred by measuring angles in radians to ensure that the periodicity is the same (apart from the dimensionless unit radian) in both cases.

See trigonometric functions in the Maths handbook for further details.

trigonometric identities

are: relationships between trigonometric functions which are independent of the value of the argument. [M1.6]

include:

$$\sin(\alpha + \beta) = \sin(\alpha)\cos(\beta) + \cos(\alpha)\sin(\beta)$$

$$\cos(\alpha + \beta) = \cos(\alpha)\cos(\beta) - \sin(\alpha)\sin(\beta)$$

$$\sin(2\alpha) = 2\sin(\alpha)\cos(\alpha)$$

$$\cos(2\alpha) = \cos^2(\alpha) - \sin^2(\alpha)$$

$$\cos(2\alpha) = 1 - 2\sin^2(\alpha)$$

$$\cos(2\alpha) = 2\cos^2(\alpha) - 1$$

$$\cos^2(\alpha/2) = \tfrac{1}{2}(1 + \cos(\alpha))$$

$$\sin^2(\alpha/2) = \tfrac{1}{2}(1 + \cos(\alpha))$$

$$\sin(\alpha) + \sin(\beta) = 2\sin\left(\frac{\alpha+\beta}{2}\right)\cos\left(\frac{\alpha-\beta}{2}\right)$$

$$\sin(\alpha) - \sin(\beta) = 2\cos\left(\frac{\alpha+\beta}{2}\right)\sin\left(\frac{\alpha-\beta}{2}\right)$$

$$\cos(\alpha) + \cos(\beta) = 2\cos\left(\frac{\alpha+\beta}{2}\right)\cos\left(\frac{\alpha-\beta}{2}\right)$$

$$\cos(\alpha) - \cos(\beta) = -2\sin\left(\frac{\alpha+\beta}{2}\right)\sin\left(\frac{\alpha-\beta}{2}\right)$$

and many others. [M1.6]

See trigonometric functions in the Maths handbook for a more detailed listing.

trigonometric ratios

are: ratios involving the sides of a right-angled triangle. [M1.6]

depend only: on the value of a particular angle of the triangle. [M1.6]

may be generalized: to produce the trigonometric functions, whose names they share. [M1.6]

See trigonometric functions in the Maths handbook.

trigonometry

is: the study of right-angled triangles and the related trigonometric ratios and trigonometric functions. [M1.6]

triple bond

is: a bond between two atoms of a chemical substance, which is equivalent to three single bonds. [P8.4]

arise: from the sharing of three electron pairs. [P8.4]

triple point

is: a point on the P-T projection of a PVT-surface, at which three different phases (for example solid, liquid, and vapour) can coexist at the same pressure and temperature, each phase having the same molar volume (or density). [P7.2P7.4]

triple-point cell

for: H_2O

is: an apparatus rather like a double-walled version of a thermos flask. [P7.2]

has: an inside space held at the temperature of 273.16 K at which solid, liquid, and vapour H_2O are in equilibrium together. [P7.2]

also has: an outside jacket evacuated to a vacuum as in a thermos flask, in order to act as a thermal insulator. [P7.2]

moreover, has: an extra jacket, between the vacuum and the inside space, where the H_2O is held. When prepared, this H_2O has at least some of each of the phases – solid, liquid, and vapour – in equilibrium together, which can happen only at the triple-point temperature. [P7.2]

triple-point line

is: a straight line on a *PVT*-surface. [P7.4]

is: parallel to the volume axis. [P7.4]

passes: through points that represent states in which three phases coexist in equilibrium. [P7.4]

is: of finite length. [P7.4]

delineates: the finite range of volume where three phases of the sample can coexist. [P7.4]

triple-point pressure

is: the unique pressure that corresponds to the triple point of a substance. [P7.4]

triple-point temperature

is: the unique temperature that corresponds to the triple point of a substance.

is exemplified: by the temperature of the triple point of H_2O which, by definition, is exactly 273.16 K [P7.2]

triple-point volume

is: one of the volumes along the triple-point line of a fixed quantity of a given substance. [P7.4]

is specified: by particular conditions, such as the requirement that the sample should contain one mole of the substance and that it should be purely liquid. [P7.4]

tritium

is: the isotope of hydrogen which has mass number $A = 3$. [P9.3]

is: a radioisotope which emits β-particles. [P9.3]

does not occur: naturally. [P9.3]

can be produced: artificially in nuclear fusion reactions. [P9.3]

triton

is: a tritium nucleus, ${}^{3}_{1}H$ also represented as T or sometimes t. [P9.3]

tuning circuit

is: an electrical circuit which contains both inductance and capacitance. [P5.3]

behaves: as an electrical oscillator, which may be driven by an applied voltage. [P5.3]

has: a resonance frequency and a narrow resonance absorption bandwidth. [P5.3]

can: select and respond only to a very narrow range of applied frequencies. [P5.3]

tunnel diode

is: a device that can be used to control the flow of current in a suitable electric circuit, and which operates by virtue of quantum tunnelling [P11.1]

tunnel junction

is: an electronic device which switches electrical currents using quantum tunnelling. [P10.2]

turbulence

is: the situation in which forces of friction are produced by uncoordinated or irregular internal motions of a gas or a liquid. [P2.3]

turning point

in: any graph of the form $y = f(x)$

is: any point at which the value of y changes from increasing to decreasing or *vice-versa* as the value of x is altered. [M1.3]

therefore is: a point $(a, f(a))$ on the graph of the function $f(x)$ at which the derivative $f'(x) = 0$ and the tangent to the graph does not cross the graph itself. [M4.4]

is exemplified: by local maxima and local minima. [M4.4]

in particular is exemplified: by a position, during an oscillation, where the magnitude of the displacement reaches a maximum value, and the oscillation begins to move back towards the position of equilibrium. [P5.1]

turns ratio

in: a transformer

is: the ratio of the number of turns N_s on the secondary coil to the number of turns N_p on the primary coil of the transformer. [P4.4]

is equal: in an ideal transformer, to the ratio of the induced voltage V_s in the secondary coil to the applied voltage V_p in the primary coil: $V_s/V_p = N_s/N_p$. [P4.4]

two-dimensional

describes: an object or situation which requires the use of a coordinate system with *two* independent axes for its adequate description.   [P2.1, P2.2]

two-point form

of: the equation of a straight line

is: $\dfrac{y - y_1}{x - x_1} = \dfrac{y_2 - y_1}{x_2 - x_1}$

where (x_1, y_1) and (x_2, y_2) are both points on the straight line. [M1.3, M2.2]

typical elements

are: a set of chemical elements whose atoms have ground state outer electronic configurations of the type ns^x, where n = 1 to 7 inclusive and x = 1 or 2, or of the type $ns^2\,np^x$ where n = 1 to 7 inclusive and x = 1 to 6 inclusive. [P8.4]

ultrasonic waves

are: sound waves with a frequency greater then the highest frequency normally audible to healthy young humans.

usually have: frequencies in the range 20 kHz to 5 MHz. [P5.7]

ultraviolet radiation

is: a type of electromagnetic radiation which is characterized by wavelengths in the range between those of X-rays and visible light (i.e. approximately 5 nm to 400 nm allowing a considerable overlap with X-rays).

See electromagnetic spectrum.

unaccommodated (eye)

is: an eye in which the ciliary muscles (which control the lens) are fully relaxed. [P6.4]

is focused: at its far point (usually infinity). [P6.4]

Contrast with accommodated eye. [P6.4]

unbalanced bridge

is: a bridge circuit with a non-zero output voltage. [P4.1]

unbound state

of: a quantum system

is: a state of a composite system in which the components of the system may be arbitrarily far apart and in which their separation may be altered by an infinitesimal change in the energy.

is: in Schrödinger's model of the hydrogen atom, one of the states whose energy belongs to the continuum of energy levels above the ionization level, and in which the electron is freed from the atom. [P8.2]

is reached: when an electron from one of the bound states in the atom is given enough energy so that its energy becomes positive thus exceeding the zero energy that is conventionally assigned to the ionization level. [P8.2]

uncertainty

in: the value of a physical quantity

is: a quantitative indication of the lack of precision and/or accuracy in the value of the physical quantity. [P1.1, P1.2]

may be shown explicitly: by writing the quantity in a form such as 1.2 ± 0.2, where 0.2 is the uncertainty in this case. [P1.1, P1.2]

by default is implied: by the number of significant figures in the quoted value. [P1.1, P1.2]

See random error and systematic error.

See also Heisenberg uncertainty principle for a fundamental limitation.

in an experiment, may be known as: error.

underdamping

of: a damped harmonic oscillator

is: the condition in which the oscillator is subject to such a weak damping force that it is unable to return to rest as rapidly as a critically damped oscillator. [P5.2, P5.4]

is characterised: by oscillations whose amplitude decays exponentially with time. [P5.4]

is often used as synonymous: with light damping.

uni-axial compressional strain

is: the strain within a material caused by the application of uni-axial compressional stress. [P7.6]

is equal: to the change in length of the material divided by the original undistorted length. [P7.6]

has: a negative sign. [P7.6]

uni-axial compressional stress

is: the stress resulting from a uni-axial compressional force acting over a surface in a material. [P7.6]

has a magnitude: obtained by dividing the magnitude of the perpendicular component of the force by the area over which it acts. [P7.6]

has: a negative sign. [P7.6]

uni-axial rotation

of: a rigid body

is: a rotation of the body about a axis that is fixed with respect to the body [P2.7, P2.8]

is exemplified: by the rotation of a door as it swings on its hinges. [P2.7, P2.8]

uniform

means: independent of position.

Compare with constant.

uniform acceleration

of: a particle

is: acceleration at a uniform rate, that is therefore also a constant rate in this case. [M4.1, P2.1]

is described: for a particle moving along the *x*-axis, by the uniform acceleration equations. [M4.1, P2.1]

is also called: constant acceleration. [M4.1, P2.1]

uniform acceleration equations

for: a particle undergoing uniform acceleration in one-dimensional (linear) motion

relate: the displacement s_x and final velocity v_x at time t to the initial velocity u_x at time $t = 0$ and the (constant) acceleration a_x. [P2.1, P2.2]

are given: by

$$v_x = u_x + a_x t$$

$$s_x = u_x t + \tfrac{1}{2} a_x t^2$$

$$v_x^2 = u_x^2 + 2 a_x s_x$$

where the displacement, s_x is taken to be zero when $t = 0$. [P2.1, P2.2]

uniform circular motion

is: a special type of motion in which a particle travels at a constant rate around a circular path.

is characterized: by the radius r of the circle, the angular speed ω of the particle, and the speed of the particle, which is $v = r\omega$. [P2.6]

is also characterized: by the acceleration of the particle, which points towards the centre of the circle and has magnitude $r\omega^2$. [P2.6]

uniform field

is: a scalar field or a vector field that has the same value at every point. In the case of a vector field both the magnitude and the direction of the field must be the same everywhere. Such fields may be represented by the same vector at every point. [M2.6, P3.3]

therefore is: a field in which the field lines are everywhere parallel. [P3.1]

is not necessarily: a constant field, which is (strictly) a field that does not change with time. [P3.3]

uniform medium

is: a medium whose properties are independent of position within the medium.

uniform (linear) motion

of: a particle

is: a special type of motion in which the particle moves along a straight line at a constant velocity. [P2.1]

therefore is characterized: by zero acceleration. [P2.1]

can be represented: by a velocity-time graph which is a straight line, parallel to the time-axis. [P2.1]

uniform motion equations

for: a particle in uniform motion

are: a set of equations which describe one-dimensional (linear) motion with uniform velocity (i.e. with acceleration $a_x = 0$). [P2.1, P2.2]

relate: the displacement s_x and velocity υ_x at time t to the initial velocity u_x at time $t = 0$. [P2.1, P2.2]

are given: by

$$s_x = u_x t$$

$$\upsilon_x = u_x = \text{constant}$$

$$a_x = 0$$

where the displacement, s_x is taken to be zero when $t = 0$. [P2.1, P2.2]

uniform speed

is: a special type of motion in which a particle moves at a constant rate, covering equal distances in equal times, irrespective of the direction of motion. [P2.1]

is also known as: constant speed.

uniform stress

See volume stress.

uniform velocity

is: a velocity that is constant, i.e. unchanging with respect to time. [M4.1]

See uniform motion.

uniqueness theorem

is: a theorem which asserts that a certain result will be unique provided that certain specified conditions are met. [M6.1]

unit

is: a quantity that, by general agreement, provides the basis for a system of measurement. [P1.1]

is exemplified: by the SI units of the metre, kilogram and second. [P1.1]

permits: expression of the values of physical quantities as products of appropriate numbers and units. [P1.1]

unit cell

is: a conventionally chosen set of points in space which, when regularly repeated throughout space, produces one of the 14 fundamentally different three-dimensional lattices (three of which have cubic unit cells) [P11.4]

unit area

is: an area of one square unit. The square unit may be a square metre, for example.

unit potential difference

is: a potential difference of one unit. The unit may be a volt, for example.

unit length

is: a length of one unit. The unit may be a metre, for example.

unit (point) charge

is: a particle with an electric charge of one unit. The unit may be a coulomb, for example.

unit (point) mass

is: a particle with a mass of one unit. The unit may be a kilogram, for example.

unit time

is: an interval of time of one unit. The unit may be a second, for example.

unit vector

in: the direction of any vector $\boldsymbol{a}$,

is: a vector of magnitude 1, given by $\hat{\boldsymbol{a}} = \dfrac{\boldsymbol{a}}{|\boldsymbol{a}|}$. [M2.5, P2.8]

is denoted: for the directions of the Cartesian axes x, y and z by $\boldsymbol{i}, \boldsymbol{j}$ and $\boldsymbol{k}$. These are sometimes referred to as Cartesian unit vectors. [M2.5, P2.7, P2.8, P3.1]

unit volume

is: a volume of one cubic unit. The cubic unit may be a metre cubed, for example.

unit wavelength

is: a wavelength of one unit. The unit may be a metre, for example.

universal constant

is: any constant that is believed to have the same value throughout the Universe. [P1.1]

is synonymous: with fundamental constant.

universal gas constant

is: the physical constant R that appears in the equation of state of an ideal gas; $PV = nRT$. [P7.2]

has: the value $R = 8.314\,\mathrm{J\,K^{-1}\,mol^{-1}}$ (to four significant figures). [P7.2]

is related: to Boltzmann's constant k and Avogadro's constant N_A by $R = N_\mathrm{A}k$.

is synonymous: with molar gas constant.

universal gravitational constant

is: the fundamental constant G that appears in Newton's universal law of gravitation. [P2.3, P3.2]

has: the value $G = 6.672 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$ (to four significant figures). [P2.3, P3.1, P3.2]

is synonymous: with Newton's universal gravitational constant and gravitational constant.

universal law of gravitation

See law of universal gravitation.

Universe

is: the system being studied, plus its environment. [P7.3, P7.4]

is also: the cosmos, the totality of matter and energy in existance.

unknown (variable)

in: an equation

is: an independent variable, the value of which is to be found by solution of the equation. [M1.4]

unpaired electron

is: an electron that is not paired with another of opposite spin. [P8.3]

See Hund's rule.

unpolarized

describes: light in which there is no preferred direction of polarization.
[P6.1]

unstable equilibrium

of: a system

describes: a state of equilibrium in which a small disturbance of the system results in a tendency for the system to depart further from its initial equilibrium state. [P5.1]

unstable nucleus

is: a nucleus that will eventually undergo radioactive decay.

is characterized: by a time interval $\tau_{1/2}$ called the half-life, which determines the probability that the nucleus will decay within a given time from any specified starting time, $P(t) = 1 - 2^{t/\tau_{1/2}}$.

is alternatively characterized: by a decay constant $\lambda = \log_e 2/\tau$, so that $P(t) = 1 - e^{-\lambda t}$.

upper limit (of integration)

See definite integral.

upper limit (of summation)

See summation symbol.

upthrust

See buoyancy force.

vacuum

is ideally: in classical physics, a region of space in which there is no matter.

is in practice: a region of space in which there is inevitably a gas, but a gas of very low density.

is: in quantum theory (specifically quantum field theory), a complicated state in its own right in which particles may be found due to quantum fluctuations.

valence band

in: a solid

is: the highest electron energy band that is filled or partly filled at absolute zero. It contains the highest energy electrons, and therefore the most weakly bound electrons. [P11.4]

valence electrons

in: an atom

are: the outermost electrons, which participate in bonding via sharing or transfer to neighbouring atoms. [P7.1]

valency

of: an element

is: the property that determines its ability to combine with other elements. [P8.4]

is equal: to the number of atoms of hydrogen that combine with one atom of the element. [P8.4]

alternatively can be determined: if the element does not combine with hydrogen, from the known valency of another element with which it does combine. [P8.4]

van der Waals bonding

is: a weak bond resulting from the interaction of electric dipole moments (or distortions from spherical symmetry) of two atoms or molecules. [P7.1]

has energy: typically on the scale of millielectronvolts. [P7.1]

van der Waals equation of state

is: a modification of the ideal gas equation of state. [P7.5]

takes into account: the finite size of the molecules of the gas (the excluded volume effect) and the effect of long-range interactions (intermolecular forces) on the gas pressure. [P7.5]

is written: as $\left(P + \dfrac{a}{V_{\rm m}^2}\right)(V_{\rm m} - b) = RT$,

where $V_{\rm m}$ represents the volume per mole, R is the molar gas constant and a and b can be regarded as empirical constants, although they relate to intermolecular forces and to the excluded volume effect respectively. [P7.5]

van der Waals force

is: an attractive force between electric dipoles which are induced in electrically neutral atoms or molecules by asymmetrical electron distributions. [P3.3]

vaporization

is: the phase transition in which a liquid becomes a vapour. [P7.4]

See also latent heat. [P7.4]

vaporization curve

of: a substance

is: the curve on the *P*-*T* projection of the substance's *PVT*-surface that separates the vapour phase from the liquid phase. [P7.4]

vapour

is: a gas at a temperature which is less than its critical temperature. [P7.4]

variable

is: a quantity whose value may vary. [M1.3]

is: a quantity whose (unknown) value is designated by a mathematical symbol for the purpose of performing mathematical operations. [M1.1]

vector

is: a mathematical entity which can be represented by a directed line segment (an arrow).   [M2.4, M2.5, P2.1]

can be used: to represent a physical quantity that has magnitude and direction. (Such quantities are called vector quantities.)   [P2.1]

can be formed: by adding together given vectors (i.e. vector addition) or by multiplying a given vector by a number (i.e. by scaling).   [P2.1, P2.2]

usually is denoted: in printed texts by bold symbols such as $\boldsymbol{a}$, $\boldsymbol{E}$, $\boldsymbol{r}$, and $\boldsymbol{F}$.

is also denoted: in handwriting by a wavy line underneath it ($\utilde{a}$, $\utilde{E}$, etc.); the wavy underline is a printer's mark meaning 'make the character bold'.   [M2.4, M2.5]

can be represented: in *n*-dimensions, by *n* scalar components which are usually presented in the form of an ordered multiple such as an ordered pair in two-dimensions or an ordered triple in three-dimensions.   [P2.2]

vector addition

is: the operation of adding two (or more) vectors together to obtain a vector sum that is itself a vector. [M2.4]

can be represented graphically: by means of the triangle rule or, equivalently, the parallelogram rule. [M2.4]

is expressed algebraically: (for three-dimensional vectors) by the rule

$$\begin{aligned}\boldsymbol{a}+\boldsymbol{b} &= \left(a_x, a_y, a_z\right)+\left(b_x, b_y, b_z\right)\\ &= \left(a_x+b_x, a_y+b_y, a_z+b_z\right)\end{aligned}$$

[P2.2]

vector algebra

is: the branch of mathematics concerned with the behaviour of vectors under the operations of vector addition and scaling and with the formation of scalar products and vector products. [M2.4]

vector difference

between: two vectors $\boldsymbol{a} = (a_x, a_y, a_z)$ and $\boldsymbol{b} = (b_x, b_y, b_z)$

is: the sum of the vectors $\boldsymbol{a}$ and $-\boldsymbol{b}$

is given: in terms of components, by

$$\begin{aligned}\boldsymbol{a} - \boldsymbol{b} &= (a_x, a_y, a_z) - (b_x, b_y, b_z) \\ &= (a_x - b_x, a_y - b_y, a_z - b_z)\end{aligned}$$

[M2.4, P2.2]

vector field

throughout: some region of space

is: a quantity that may be fully specified by a vector quantity at each point within that region. [P3.1]

therefore is: a field $\boldsymbol{A}(\boldsymbol{r})$ which associates a definite value of the vector quantity $\boldsymbol{A}$ with each point specified by position vector $\boldsymbol{r}$. In short, it is a vector valued function of $\boldsymbol{r}$. [P3.1]

is said to be: uniform**,** if all the vectors specifying the field are parallel in direction and have the same magnitude at every point within the field. [M2.6, P3.1]

vector product

of: two vectors $\boldsymbol{a} = (a_x, a_y, a_z)$ and $\boldsymbol{b} = (b_x, b_y, b_z)$

is: a vector quantity denoted by $\boldsymbol{a} \times \boldsymbol{b}$. [M2.7, P2.7, P2.8, P4.3]

has a magnitude: $|\boldsymbol{a}||\boldsymbol{b}|\sin\theta$, where $|\boldsymbol{a}|$ and $|\boldsymbol{b}|$ are the magnitudes of the vectors, and θ is the angle from the direction of $\boldsymbol{a}$ to the direction of $\boldsymbol{b}$. [M2.7, P2.7, P2.8, P4.3]

has a direction: perpendicular to $\boldsymbol{a}$ and $\boldsymbol{b}$ in the sense given by the right-hand rule. [M2.7, P2.7, P2.8, P4.3]

therefore may be written: $|\boldsymbol{a}||\boldsymbol{b}|\sin\theta\,\hat{\boldsymbol{n}}$, where $\hat{\boldsymbol{n}}$ is an appropriately directed unit vector.

can be computed: in terms of scalar components, using

$$\boldsymbol{a} \times \boldsymbol{b} = (a_yb_z - b_ya_z,\ a_zb_x - b_za_x,\ a_xb_y - b_xa_y)$$ [M2.7]

has the property: that $\boldsymbol{a} \times \boldsymbol{b} = -\boldsymbol{b} \times \boldsymbol{a}$ (note the minus sign) [M2.7]

is also called: cross product. [P2.7]

See vector product in the Maths handbook for further details.

vector quantity

is: a quantity which has both magnitude and direction and which satisfies the rules of vector algebra (see vector addition and scaling). [P2.2]

is represented: by a vector. [M2.4, M2.5, P2.2]

as a term, is used interchangeably: with the term vector. [M2.4, M2.5]

vector sum

of: two vectors $\boldsymbol{a} = (a_x, a_y, a_z)$ and $\boldsymbol{b} = (b_x, b_y, b_z)$

is: the vector that results from the vector addition of those vectors. [M2.4, P2.2]

may be constructed graphically: by means of the triangle rule or the parallelogram rule. [M2.4, P2.2]

is expressed algebraically: (for three-dimensional vectors) by the rule

$$\begin{aligned}\boldsymbol{a} + \boldsymbol{b} &= (a_x, a_y, a_z) + (b_x, b_y, b_z) \\ &= (a_x + b_x, a_y + b_y, a_z + b_z)\end{aligned}$$ [M2.4, P2.2]

vector triple product

is: a product of three vectors which may be written as $\boldsymbol{a} \times (\boldsymbol{b} \times \boldsymbol{c}.)$. Note that the brackets are essential here since $\boldsymbol{a} \times (\boldsymbol{b} \times \boldsymbol{c}.)$ is generally quite different from $(\boldsymbol{a} \times \boldsymbol{b}) \times \boldsymbol{c}$. [M2.7]

can be evaluated: from the identity $\boldsymbol{a} \times (\boldsymbol{b} \times \boldsymbol{c}) = \boldsymbol{b}(\boldsymbol{a} \cdot \boldsymbol{c}) - \boldsymbol{c}(\boldsymbol{a} \cdot \boldsymbol{b})$ (the bac cab rule). [M2.7]

See scalar product in the Maths handbook.

velocity

See instantaneous velocity.

velocity selector

is: a device for selecting charged particles of a particular velocity, using a combination of an electric field and a magnetic field. [P4.3]

velocity-time graph

for: a particle moving with linear motion along the *x*-axis

is: a graph of the velocity v_x of the particle against time t [M5.1]

conventionally is plotted: with velocity vertical and time horizontal. [M4.1, P2.1]

has: as its gradient at any particular time, the instantaneous acceleration at that time. [M4.1, P2.1]

vertex (of a parabola)

informally is: the turning point of a parabola, or similar curve. [M1.3]

more formally, is: the point on a parabola that is closest to the directrix. [M1.3, M2.3]

See pole.

See also vertices (of a polygon) for a different meaning.

vertex (of a lens)

is: the point at which the optical axis intersects the curved surface of a lens. [P6.3]

is synonymous: with pole (of a lens). [P6.3]

vertical asymptote

See asymptote.

vertically opposite

describes: the pairs of equal angles that are produced opposite one another when two straight lines intersect. [M2.1]

vertices (of a polygon)

are: the corners of the polygon (the singular of vertices is vertex). [M2.1]

vibration

is synonymous: with oscillation.

vibrational kinetic energy

is usually: kinetic energy associated with the oscillatory motion of parts of a system relative to its centre of mass.

should usually be: distinguished from any translational kinetic energy arising from the motion of the centre of mass of an oscillator.

is exemplified by: the vibrational kinetic energy of the molecules in a diatomic ideal gas.

virtual image

is: an image from which light rays appear to diverge. [P6.2]

may be created: by reflection at a mirror or refraction at a lens. [P6.3]

cannot be formed: on a screen, since rays do not actually pass through it but only appear to have come from it. [P6.2, P6.3]

virtual object

is located: at the place towards which rays converge, before they are deflected by some interposed component such as a lens or a mirror. [P6.3]

viscosity

is: the phenomenon of internal friction in a fluid, leading to energy dissipation and stresses due to distortion of fluid elements. [P2.3, P7.6]

arises microscopically: from the transport of molecular momentum between adjacent layers of fluid in relative motion. There is a net transport of momentum from regions of high momentum to regions of low momentum, this tends to reduce the momentum difference between the layers and therefore the relative motion. [P7.5]

is therefore: a transport process.

is also: an abbreviation for the coefficient of viscosity, which is a measure of the difficulty with which a fluid flows (higher for treacle and motor oil than for water). [P5.2]

viscous

means: pertaining to viscosity.

viscous forces

are: forces arising from viscosity. [P5.2]

are a result: at the molecular level, of the transfer of momentum from one 'layer' in a moving fluid to another, or to a body moving through the fluid. [P5.2]

See Stokes' law.

visible light

is: light that can be detected by the human eye.

visible spectrum

is: the range of different colours of light that make up white light. [P6.2]

can be seen: by allowing a beam of white light to undergo dispersion in a glass prism, or some similar optical device. [P6.2]

broadly corresponds: to different wavelengths in the approximate range 750 nm to 400 nm though the perception of colour by humans involves other factors. The different colours normally recognized (in the English language) within the visible spectrum (in order of decreasing wavelength) are red, orange, yellow, green, blue, indigo and violet. [P6.2]

visual acuity

is: the ability of the eye to resolve detail in an object, or to distinguish two objects which are or appear to be narrowly separated. [P6.4]

is also: the resolution limit of the eye. [P6.4]

vitreous humour

is: the clear jelly-like fluid which fills the eye and helps it to keep its shape. [P6.4]

vitrification

is: a process for reducing the volume of high-level radioactive waste by converting it into solid glass blocks. [P9.3]

volt, V

is: the SI unit of electrical potential and potential difference.

is defined: by $1\,V = 1\,W\,A^{-1}$, so it is the potential difference between two points on a conductor such that a current of 1 ampere flowing between them dissipates a power of 1 watt. [P3.3, P4.1]

voltage

See electric potential, electrical potential difference.   [P4.1]

voltage difference

See electric potential difference.

voltage divider

is: a circuit which produces an output voltage that is a predetermined fraction of the voltage from a voltage generator. [P4.1]

in its simplest form, consists: of two resistors connected in series with the supply voltage, with the output being the voltage across one of the resistors. [P4.1]

voltage divider equation

is: an equation which describes the voltage across a resistor that is in series with another resistor and a voltage generator. [P4.1]

voltage drop

between: two points

is: the magnitude of the difference in electrical potential between the two points

voltage generator

is: a device that acts as a source of potential difference, e.g. a battery or a dynamo. [P5.5]

voltmeter

is: a device for measuring voltage difference. [P4.1]

is connected: to the two points between which the potential difference. is to be measured, and therefore is in parallel with one or more circuit components. [P4.1]

ideally has: a very high resistance, so that it does not affect the circuit to which it is connected. [P4.1]

volume

is: the quantity of space occupied by a body, object or sample. [P7.2]

has as its SI unit: m^3.

volume of revolution

is: the volume of a solid of revolution. [M5.4]

volume strain

is: the strain $\varepsilon_{\rm vol}$ within a material caused by the application of a volume stress (i.e. a pressure). [P7.6]

is given: by $\varepsilon_{\rm vol} = -\Delta V/V$, where ΔV is the increase in volume of the material and V is the original volume, (note the minus sign, and that ΔV is negative if the volume decreases). [P7.6]

therefore is: positive if the volume decreases. [P7.6]

volume stress

is: the stress σ_{vol} resulting from a change in the compressional forces acting perpendicularly and uniformly over all surfaces of a body (i.e. a change in pressure ΔP). [P7.6]

is given: by the increase in the inward perpendicular component of the force divided by the area over which it acts, so $\sigma_{vol} = \Delta P$. [P7.6]

therefore is: positive if the applied pressure increases. [P7.6]

is also called: a uniform stress. [P7.6]

watt, W

is: the SI unit of power.

is defined: by $1\,\mathrm{W} = 1\,\mathrm{J\,s^{-1}}$, so it is the power that transfers energy at the rate of 1 joule per second. [P2.4, P4.1]

wave

is: a 'disturbance' that varies with position and time, and satisfies a wave equation. [P5.6]

is exemplified: by a sinusoidal transverse displacement wave $y = A\sin[kx - \omega t + \phi]$ that satisfies the one-dimensional wave equation; where A is the amplitude, $k = 2\pi/\lambda$ is the angular wavenumber, $\omega = 2\pi/T$ is the angular frequency, and f is the phase constant. [P5.6]

See travelling wave and standing wave.

See also periodic wave and solitary wave.

wave equation

is: the linear partial differential equation which describes the motion of any travelling wave. [M6.4, P5.6]

in its simplest form, is given: by

$$\frac{\partial^2 \Psi}{\partial x^2} - \frac{1}{v^2}\frac{\partial^2 \Psi}{\partial t^2} = 0$$

where $v^2 = \omega^2/k^2$, in which form it is usually referred to as 'the' wave equation. [M6.4, P5.6]

wave form

of: a wave at a given position

is: a representation of the disturbance that the wave causes at the given position over a given time. If the disturbance that constitutes the wave is defined by a function $f(x, t)$, then the wave form at the point $x = x_1$ may be represented by the graph of $y = f(x_1, t)$. [M6.4, P5.6]

wave group

is: the result of combining several different waves with slightly different frequencies (usually via the principle of superposition). [P5.6, P10.4]

generally has: in a system that exhibits dispersion, an envelope that travels at a group speed that is different from the phase speed of the individual waves that make up the group. [P5.6, P10.4]

See also wave packet.

wave mechanics

See quantum mechanics.

wave model of light

is: a highly successful mathematical model of light that accounts for many optical phenomena in terms of classical electromagnetic waves. [P6.2]

is unable: to account for certain aspects of the behaviour of light particularly its interaction with matter; these are now explained in terms of quantum theory. [P6.2]

wave packet

is: the 'disturbance' that results from the superposition of many different waves, usually with different amplitudes and slightly different wavelengths and/or frequencies. [P10.2, P10.4]

can be used: in quantum mechanics to represent the wavefunction of a localized particle. [P10.2, P10.4]

See also wave group.

wave profile

is: the 'shape' of a wave at any given time. If the disturbance that constitutes the wave is defined by a function $f(x, t)$ then the wave profile at a given time $t = t_1$ may be represented by the graph of the function $y = f(x, t_1)$. [M6.4, P5.6]

wave train

is: a finite part of a wave that is sufficiently large to encompass several wavelengths. [P5.6]

wave vector

is: a generalization of the scalar angular wavenumber to a vector quantity which characterizes waves propagating in two- or three-dimensions. [P5.6]

has magnitude: equal to $2\pi/\lambda$. [P5.6]

has direction: parallel to the direction of propagation. [P5.6]

usually is denoted: by the symbol $\boldsymbol{k}$. [P5.6]

more properly is referred to: as the angular wave vector, but this term is almost never used in practice. [P5.6]

is also referred to: as the propagation vector.

wave/particle duality

is: the assertion, in quantum physics, that some systems (e.g. photons, electrons, atoms) may exhibit either wave-like or particle-like behaviour, according to circumstance. [P10.1]

wavefront

of: a wave

is: a line (in two-dimensions) or a surface (in three-dimensions) that passes only through points at which the phase of a wave has the same value. It is a surface of constant phase. [P5.6, P6.1, P6.2]

at any point, is always: at right angles to the direction of propagation of the wave. [P5.6]

wavefunction

of: a physical system

in: quantum mechanics

is: a mathematical function that describes the quantum state of the system and specifies its quantum mechanical behaviour. [P10.3]

always corresponds: to a particular quantum state. [P8.3]

is: a complex quantity, $\Psi(x, t)$, which depends on position and time. [M6.4, P10.3, P10.4, P11.1]

contains: all the information we can know about the system. [M6.4, P10.3, P10.4, P11.1]

is exemplified: by the stationary state solutions of the time-dependent Schrödinger equation, which are the wavefunctions corresponding to states of definite energy. [M6.4, P10.3, P10.4, P11.1]

See also spatial wavefunction and temporal wavefunction.

wavelength

is: the distance λ between any two adjacent equivalent points of a (spatially) periodic wave. [M6.4, P5.6, P5.7]

is exemplified: in the case of a sinusoidal wave, by the distance between adjacent wave crests at a given time. [M6.4, P5.6, P5.7]

more colloquially, is: the distance from one peak to the next or, equivalently, from one trough to the next. [P6.1]

wavenumber

is: the number of spatial cycles of a wave per unit length. [P5.6, P10.2]

is equal: to the reciprocal of the wavelength: $\sigma = 1/\lambda$. [P5.6, P10.2]

as a term, is also widely used: to describe the quantity $k = 2\pi/\lambda$, which is more properly referred to as the angular wavenumber. [P5.6, P10.2]

weak interaction

is: the fundamental interaction that is ultimately responsible for radioactive β-decay.

has nothing to do: with weak bonds (van der Waals bonds). [P9.2]

weber, Wb

is: the SI unit of magnetic flux.

is defined by: $1\,\mathrm{Wb} = 1\,\mathrm{T\,m^2}$, so it is the magnetic flux through an area of 1 (metre) squared placed perpendicular to a uniform magnetic field of strength 1 tesla. [P4.4]

weight

is: a vector quantity. [M2.4]

is: the gravitational force exerted on an object by the Earth (or the Moon or some other massive body). [M2.4, P2.3, P2.6]

has direction: from the centre of mass of the object towards the centre of the Earth. Near the surface of the Earth, the weight of an object acts vertically downwards. [P2.3, P3.2]

has magnitude: given by the product of the object's mass and g the magnitude of the acceleration due to gravity on Earth. [P2.3, P3.2]

more strictly, is: the resultant gravitational force exerted on the object by all other objects in the Universe. [P3.1]

weightlessness

is experienced: by astronauts in orbiting vehicles, and parachutists in early free fall (no air resistance), because they are not being supported by any reaction force. [P3.2]

is: somewhat of a misnomer, since they still have weight. What they don't have is any reaction force against their weight. [P3.2]

white light

is: a specific mix of the various colours of light belonging to the visible spectrum, such that the overall effect is similar to that of ordinary daylight. [P6.2]

more strictly, is: in terms of the wave model of light, a mixture of waves of different wavelengths, with the amplitude of each wave such that the combined effect of their superposition is similar to that of daylight. [P6.2]

can be simulated visually: by the combination of just a few wavelengths (e.g. red, green and blue, as in a colour television). [P6.2]

but in physics, is strictly: light with a continuous emission spectrum, containing a continuous distribution of wavelengths over the entire visible spectrum. Such a spectrum is produced by a hot object (e.g. the Sun) with a surface temperature of about 5800 K. [P8.2]

can be dispersed: by a diffraction grating or a prism into all the colours of the rainbow. [P8.2]

work

is: energy transferred between a system and its environment by any means that does not directly involve temperature differences (i.e. by any means other than heat transfer). [P7.3, P7.4]

is exemplified: by the (mechanical) work $\boldsymbol{F} \cdot \boldsymbol{s}$ done by a constant force $\boldsymbol{F}$ acting over a displacement $\boldsymbol{s}$. [P2.4, P7.3, P7.4]

can be determined: if the force varies as its point of application moves along a given path, as a limit of a sum (i.e. a line integral) $\int_A^B \boldsymbol{F} \cdot d\boldsymbol{s} = \lim_{\Delta s \to 0} \sum \boldsymbol{F} \cdot \Delta\boldsymbol{s}$.

[M2.6]

has as its SI unit: the joule (J), where $1\,\mathrm{J} = 1\,\mathrm{N\,m} = 1\,\mathrm{kg\,m^2\,s^{-2}}$. [P2.5]

See also first law of thermodynamics.

work done

See work.

work function

of: a material, usually a metal

is: the **minimum** energy required to remove electrons from the material. Thus when electromagnetic radiation of frequency f (i.e. of energy hf) impinges on the material, the **maximum** kinetic energy of the ejected electrons will be given by:

$E = hf - \phi$ [P10.1]

See threshold frequency.

work-energy theorem

states: that when a single resultant force does work on a system, the kinetic energy of the system increases by an amount which is equal to the work done on the system. [P2.4]

x-axis

generally is: an axis of a graph showing values of a variable x. [P1.3]

as a term, is often used: to describe the horizontal axis of any graph, irrespective of the quantity actually being plotted on that axis. [P1.3]

is also: one axis of a Cartesian coordinate system.

X-rays

are: a form of electromagnetic radiation, characterized by wavelengths in the range between those of γ-rays (gamma-rays) and ultraviolet radiation (i.e. in the approximate range 0.5 nm to 100 nm).

See electromagnetic spectrum.

X-ray diffraction

is: the diffraction of X-rays by a regular array of atoms (as in a crystal). [P7.1]

results in: a diffraction pattern with sharp local maxima of intensity in directions determined by Bragg's law. [P7.1]

y-axis

generally is: an axis of a graph showing values of a variable y. [P1.3]

as a term, is often used: to describe the vertical axis of any graph, irrespective of the quantity actually being plotted on that axis. [P1.3]

is also: one axis of a Cartesian coordinate system.

y-intercept

See intercept.

yield point

is: the maximum stress that a solid can sustain without undergoing permanent deformation. [P7.6]

therefore is: the point on the loading curve which marks the end of the elastic region and the start of the plastic region. [P7.6]

is also called: the elastic limit. [P7.6]

Young's experiment

is: a classic demonstration of interference. [P6.1]

has as input: light of wavelength λ normally incident on two narrow parallel slits which are separated by a small distance d. [P6.1]

has as output: an interference pattern consisting of alternate bright and dark bands (interference fringes) on a distant screen. The bright fringes of order n are observed at angles θ_n from the straight-through direction given by

$$n\lambda = d\sin\theta_n$$

where $n = 0, \pm 1, \pm 2...$ [P6.1]

Young's modulus

of: a material

is: an elastic modulus, conventionally denoted Y (or exceptionally E), that is particularly relevant to thin rods or narrow rails. [P5.7, P7.6]

is defined: as the ratio of the applied tensile stress $\sigma_{\rm T}$ to the resulting tensile strain $\varepsilon_{\rm T}$:

$$Y = \frac{\sigma_{\rm T}}{\varepsilon_{\rm T}} = \frac{F/A}{\Delta l/l}$$ [P7.6]

where F/A is the magnitude of the perpendicular force per unit cross-sectional area, and $\Delta l/l$ is the fractional change in length. [P5.7]

has as its SI unit: $\rm N\,m^{-2}$ or Pa. [P5.7]

z-axis

generally is: an axis of a graph showing values of a variable *z*. [M2.2, P1.3]

as a term, is often used: to describe the third axis of any three-dimensional graph, irrespective of the quantity actually being plotted on that axis. [M2.2, P1.3]

is also: one axis of a Cartesian coordinate system.

Zeeman effect

is: the splitting of atomic energy levels and their associated spectral lines in the presence of a magnetic field. [P8.3]

is caused: by the magnetic field, which removes the degeneracy of energy levels of electron subshells. [P8.3]

zero point energy

is: the minimum kinetic energy for a confined particle, resulting from the wave nature of matter as described by quantum mechanics. [P10.4, P11.2]

is exemplified: by the ground state energy of a particle in a one-dimensional box, which is inversely proportional to the square of the length of the box. [P10.4, P11.2]

zero vector

is: a vector of zero magnitude that may be associated with any direction. [M2.4, M2.5]

is denoted: as $\mathbf{0}$ and plays a similar role to the number zero in the set of real numbers. [M2.4, M2.5]

is defined: by the requirement that $\boldsymbol{a} + \mathbf{0} = \boldsymbol{a}$ for any vector $\boldsymbol{a}$. [P2.2]

is included: in the set of all vectors, to ensure that the rules of vector algebra are consistent. [M2.4, M2.5]

zeros (of a function)

are: the values of the independent variables of the function, for which the function is zero. [M1.4]

also are: the roots of the equation $f(x) = 0$. [M1.4]

zeroth law of thermodynamics

states: that if two of three separate systems can in separate experiments be shown to be in mutual thermal equilibrium with the third, then they will be found to be in mutual thermal equilibrium with each other. [P7.2]

sounds: so obvious as to make it unnecessary to glorify it with a name. In fact, as its name suggests, it was a bit of an afterthought. [P7.2]

but logically is: very important, because it leads directly to the concept of temperature and the setting up of temperature scales and the various procedures for temperature measurement. [P7.2]