A

absolute uncertainty
Absolute uncertainty is a direct statement of the confidence limits of a reading, for example the statement that an electric current is 2.32 A implies an absolute uncertainty of ±0.01 A.
[Chapter 2]

absolute zero
Absolute temperature is the extrapolated temperature at which the pressure and volume of an ideal gas are predicted to be zero. It is the temperature at which the molecules have no random kinetic energy.
[Chapter 11]

absorption spectra
When a continuous spectrum of light is shone through an element in gaseous form, specific frequencies are preferentially absorbed (the frequencies of the element’s emission spectrum). The resulting spectrum (i.e. most frequencies with some specific ones missing) is known as the element’s absorption spectrum.
[Chapter 16]

acceleration
The acceleration of an object is its rate of change of velocity in a particular direction. It is a vector quantity.
[Chapter 3]

accuracy
An accurate reading is one with a small systematic error, i.e. the measured value is close to the true value.
[Chapter 2]
**activity**
The activity of a radioactive source is the rate of decay, i.e. the number of nuclei that decay in unit time.

\[
A = -\frac{\Delta N}{\Delta t}
\]

- \( A \) is the activity of the source (rate of decay) in Bq,
- \( \Delta N \) is the change in number of nuclei available to decay,
- \( \Delta t \) is the time taken in s.

The activity also changes exponentially:

\[
A = \lambda N = \lambda N_0 e^{-\lambda t}
\]

- \( A \) is the activity of the source (rate of decay) in Bq,
- \( N \) is the number of atoms in the sample still available to decay,
- \( N_0 \) is the original number of atoms in the sample,
- \( e \) is the number 2.718,
- \( \lambda \) is the decay constant in s\(^{-1}\),
- \( t \) is the time taken in s.

[Chapter 17]

**adiabatic**
An adiabatic change is one that takes place without any energy transfer to or from the gas.

[Chapter 11]

**albedo**
Some of the radiation received by a planet is reflected back into space. The albedo of a surface is the ratio of the power that is scattered (reflected) from the surface compared to total incident power received. It is a ratio and has no units.

\[
albedo = \frac{\text{total scattered power}}{\text{total incident power}}
\]

Powers are measured in W (alternatively power per unit area may be appropriate: (W m\(^{-2}\))

[Chapter 19]

**alpha particles**
Alpha particles are helium nuclei (two protons and two neutrons) emitted as a result of a decaying unstable nucleus.

[Chapter 16]

**amplitude**
The amplitude in simple harmonic motion (SHM) is the maximum displacement from the mean position during one oscillation. The amplitude \( A(x_0) \) of a wave is the maximum displacement from the mean.

[Chapters 7 and 8]

**analogue**
An analogue store of information encodes the information using a range of possible values.

[Chapter 24]

**analysers**
An analyser is a polarizer used to detect polarized light.

[Chapter 9]
**angular frequency**

When an object is undergoing SHM an important constant for the motion is its angular frequency \( \omega \). It is related to the time period and is a measure of the rate of the motion.

\[
\omega = \frac{2\pi}{T}
\]

\( \omega \) is angular frequency in rad s\(^{-1} \)

\( T \) is the time period in s.

[Chapter 7]

**angular velocity**

When an object is undergoing uniform circular motion at constant speed, the angular velocity is the rate of change of angle (as measured between the radius from the centre of the circle to the object and one of the axes).

\[
\omega = \frac{\Delta \theta}{\Delta t}
\]

\( \omega \) is angular velocity in rad s\(^{-1} \)

\( \Delta \theta \) is the change in angle in rad

\( \Delta t \) is the time taken in s

[Chapter 4]

**antinodes**

An antinode is a point on a standing wave that has the maximum amplitude.

[Chapter 9]

**artificial (induced) transmutation**

Artificial (induced) transmutation can take place when a nucleus is bombarded by a nucleon, an alpha particle, or other small nucleus. The target nucleus first ‘captures’ the incoming object and then an emission or decay takes place. For example, when nitrogen is bombarded by alpha particles, oxygen can be created with the emission of a proton:

\[
\frac{4}{2}^4\alpha + ^{14}\text{N} \rightarrow ^{16}\text{O} + ^{1}\text{p}.
\]

[Chapter 16]

**Avogadro constant**

This is the number of atoms in 0.012 kg of carbon-12 (\(^{12}\text{C} \)), i.e. in one mol. It is \( 6.02 \times 10^{23} \).

[Chapter 10]

**average (speed, velocity, acceleration)**

The average value over a period of time is the steady (constant) value that would have given the same result.

[Chapter 3]

**B**

**Bainbridge mass spectrometer**

A mass spectrometer allows the isotopic content of a sample to be measured. Ions of the same velocity but different mass will follow different circular paths when moving in a constant perpendicular magnetic field.

[Chapter 17]
beta\textsuperscript{–} decay
β\textsuperscript{–} decay is the emission of a fast-moving electron when a neutron decays into a proton, a β\textsuperscript{–} particle, and an antineutrino.
[Chapter 17]

beta\textsuperscript{+} decay
β\textsuperscript{+} decay is the emission of a fast-moving positive electron (positron) when a proton decays into a neutron, a β\textsuperscript{+} particle, and a neutrino.
[Chapter 17]

beta particles
Beta particles are fast-moving electrons or positrons that have been emitted as a result of a decaying unstable nucleus.
[Chapter 16]

binary numbers
Binary numbers are numbers to the base of 2. The only possible digits are 1 or 0.
[Chapter 24]

binding energy
The binding energy is the amount of energy that is released when a nucleus is assembled from its component nucleons. It is also the amount of energy that needs to be added in order to separate a nucleus into its individual nucleons.
[Chapter 16]

binding energy per nucleon
The binding energy per nucleon is the total binding energy for a particular nucleus divided by the number of nucleons contained in the nucleus. A larger binding energy per nucleon represents a nucleus that is more energetically stable.
[Chapter 16]

bit
A bit is a single binary digit, which will be either 1 or 0.
[Chapter 24]

black-body radiation
At a given temperature, different surfaces will radiate different amounts of EM radiation. The maximum theoretical amount that can be emitted from any surface is known as black-body radiation (a ‘perfect’ emitter is also a ‘perfect’ absorber and a black surface is the best absorber). The characteristics of black-body radiation are mathematically described by the Stefan–Boltzmann law and Wien’s law.
[Chapter 19]

boiling
Boiling is the process by which the molecules of a liquid spontaneous change from the liquid phase into the gas phase throughout the body of the liquid. This takes place at the liquid’s boiling point.
[Chapter 10]
Brewster's law
At one particular angle of incidence, EM reflecting from surface will be completely plane polarized. This happens when:

\[ n = \tan \phi \]

\( n \) is the refractive index between the two media involved, 
\( \phi \) is the incident angle for completely plane-polarized reflections – the polarizing angle – in ° or rad. [Chapter 9]

C

capacitance
A device that can store charge is called a capacitor. The capacitance is defined as:

\[ c = \frac{q}{V} \]

\( C \) is the capacitance in F, 
\( q \) is the charge stored in C, 
\( V \) is the p.d. across the capacitor in V. [Chapter 24]

carbon dioxide capture and storage
Carbon dioxide is emitted by fossil fuel power stations. A traditional power station just releases it into the environment, potentially increasing the enhanced greenhouse effect. Carbon capture and storage is the general term for preventing its release into the environment. [Chapter 21]

charge, types of
There are two types of charge – positive and negative. [Chapter 13]

charge-coupled devices (CCDs)
CCDs are used for image capture across a large range of the EM spectrum. Examples include digital cameras, video cameras, telescopes (including the Hubble telescope), and medical X-ray imaging. [Chapter 24]

charged particle scattering experiments
On the atomic scale, charge particles (e.g. alpha particles) can be scattered by nuclei as a result of the Coulomb repulsion between the charge particle and the nucleus. Energy conservation can be used to determine the closest-approach distances and thus estimate the upper limit for the size of a nucleus. [Chapter 16]

coefficient of volume expansion
The coefficient of volume expansion is the fractional change in volume per degree change in temperature. Its units are K\(^{-1}\). [Chapter 20]

combined heating and power systems (CHP)
Combined heating and power systems (CHP) improve the overall efficiency of electricity generation by utilizing the thermal energy generated to, for example, supply hot water for local domestic supply. [Chapter 21]
components of vectors
When a vector is resolved into different directions, the results are called the components of the original vector. If a vector \( \mathbf{A} \) makes an angle \( \theta \) with the horizontal, then the horizontal component \( A_H \) and vertical component \( A_V \) are given by:
\[
A_H = A \cos \theta \\
A_V = A \sin \theta
\]
[Chapter 3]

compressions
Compressions are the points on a longitudinal wave where all the particles are ‘bunched together’ (high pressure).
[Chapter 8]

conductors, properties of
A material that allows the flow of charge through it is called an electrical conductor.
[Chapter 13]

conservation of charge, law of
The law of conservation of charge states that the total charge of an isolated system of interacting particles always remains the same.
[Chapter 13]

conservation of linear momentum, law of
The law of conservation of linear momentum states that the total linear momentum of a system of interacting particles remains constant provided there is no resultant external force (i.e. the system is isolated).
[Chapter 4]

constant acceleration equation
Provided that the acceleration \( a \) of an object moving along a straight line is constant, then the following equations can be used:
\[
s = \frac{u + v}{2} \, t \\
s = ut + \frac{1}{2} at^2 \\
v^2 = u^2 + 2as
\]
where
\( s \) is the distance travelled in m,
\( u \) is the initial velocity in ms\(^{-1}\),
\( v \) is the final velocity in ms\(^{-1}\),
\( t \) is the time taken in s,
\( a \) is the acceleration in ms\(^{-2}\).
[Chapter 3]

constructive interference
When two identical waves meet at a point and the waves are exactly in phase, the resulting wave has twice the amplitude of either of the original waves.
[Chapter 8]

control rods
Control rods are movable rods that readily absorb neutrons. They can be introduced or removed from the reaction chamber in order to control the chain reaction.
[Chapter 23]
controlled nuclear fission
Controlled nuclear fission takes place in power stations. Excess neutrons are absorbed to ensure that the nuclear reactions take place at a constant rate. [Chapter 23]

correlation and cause
Two measurements are correlated if there is a statistical/mathematical link between the measurements. Two measurements are said to have a causal link if one measurement is related to a factor that causes a change in the second measurement. The fact that two measurements are correlated does not imply that there is a causal link between the two. [Chapter 15]

Coulomb’s law
Coulomb’s law states that the electrostatic force between any two point charges masses is proportional the product of the charges and inversely proportional to the square of their distance of separation.
There are two equivalent ways of expressing this mathematically
\[
F = k \frac{q_1 q_2}{r^2}
\]
or
\[
F = k \frac{q_1 q_2}{4 \pi \varepsilon_0 r^2}
\]
F is electrostatic force between the two point charges in N,
\(q_1\) is the charge of one of the point charges masses in C,
\(q_2\) is the charge of the other point charge in C,
r is the separation of the point charges in m,
k is the Coulomb constant (= \(8.99 \times 10^9\) N m\(^2\) C\(^{-2}\)),
\(\varepsilon_0\) is the permittivity of free space (= \(8.85 \times 10^{-12}\) C\(^2\) N\(^{-1}\) m\(^{-2}\)). [Chapter 13]

centripetal acceleration (CPA)
Centripetal acceleration is the acceleration of an object moving at constant speed in uniform circular motion. Even though the speed is constant, the direction of the object’s velocity is changing all the time, so the object must be accelerating. The resultant force that must be causing this acceleration is called the centripetal force (CPF). The direction of the centripetal acceleration and the CPF is always in towards the centre of the circle.
\[
a = \frac{v^2}{r} = \frac{4 \pi^2 r}{T^2}
\]
a is the centripetal acceleration in m s\(^{-2}\),
v is the speed in m s\(^{-1}\),
r is the radius of the circle in m,
T is the orbital time period in s. [Chapter 4]

conservation of energy, principle of
Energy cannot be created or destroyed – it just changes form from one type of energy to another. [Chapter 5]

crest
The crest is the peak of a transverse wave (the point of maximum positive displacement). [Chapter 8]
damping
Damping involves a force that is always in the opposite direction to the direction of motion of the oscillating particle and is a dissipative force (i.e. the oscillating particle loses energy).
[Chapter 7]

de Broglie equation
de Broglie hypothesized that all moving particles have a ‘matter wave’ associated with them. The same equation can be used to calculate the momentum associated with photons.
The de Broglie equation is:
\[ p = \frac{h}{\lambda} \]
\( p \) is the momentum in kg m s\(^{-1}\),
\( h \) is Planck’s constant (6.63 \( \times \) 10\(^{-34}\) J s)
\( \lambda \) is the wavelength in m.
[Chapter 17]

decay constant and half-life
The relationship between decay constant and half-life is:
\[ T = \frac{\ln 2}{\frac{\lambda}{2}} \]
\( T \) is the half-life in s,
\( \frac{\ln 2}{\lambda} \) is the decay constant in s\(^{-1}\).
[Chapter 17]

decimal numbers
Decimal numbers are numbers to the base of 10. The possible digits are 0, 1, 2, 3, 4, 5, 6, 7, 8, or 9 (i.e. ‘normal numbers’).
[Chapter 24]

degraded energy
In any process that involves energy transformations, the energy that is transferred to the surroundings (thermal energy) is no longer available to perform useful work. This unavailable energy is known as degraded energy.
[Chapter 18]

derived unit
A unit that is defined in terms of fundamental units, e.g. m s\(^{-1}\), N, etc.
[Chapter 2]

destructive interference
When two identical waves meet at a point and the waves are exactly (180°) out of phase, the resulting wave has zero amplitude – the two waves cancel each other.
[Chapter 8]
**diffraction**

Diffraction is the phenomenon of the spreading of a wave after an aperture or obstacle. It is the process by which wave energy is received in the geometric shadow region after an obstacle or gap. For diffraction to be noticeable, the size of the obstacle or gap needs to be the same order of magnitude as the wavelength. Examples include the spreading of sound around corners or the bending of water waves around a harbour wall.

[Chapter 8]

**diffraction equation for angle of first minimum at a circular aperture**

The equation for the angle of the first minimum of the diffraction pattern resulting from a circular aperture is:

\[ \theta = 1.22 \frac{\lambda}{b} \]

\( \theta \) is angle between the ‘straight through’ direction and the first minimum in rad,
\( \lambda \) is the wavelength of light in m,
\( b \) is the slit diameter in m.

[Chapter 9]

**diffraction equation for angle of first minimum at a single slit**

The equation for the angle of the first minimum of the diffraction pattern resulting from a single slit is:

\[ \theta = \frac{\lambda}{b} \]

\( \theta \) is angle between the ‘straight through’ direction and the first minimum in rad,
\( \lambda \) is the wavelength of light in m,
\( b \) is the slit width in m.

[Chapter 9]

**digital**

A digital store of information encodes the information using only two possible values (1 or 0).

[Chapter 24]

**direction of the force on a current in a magnetic field**

The direction of the force on a current in a magnetic field is perpendicular to the plane that contains the current and the magnetic field. If the current is in the \( x \) direction and the magnetic field is in the \( y \) direction of a standard graph plotted on a piece of paper, then the force will be out of the paper, in the \( z \) direction, as described by Flemming’s left-hand rule.

[Chapter 13]

**direction of the force on a moving charge in a magnetic field**

The direction of force on a moving charge is perpendicular to the plane that contains the direction vector of the charge and the magnetic field. If the charge is moving in the \( x \) direction, and the magnetic field is in the \( y \) direction of a standard graph plotted on a piece of paper, then the force will be out of the paper, in the \( z \) direction, as described by Flemming’s left-hand rule.

[Chapter 13]

**direction of magnetic field**

The direction of a magnetic field at any point is defined as the direction of the force that would be felt by the north pole of a small test magnet if placed at that point.

[Chapter 13]
**displacement**
The displacement of an object is the distance from the origin in a particular direction. Displacement is a vector quantity.
For an object undergoing SHM, the instantaneous displacement is the distance between the mean (average or equilibrium) position and its actual position in a given direction.
For particles displaced by a travelling wave, the instantaneous displacement $x$ is the distance between the mean (average or equilibrium) position and its actual position in a given direction.
[Chapters 3, 7, and 8]

**Doppler approximation for EM waves**
The change in frequency of EM waves as a result of the relative motion between source and observer is given by the following approximation:

$$\Delta f = \frac{v}{c} f$$

$\Delta f$ is the difference between observed frequency and emitted frequency of EM radiation in Hz, $v$ is the relative velocity of source and observer in m s$^{-1}$, $f$ is the frequency of EM radiation as measured by the source in Hz, $c$ is the speed of EM waves in m s$^{-1}$.
[Chapter 9]

**Doppler effect**
The Doppler effect is a change in frequency of a wave that results from either a moving source of waves, a moving observer, or both. Examples include the changing pitch of a car’s horn as it moves past an observer, or the redshift of light emitted from galaxies that are receding from us. Applications include blood-flow measurements and measurements of vehicle speed. Both situations involve a ‘double Doppler’ effect as waves are reflected from moving objects.
[Chapter 8]

**Doppler effect with a moving source**
The Doppler equations for the change of sound frequency are:

**Moving source:**

$$f' = f \left( \frac{v}{v \pm u_s} \right)$$

NB + if the source is moving away from the observer, – if the source is moving towards the observer.

**Moving observer:**

$$f' = f \left( \frac{v \pm u_o}{v} \right)$$

NB + if the observer is moving towards the source, – if the observer is moving away from the source.

$f$ is the frequency of sound measured when there is no relative motion in Hz, $f'$ is the observed frequency of sound measured when there is relative motion in Hz, $v$ is the speed of sound in still air in m s$^{-1}$, $u_s$ is the speed of source in m s$^{-1}$, $u_o$ is the speed of observer in m s$^{-1}$.
[Chapter 9]
efficiency
Approximate overall energy efficiencies for different types of power station are:
Coal 35%
Gas 45%
Oil 38%
Each of these could theoretically be increased by an additional 7 percentage points at maximum.
[Chapter 18]

efficiency
Efficiency is the ratio of useful energy to the total energy transferred, often expressed as a percentage. An equivalent definition is the ratio of useful power out to total power in. It is a scalar quantity without units.
[Chapter 5]

Einstein's equation
Einstein's explanation of the photoelectric effect is:
\[ hf = \phi + E_{max} \]
\( f \) is the frequency of incident EM radiation in Hz,
\( h \) is Planck's constant \((6.63 \times 10^{-34} \text{ J s})\),
\( \phi \) is the work function of the surface in J,
\( E_{max} \) is the maximum kinetic energy of the emitted photoelectrons.
[Chapter 17]

Einstein's mass–energy equivalence relationship
Einstein's mass–energy equivalence relationship allows us to calculate the energy that is in the form of mass:
\[ E = mc^2 \]
\( E \) is the energy equivalent in J,
\( m \) is the mass in kg,
\( c \) is the speed of light \((3 \times 10^8 \text{ m s}^{-1})\).
An alternative unit of mass can be used to make the calculations very straightforward. If \( E \) is the energy equivalent in MeV and \( m \) is the mass in MeV \( c^{-2} \), the number used for energy and mass will be the same.
[Chapter 16]

elastic collisions
Elastic collisions are collisions in which no energy is gained or lost. Collisions between atoms and molecules can be taken to be elastic.
[Chapter 4]

electric field strength
The electric field strength at any point is defined as the force per unit charge on a test point charge placed at that location. It is a vector quantity.
\[ E = \frac{F}{q} \]
\( E \) is the electric field strength in \( \text{N C}^{-1} \),
\( F \) is the electric force on a test point charge in N,
\( q \) is the charge of the test point charge in C
[Chapter 13]
**electric field strength vs electrical potential gradient**

The formula relating Electric field strength to electric potential gradient is:

\[ E = -\frac{\Delta V}{\Delta x} \]

- \( E \) is the electric field strength in N C\(^{-1}\),
- \( \Delta V \) is the difference in electric potential in V,
- \( \Delta x \) is the distance over which the difference in electric potential has been measured in m.

[Chapter 14]

**electric potential**

The electrical potential difference (p.d.) between two points is the difference in electrical energy per unit test charge between the points.

The electrical potential at a point is electrical energy per unit test charge at that point. The zero of electrical potential is taken to be at infinity so electrical potential is equal to the work done per unit charge in bringing a small point test charge from infinity to that point. It is a scalar quantity.

\[ \Delta V = \frac{\Delta E_p}{q} \]

- \( \Delta V \) is the difference in electrical potential (the pd) between two points in J C\(^{-1}\),
- \( \Delta E_p \) is the difference in electrical potential energy when a small test charge moves between the two points in J,
- \( q \) is the charge of the test point charge.

[Chapter 14]

**electric potential due to a point charge, formula for**

There are two equivalent ways of expressing the formula for electric potential due to a point charge. They are:

\[ V = \frac{kq}{r} \]

or

\[ V = \frac{q}{4\pi\varepsilon_0 r} \]

- \( V \) is the electric potential at a fixed distance away from a point charge in V,
- \( q \) is the charge producing the electric potential in C,
- \( r \) is the fixed distance away from the point charge in m,
- \( k \) is the Coulomb constant (= 8.99 \times 10^9 \text{ N m}^2 \text{ C}^{-2})
- \( \varepsilon_0 \) is the permittivity of free space (= 8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}).

[Chapter 14]

**electric current**

Current is the rate of flow of charge:

\[ I = \frac{\Delta q}{\Delta t} \]

- \( \Delta q \) is the charge flowed in C,
- \( \Delta t \) is the time taken in s,
- \( I \) is the current in A.

[Chapter 12]
**electric potential difference**
The electric potential difference (p.d.) between two points is the energy difference per unit charge:

\[ \Delta V = \frac{\Delta E}{q} \]

\( \Delta V \) is the pd between two points measured in J C\(^{-1}\) or V,
\( \Delta E \) is the difference in electrical energy between the two points measured in J – this is equal to the work done in moving the charge \( q \) between the two points,
\( q \) is the charge in C.

[Chapter 11]

**electric power dissipation**
The electric power dissipation is a device is the product of the p.d. across it and the current flowing through it. This can be expressed in several ways:

\[ P = VI = I^2R = \frac{V^2}{R} \]

\( P \) is the power dissipated in W,
\( V \) is the pd in V,
\( I \) is the current in A,
\( R \) is the resistance in \( \Omega \).

[Chapter 12]

**electromagnetic (EM) waves**
All electromagnetic waves travel with the same speed in a vacuum (free space). Typical approximate wavelengths are:
- gamma rays: \( 10^{-15} - 10^{-10} \) m
- X-ray: \( 10^{-10} - 10^{-8} \) m
- UV: \( 10^{-8} - 10^{-7} \) m
- visible: 400 nm – 700 nm
- IR: \( 10^{-6} - 10^{-3} \) m
- microwave: \( 10^{-3} - 10^0 \) m
- radio: \( 10^0 - 10^5 \) m

[Chapter 8]

**‘electron in a box’ model**
The ‘electron in a box’ model pictures an electron as being confined to a fixed region in one dimension – the size of the box. Analyses of possible standing-wave patterns for the electron’s wavefunction result in only discrete energy levels being available. The available energy levels are:

\[ E_k = \frac{n^2\hbar^2}{8m_eL^2} \]

\( E_k \) is a possible kinetic energy for the electron in J,
\( n \) is an integer (1, 2, 3, 4 etc.),
\( \hbar \) is Planck’s constant (6.63 \( \times \) \( 10^{-34} \) J s),
\( m_e \) is the mass of the electron (9.11 \( \times \) \( 10^{-31} \) kg),
\( L \) is the size of the box in m.

[Chapter 17]

**electronvolt**
The electronvolt is a unit of energy used on the atomic scale. It is the energy gained or lost by one electron as it moves through a p.d. of 1 volt.

\[ 1 \text{ eV} = 1.6 \times 10^{-19} \text{ J} \]

[Chapter 14]
**e.m.f.**
The total energy dissipated per unit charge around a circuit is called the e.m.f., \( \varepsilon \). This is a historical term which stands for electromotive force.
[Chapter 12]

**e.m.f. induced in a straight conductor moving in a magnetic field, formula for**
The e.m.f. induced in a straight conductor moving perpendicular to a magnetic field is given by:
\[
\varepsilon = Bvl
\]
\( \varepsilon \) is the induced e.m.f. in V,
\( B \) is the magnetic field strength in T (Wb m\(^{-2}\)),
\( v \) is the velocity of the conductor in m s\(^{-1}\),
\( l \) is the length of the conductor in m.
[Chapter 15]

**emission spectra**
When an element is hot enough (given enough energy) it emits light. Analysis of this light shows that each element only emits specific frequencies. These specific frequencies form the element's emission spectrum.
[Chapter 16]

**emissivity**
The emissivity, \( \varepsilon \), is the ratio of power radiated per unit area by a given surface to the power radiated per unit area by a black body at the same temperature. It has no units.
\[
P = \varepsilon \sigma AT^4
\]
\( P \) is the total power radiated by a surface in W,
\( \varepsilon \) is the emissivity of the surface (no units),
\( \sigma \) is the Stefan–Boltzmann constant (5.67 \( \times \) 10\(^{-8}\) W m\(^{-2}\) K\(^{-4}\)),
\( A \) is the surface area in m\(^{-2}\),
\( T \) is the absolute temperature of the black body in K.
[Chapter 19]

**energy**
The energy transferred to a body is the work that has been done on the body. If a body has an energy \( E \), then the amount of work that the body is capable of doing is \( E \). Energy is a scalar quantity.
[Chapter 5]

**energy balance climate model**
If the incoming radiation intensity to a planet's surface and its outgoing radiation intensity are not equal, then the planet's temperature will vary as given by:
\[
\Delta T = \frac{(I_{\text{in}} - I_{\text{out}}) \Delta t}{C_s}
\]
\( \Delta T \) is the temperature change of the planet in K,
\( I_{\text{in}} \) is the incoming radiation intensity in W m\(^{-2}\),
\( I_{\text{out}} \) is the outgoing radiation intensity in W m\(^{-2}\),
\( \Delta t \) is the time taken in s,
\( C_s \) is the surface heat capacity in J m\(^{-2}\) K\(^{-1}\).
[Chapter 19]
energy density
Energy density is defined as the energy liberated per unit mass of fuel consumed. It is measured in J kg\(^{-1}\).
[Chapter 18]

energy gained by a charge accelerated by a p.d.
The final velocity of a charge that is accelerated from rest by a p.d. is given by:
\[ V_e = \frac{1}{2} mv^2 \]
\( V \) is the accelerating pd measured in V,
\( e \) is the charge being accelerated in C,
\( m \) is the mass being accelerated in kg,
\( v \) is the final velocity of the charge in m s\(^{-1}\).
[Chapter 14]

enhanced greenhouse effect
An enhanced greenhouse effect is an increase in the greenhouse effect caused by human activities. One possible effect of an enhanced greenhouse effect is a rise in mean sea level. International efforts to reduce the enhanced greenhouse effect include the Intergovernmental Panel on Climate Change (IPCC), the Kyoto protocol (an amendment to the United Nations Framework Convention on Climate Change) and the Asia–Pacific Partnership on Clean Development and Climate (APPCDC).
[Chapter 20]

entropy
Entropy is a system property that expresses the degree of disorder in the system.
[Chapter 11]

equation of state for ideal gas
The equation of state for ideal gas is:
\[ PV = nRT \]
\( P \) is the pressure of the gas in Pa,
\( V \) is the volume of the gas in m\(^3\),
\( n \) is the number of moles of the gas in mol,
\( R \) is the molar gas constant (8.31 J K\(^{-1}\) mol\(^{-1}\)),
\( T \) is the absolute temperature of the gas in K.
[Chapter 11]

equipotential surfaces and electrical field lines
Electric field lines are always at right angles to equipotential surfaces.
[Chapter 14]

equipotential surfaces and gravitational field lines
Gravitational field lines are always at right angles to equipotential surfaces.
[Chapter 14]

error bar
An error bar on a graph indicates the absolute uncertainty associated with the point being plotted. They can be included in the x direction, the y direction, or both.
[Chapter 2]
escape speed from a planet

The escape speed from a planet is the speed that an object needs to have at the surface of the planet in order to have enough kinetic energy to escape the gravitational attraction of the planet. Assuming that the planet is isolated from all other planets, the formula for the escape speed is:

\[ v_{\text{escape}} = \sqrt{\frac{2GM}{R_p}} \]

\( v_{\text{escape}} \) is the escape speed from the planet in m s\(^{-1}\),
\( G \) is the universal gravitational constant (= 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} ),
\( M \) is the mass of the planet in kg,
\( R_p \) is the radius of the planet in m.

[Chapter 14]

evaporation

Evaporation is the process by which individual molecules (the faster-moving ones) leave the surface of a liquid and enter the gas phase. Evaporation only takes place at the surface of the liquid at temperatures below the liquid’s boiling point.

[Chapter 10]

F

Faraday’s law and Lenz’s law

Faraday’s law states that the magnitude of an induced e.m.f. is proportional to the rate of change of flux linkage.
Lenz’s law states that the direction of the induced e.m.f. is such that if an induced current were able to flow, it would oppose the change which caused it.
Both laws are combined in the following relationship:

\[ \varepsilon = -N \frac{\Delta \phi}{\Delta t} \]

\( \varepsilon \) is the induced e.m.f. in V,
\( N \) is the number of turns of the coil,
\( \Delta \phi \) is the change of magnetic flux in Wb,
\( \Delta t \) is the time taken in s,
The negative sign is Lenz’s law.

[Chapter 15]

first law of thermodynamics (principle of energy conservation)

The first law of thermodynamics is the same as the principle of energy conservation:

\[ Q = \Delta U + W \]

\( Q \) is the energy transferred to the gas from its surroundings in J,
\( \Delta U \) is the increase in the internal energy of the gas in J,
\( W \) is the work done by the gas in J.

[Chapter 11]

forced oscillations

It is possible to force a system to oscillate at any frequency by subjecting it to a changing force at that frequency. Such oscillations are forced oscillations.

[Chapter 7]
**fractional uncertainty**
Fractional uncertainty is the ratio between the absolute uncertainty and the recorded value; for example, 2.32 A ± 0.01 A implies a fractional uncertainty of ±4.3 × 10^{-2}.
[Chapter 2]

**frequency**
The frequency \( f \) is the number of completed oscillations in a given period of time, SI unit: Hz (number of oscillations per second).
[Chapters 7 and 8]

**frequency vs period**
There is a connection between the frequency of SHM and its period:

\[
T = \frac{1}{f}
\]

\( T \) is the time period in s,
\( f \) is the frequency in Hz.
[Chapter 7]

**fuel enrichment**
Enrichment is the process by which the isotopic composition of a nuclear fuel is increased to make nuclear fissions more likely. Typically, uranium fuel rods are enriched to ensure that the percentage content of uranium-235 is increased.
[Chapter 23]

**fundamental unit**
A unit that is defined from first principles, i.e. kg, m, s, A, mol, or K.
[Chapter 2]

**fundamental units in SI system**
Six important fundamental SI units are kilogram (mass), metre (length), second (time), ampere (electric current), mole (amount of substance), and kelvin (absolute temperature).
[Chapter 2]

---

**G**

**gamma radiation**
Gamma radiation is photons of high-energy electromagnetic radiation emitted as a result of a nucleus changing from an excited state into a lower energy state.
[Chapter 16]

**gravitational field strength (\( g \)) at planet’s surface**
The magnitude of the gravitational field strength at the surface of a planet assuming that all its mass is concentrated at its centre is given by:

\[
g = G \frac{M}{r^2}
\]

\( g \) is the gravitational field strength at the surface of the planet in N m^{-1},
\( M \) is the mass of the planet in kg,
\( r \) is the radius of the planet in m,
\( G \) is the universal gravitational constant (≈ 6.67 × 10^{-11} N m^2 kg^{-2}).
[Chapter 13]
**gravitational field strength**
The gravitational field strength at any point is defined as the force per unit mass on a test point mass placed at that location. It is a vector quantity.

\[ g = \frac{F}{m} \]

- \( g \) is the gravitational field strength in N m\(^{-1}\)
- \( F \) is the gravitational force on a test point mass in N
- \( m \) is the mass of the test point mass in kg

[Chapter 13]

**gravitational field strength vs gravitational potential gradient**
The formula relating gravitational field strength to gravitational potential gradient is:

\[ g = \frac{\Delta V}{\Delta r} \]

- \( g \) is the gravitational field strength in N kg\(^{-1}\)
- \( \Delta V \) is the difference in gravitational potential in J kg\(^{-1}\)
- \( \Delta r \) is the distance over which the difference in gravitational potential has been measured in m.

[Chapter 14]

**gravitational potential**
The gravitational potential difference between two points is the difference in gravitational energy per unit test mass between the points.
The gravitational potential at a point is gravitational energy per unit test mass at that point. The zero of gravitational potential is taken to be at infinity so gravitational potential is equal to the work done per unit mass in bringing a small point test mass from infinity to that point. It is a scalar quantity.

\[ \Delta V = \frac{\Delta E_P}{m} \]

- \( \Delta V \) is the difference in gravitational potential between two points in J kg\(^{-1}\)
- \( \Delta E_P \) is the difference in gravitational potential energy when a small test mass moves between the two points in J
- \( m \) is the mass of the test point mass.

[Chapter 14]

**gravitational potential due to a point mass, formula for**
The formula for gravitational potential due to a point mass is:

\[ V = -\frac{Gm}{r} \]

- \( V \) is the gravitational potential at a fixed distance away from a point mass in J kg\(^{-1}\)
- \( G \) is the universal gravitational constant (= \( 6.67 \times 10^{-11} \) N m\(^2\) kg\(^{-2}\))
- \( m \) is the mass causing the gravitational potential in kg
- \( r \) is the fixed distance away from the mass in m.

[Chapter 14]
**gravitational potential energy**
Gravitational potential energy is energy that a body has as a result of its position in a gravitational field. It is a scalar quantity.
\[ \Delta E_p = mg\Delta h \]
\( \Delta E_p \) is the increase in gravitational potential energy when an object is lifted in a uniform gravitational field, measured in J,
m is the mass in kg,
g is the uniform gravitational field strength in N kg\(^{-1}\),
\( \Delta h \) is the increase in height of the object in m.
[Chapter 5]

**greenhouse effect**
The atmosphere is transparent to many frequencies of electromagnetic radiation. Much of the power received from the Sun is in the visible and ultraviolet regions. This causes the surface of the Earth to warm up and radiate in the infrared. Some of this infrared radiation is absorbed by gases in the atmosphere, causing the atmosphere to warm up, and re-radiated in all directions. The net effect is that the atmosphere and the surface of the Earth are warmed.
[Chapter 19]

**greenhouse gas**
The gases in the atmosphere that absorb infrared radiation are called greenhouse gases. The principle greenhouse gases are methane, water vapour, carbon dioxide and nitrous oxide. Ozone and chlorofluorocarbons (CFCs) also contribute to the greenhouse effect.
[Chapter 19]

**H**

**heat exchanger**
The heat exchanger allows the nuclear reactions to occur in a place that is sealed off from the rest of the environment. The reactions increase the temperature in the core. This thermal energy is transferred to heat water, and the steam that is produced turns the turbines.
[Chapter 23]

**Heisenberg uncertainty**
Heisenberg was able to show that conjugate quantities, position–momentum and time–energy, cannot be known precisely at the same time. The limits are given by his uncertainty principle:
\[ \Delta x \Delta p \geq \frac{h}{4\pi} \]
\[ \Delta E \Delta t \geq \frac{h}{3\pi} \]
\( \Delta x \) is the uncertainty in position in m,
\( \Delta p \) is the uncertainty in momentum in N s,
\( \Delta E \) is the uncertainty in energy in J,
\( \Delta t \) is the uncertainty in time in s,
h is Planck’s constant (6.63 × 10\(^{-34}\) J s).
[Chapter 17]
hybrid vehicles
Traditional vehicles run on petrol or diesel. An electric vehicle runs on batteries. A hybrid vehicle uses electric motors with a petrol engine as back-up to provide additional power when necessary. Sophisticated computerized systems switch from the electric motor to the petrol engine and back as required.
[Chapter 21]

hydroelectric schemes (lake storage, tidal water storage, pump storage)
Hydroelectric power stations use the gravitational potential energy of water to generate electrical energy. Lake storage allows water that has fallen as rain to collect in a reservoir that is as high as is feasible. This water is allowed to flow downhill. Tidal power stations trap water at high tides and release it during a low tide. Pump storage involves pumping water from a low reservoir to a high reservoir for later release downhill. Although less energy will be generated that went into pumping the water uphill, it still allows for a large-scale method of storing energy.
[Chapter 22]

ideal ammeter
A perfect ammeter has zero resistance. It is connected in series at the point where the current needs to be measured.
[Chapter 12]

ideal gas and real gas
An ideal gas is one that follows the equation of state for ideal gases for all values of pressure, volume and temperature. Ideal gases cannot be liquefied. Real gases show deviations from the equation of state for ideal gases. Real gas behaviour can approximate to ideal gas behaviour at low pressures.
[Chapter 11]

ideal gas, assumptions of
The assumptions of the kinetic model of an ideal gas are:
Newton’s laws apply to molecular behaviour.
There are no intermolecular forces (except in collisions).
The molecules are treated as points.
The molecules are in random motion.
The collisions between the molecules are elastic.
There is no time spent in collisions.
[Chapter 10]
ideal transformer (step-up and step-down)
An ideal transformer changes the voltage of an alternating current (AC) input without any loss of energy. If the output voltage (on the secondary) is greater than the input voltage (on the primary), it is known as a step-up transformer. If the output voltage (on the secondary) is less than the input voltage (on the primary), it is known as a step-down transformer.

The currents and voltages are related to the number of turns on the primary and the secondary:

\[
\frac{I_s}{I_p} = \frac{N_p}{N_s} = \frac{V_p}{V_s}
\]

- \(I_s\) is the current in the secondary coil in A,
- \(I_p\) is the current in the primary coil in A,
- \(V_p\) is the voltage across the primary coil in V,
- \(V_s\) is the voltage across the secondary coil in V,
- \(N_p\) is the number of turns in the primary coil,
- \(N_s\) is the number of turns in the secondary coil.

[Chapter 15]

ideal voltmeter
A perfect voltmeter has infinite resistance. It is connected in parallel between the two points where the p.d. needs to be measured.

[Chapter 12]

impulse
The impulse given to an object is the product of the resultant force acting on the object and the time for which this force acts. It is equal to change of momentum of the object. It is a vector quantity.

\[
\text{Impulse} = F \Delta t = m \Delta v
\]

- \(F\) is the resultant force in N,
- \(\Delta t\) is the time taken in s,
- \(m\) is the mass in kg,
- \(\Delta v\) is the change in velocity in m s\(^{-1}\).

[Chapter 4]

induction
An e.m.f. is induced in a conductor whenever there is relative motion between the conductor and a magnetic field i.e. whenever magnetic lines of flux are cut. Induction also takes place whenever there is a time-changing magnetic flux passing through a coil of wire.

[Chapter 15]

inelastic collisions
Inelastic collisions are collisions in which the objects involved in the collision lose energy (e.g. to thermal energy or to sound). All laboratory collisions are inelastic.

[Chapter 4]

instantaneous (speed, velocity, acceleration)
The instantaneous value is the value at one particular instant of time.

[Chapter 3]

insulators, properties of
A material that does not allows the flow of charge through it is called an electrical insulator.

[Chapter 13]
**intensity**

The intensity of a wave is the power per unit area that is received by the observer. It is related to the amplitude of the wave.

\[ I = \frac{p}{A} \]
\[ I \propto x_0^2 \]

- \( I \) is the intensity in W m\(^{-2}\),
- \( p \) is the power received in W,
- \( A \) is the area at right angles to the wave that receives the \( p \),
- \( x_0 \) is the amplitude of the wave; its units depend on the type of wave.

[Chapters 8 and 19]

**internal energy**

The internal energy of a substance is the total potential energy and random kinetic energy of the molecules of the substance.

[Chapter 10]

**internal resistance of a battery**

Some of the electrical energy generated by the chemical reactions inside a battery will be dissipated within the battery itself when a current flows. The internal resistance of a battery is the effective extra resistance that is added to a circuit by the battery.

\[ \varepsilon = I(R + r) \]

- \( \varepsilon \) is the e.m.f. of the battery in V,
- \( I \) is the current in A,
- \( R \) is the external resistance in \( \Omega \),
- \( r \) is the internal resistance of the battery in \( \Omega \).

[Chapter 12]

**isobaric**

An isobaric change is one that takes place at constant pressure.

[Chapter 11]

**isochoric (isovolumetric)**

An isochoric (isovolumetric) change is one that takes place at constant volume.

[Chapter 11]

**isothermal**

An isothermal change is one that takes place at constant temperature.

[Chapter 11]

**isotope**

Isotopes are nuclides that contain the same number of protons (and are thus the same element) but different numbers of neutrons.

[Chapter 16]

**K**

**Kelvin scale of temperature**

The Kelvin scale of temperature has the same unit step as the Celsius temperature scale, but the zero of the Kelvin scale is at absolute zero (i.e. 0 °C = 273 K; 100 °C = 373 K).

[Chapter 11]
**Kelvin vs Celsius scales of temperature**
The Kelvin and Celsius scales of temperature are related:
\[ T / K = t / ^\circ C + 273 \]
\( T \) is the temperature on the Kelvin scale in K,
\( t \) is the temperature on the Celsius scale in °C.
[Chapter 10]

**Kepler’s third law**
The cube of the average radius of orbit of a planet is proportional to the square of that planet’s orbital time period.
[Chapter 14]

**kinetic energy**
Kinetic energy is the energy that a body has as a result of its motion. It is a scalar quantity.
\[ E_k = \frac{1}{2} mv^2 \]
\( E_k \) is the kinetic energy in J,
\( m \) is the mass in kg,
\( v \) is the velocity in m s\(^{-1}\).
An object's kinetic energy is related to its momentum:
\[ E_k = \frac{p^2}{2m} \]
\( E_k \) is the kinetic energy in J,
\( p \) is the momentum in kg m s\(^{-1}\),
\( m \) is the mass in kg.
[Chapter 5]

**L**

**least-significant bit**
The least-significant bit is the bit representing \( 2^0 \) and is the furthest on the right when the binary number is written down.
[Chapter 24]

**Lenz’s law**
See Faraday’s law and Lenz’s law.

**light dependent resistors**
A light dependent resistor (LDR) is a device whose resistance depends on the amount of light shining on its surface. An increase in light causes a decrease in resistance.
[Chapter 12]

**linear momentum**
Linear momentum is the product of an object’s mass and its velocity. It is a vector quantity.
\[ F = mv \]
\( F \) is the resultant force in N,
\( m \) is the mass in kg,
\( v \) is the velocity in m s\(^{-1}\).
[Chapter 4]
longitudinal waves
Longitudinal waves involve oscillations that are in the same direction as the direction of energy transfer. Sound waves are longitudinal.
[Chapter 8]

M

magnetic fields
Moving charges give rise to magnetic fields
[Chapter 13]
magnetic field, magnitude of
The magnitude of the magnetic field strength $B$ can be defined either in terms of the force on a moving charge or the force on a current. These definitions are equivalent.

*Moving charge:*
$$ F = qvB \sin \theta $$
$F$ is the magnetic force on the moving charge in N,
$q$ is the value of the charge that is moving in C,
$v$ is the velocity of the moving charge in m s$^{-1}$,
$B$ is the magnitude of the magnetic field strength in T (or Wb m$^{-2}$),
$\theta$ is the angle between the field and the charge’s velocity in °.

*Current:*
$$ F = BIL \sin \theta $$
$F$ is the magnetic force on the current in N,
$I$ is the current in A,
$L$ is the length of the wire feeling the force in m,
$B$ is the magnitude of the magnetic field strength in T (or Wb m$^{-2}$),
$\theta$ is the angle between the field and the current direction in °.
[Chapter 13]
magnetic flux
The magnetic flux passing through an area is defined as:
$$ \phi = BA \cos \theta $$
$\phi$ is the magnetic flux in Wb,
$B$ is the magnetic field strength in T(Wb m$^{-2}$),
$A$ is the area under consideration in m$^2$,
$\theta$ is the angle between the magnetic field and the normal to the surface.
[Chapter 15]
magnetic flux linkage
If the amount of flux passing through one turn of a coil is $\phi$, then the total magnetic flux linkage with all $N$ turns of the coil is $N\phi$. Its units are Wb.
[Chapter 15]
magnification
The magnification is the ratio of the length of the image on the CCD to the length of the object.
[Chapter 24]
**Malus' law**
The relationship between incident and transmitted intensities as a result of an analyser is:
\[ I = I_0 \cos^2 \theta \]

\( I \) is the intensity of the transmitted light in W m\(^{-2}\),
\( I_0 \) is the intensity of the incident light in W m\(^{-2}\),
\( \theta \) is the angle between the plane of vibration and the analyser's preferred direction.
[Chapter 9]

**mass defect**
The mass of any nucleus is less than the mass of the component nucleons that go to make it up. The difference between the mass of a nucleus and the masses of its component nucleons is called the mass defect.
[Chapter 16]

**Millikan's experiment**
Millikan's photoelectric experiment verified Einstein's interpretation of the effect:
\[ hf = hf_0 + eV \]

\( h \) is Planck's constant (6.63 \( \times \) 10\(^{-34}\) J s),
\( f \) is the frequency of incident EM radiation in Hz,
\( f_0 \) is the threshold frequency of incident EM radiation in Hz; below this frequency, no electrons are emitted,
\( e \) is the charge on an electron (1.6 \( \times \) 10\(^{-19}\) C),
\( V \) is the stopping potential in V – the minimum reverse potential that just prevents a photocurrent from being established.
[Chapter 17]

**moderator**
The moderator in a nuclear reactor is there to slow down emitted neutrons. Collisions between the fast-moving neutrons and the nuclei of the moderator slow them down and allow further nuclear reactions to take place.
[Chapter 23]

**molar mass**
The mass of one mole of a substance is called the molar mass. If an element has a certain mass number, \( A \), then the molar mass will be \( A \) grams.
[Chapter 10]

**mole**
The mole is the basic SI unit for amount of substance. One mole of any substance is equal to the amount of that substance that contains the same number of atoms as 0.012 kg of carbon-12 (\(^{12}\)C). When writing the unit is (slightly) shortened to mol.
[Chapter 10]

**most-significant bit**
The most-significant bit is the bit representing the highest power of 2 and is the furthest on the left when the binary number is written down.
[Chapter 24]
**N**

**natural frequency**
If a system is temporarily displaced from its equilibrium position, it will oscillate at its natural frequency of vibration.
[Chapter 7]

**neutrino, existence of**
The energy spectra in $\beta$ decay (both $\beta^+$ and $\beta^-$) are continuous (the $\beta$ particles are observed to have a range of possible energies). The neutrino was postulated to account for these spectra. The hypothesis being that in addition to the observed $\beta$ particles there was another unobserved particle that was sharing the energy of the decay with the $\beta$ particle.
[Chapter 17]

**neutron number, $N$**
The neutron number, $N$, is the total number of neutrons in a given nuclide.
[Chapter 16]

**Newton’s first law**
An object continues in uniform motion in a straight line or at rest unless a resultant external force acts. (‘No resultant force $\Rightarrow$ no acceleration.’)
[Chapter 4]

**Newton’s second law**
The rate of change of momentum of a body is proportional to the resultant force acting on the body.
The following two formulae are both statements of Newton’s second law:
1. $F = ma$
   $F$ is the resultant force in N,
   $m$ is the mass in kg,
   $a$ is the acceleration in m s$^{-2}$.
The direction of the acceleration is equal to the direction of the resultant force.

2. $F = \frac{\Delta p}{\Delta t}$
   $F$ is the resultant force in N,
   $\Delta p$ is the change in momentum in kg m s$^{-1}$,
   $\Delta t$ is the time taken in s.
The direction of the change of momentum is equal to the direction of the resultant force.
[Chapter 4]

**Newton’s third law**
When two bodies A and B interact, the force that A exerts on B is equal and opposite to the force that B exerts on A. These two forces are the same type of force but act on different objects.
(‘For every action there is an equal and opposite reaction.’)
[Chapter 4]
Newton’s universal law of gravitation

Newton’s universal law of gravitation states that the gravitational attraction between any two point masses is proportional to the product of the masses and inversely proportional to the square of their distance of separation.

\[ F = G \frac{m_1 m_2}{r^2} \]

- \( F \) is the gravitational force of attraction between the two point masses in N,
- \( m_1 \) is the mass of one of the point masses in kg,
- \( m_2 \) is the mass of the other point masses in kg,
- \( r \) is the separation of the point masses in m,
- \( G \) is the universal gravitational constant (\( \approx 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \)).

[Chapter 13]

nodes

A node is a point on a standing wave that is never moves – its amplitude is always zero.

[Chapter 9]

non-Ohmic conductors

Non-Ohmic conductors are conductors that do not obey Ohm’s law; for example, a filament lamp. The graph of p.d. vs. current is not a straight line.

[Chapter 12]

non-renewable energy sources

Non-renewable energy sources are those that can be used up and eventually run out.

[Chapter 18]

nuclear fission

Nuclear fission is a nuclear reaction in which large nuclei are induced to break up into small nuclei and release energy in the process.

[Chapter 16]

nuclear fusion

Nuclear fusion is a nuclear reaction in which small nuclei are induced to join together into larger nuclei and energy is released in the process. Nuclear fusion is the main source of the Sun’s energy

[Chapter 16]

nuclear model

A simple nuclear model of the atom consists of a tiny central nucleus containing all the mass and all the positive charge. The nucleus is made up of protons and neutrons. Negative electrons are kept in orbit around the nucleus as a result of the electrostatic attraction between the electrons and the nucleus. Although this simple model helps explain many atomic properties there are reasons why things cannot be this simple.

[Chapter 16]

nucleon

A nucleon is the collective name for protons and neutrons – the particles that make up the nucleus.

[Chapter 16]

nucleon number, \( A \)

The nucleon number, \( A \) is the total number of protons and neutrons in a given nuclide.

[Chapter 16]

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**nuclide**
A nuclide is the name given to a particular species of atom – one whose nucleus contains a specific numbers of protons and neutrons.
[Chapter 16]

**O**

**Ohmic conductors**
Ohmic conductors are conductors that obey Ohm’s law for a wide range of p.d. and currents. The graph of p.d. vs. current is a straight line through the origin.
[Chapter 12]

**Ohm’s law**
Ohm’s law states that the current flowing through a piece of metal is proportional to the p.d. across it, provided the temperature remains constant.

\[ V \propto I \text{ (if } T \text{ constant)} \]

- \( V \) is the pd in V,
- \( I \) is the current in A,
- \( T \) is the temperature in °C.
[Chapter 12]

**optically active substance**
An optically active substance is one that rotates the plane of polarization of light that passes through it.
[Chapter 9]

**orbital motion**
When a satellite is in orbit around a mass, it is the gravitational attraction between the satellite and the mass that provides the centripetal force for circular motion.
[Chapter 14]

**oscillating water column ocean–wave energy converter**
An oscillating water column ocean–wave energy converter uses the kinetic energy of waves to generate electrical energy.
[Chapter 22]

**P**

**path difference**
Interference often takes place at a given point in space as a result of there being two different routes for the wave energy to travel from source to that point. The path difference is the difference in the total lengths of the two routes. It is often expressed in terms of the wavelength of the wave. If the waves began their journeys in phase then for constructive interference,

\[ \text{path difference} = n\lambda \]

whereas for destructive interference,

\[ \text{path difference} = \left(n + \frac{1}{2}\right)\lambda. \]

\( \lambda \) is the wavelength in m,
\( n \) is an integer (0, 1, 2, 3, 4, etc).
[Chapter 8]
**percentage uncertainty**
Percentage uncertainty is the ratio between the absolute uncertainty and the recorded value expressed as a percentage. For example, 2.32 A ± 0.01 A implies a fractional uncertainty of ±0.4%.
[Chapter 2]

**period**
The period \( T \) is the time taken for one complete oscillation. In other words, it is the time taken for one complete wave to pass any given point. SI unit: s.
[Chapters 7 and 8]

**phase difference**
The phase difference, \( \phi \), is a measure of how ‘in step’ different particles are. If moving together, they are in phase. \( \phi \) is an angle measured in either degrees (°) or radians (rad). \( 2\pi \text{ rad (360°)} \) is one complete cycle, so \( \pi \text{ rad (180°)} \) is completely out of phase by half a cycle. A phase difference of \( \pi/2 \text{ rad (90°)} \) is a quarter of a cycle.
[Chapters 7 and 8]

**photoelectric effect**
The photoelectric effect describes the phenomena by which electrons are emitted from the surface of some metals when the surface is illuminated with electromagnetic radiation (typically UV).
[Chapter 17]

**photons**
Light energy is not emitted as a continuous wave but comes in small ‘packets’ of energy. Each ‘packet’ is called a photon. The energy of one photon depends on the frequency of light being considered.
[Chapter 16]

**photon energy**
The energy of a single photon is given by:
\[
E = hf
\]
\( E \) is the energy of the photon in J,
\( f \) is the frequency of EM radiation in Hz,
\( h \) is Planck’s constant \((6.63 \times 10^{-34} \text{ J s})\)
[Chapter 17]

**photovoltaic cell**
A photovoltaic cell (solar cell) converts a portion of the radiated energy that falls on its surface directly into a p.d. using a piece of semiconducting material; for example, a solar-powered calculator.
[Chapter 22]

**pixel**
The surface of a charge-coupled device is divided up into a large number of small areas called pixels. Each pixel represents one section of the final image.
[Chapter 24]
**polarized light**
Electromagnetic (EM) radiation consists of oscillating electric and magnetic fields that are always perpendicular to one another. The plane of vibration is defined to be the plane that contains the electric field and the direction of propagation. Unpolarized light will contain a mixture of many possible planes of vibration whereas polarized light has a fixed plane of polarization. When EM waves reflect from a surface, the reflected ray will tend to be polarized parallel to the surface.
[Chapter 8]

**polarizer**
A polarizer is any device that produces plane-polarized light from an unpolarized beam.
[Chapter 9]

**potential divider**
A potential divider circuit uses two resistors to ‘divide up’ the p.d. supplied by a battery. Each resistor will take a given share which depends on the value of its resistance and the total resistance of the circuit. For the p.d. supplied by a potential divider circuit to be unaffected by the connection of additional components, the extra components added must have a large resistance when compared to the total resistance of the potential divider. A variable potential divider circuit is called a potentiometer.
[Chapter 12]

**power**
Power is the rate of doing work, which is the same as the rate of transferring energy. Power is a scalar quantity.

\[ P = \frac{\Delta W}{\Delta t} \]

*P* is the power in W,
*\( \Delta W \)* is the work done (energy transferred) in J,
*\( \Delta t \)* is the time taken in s.

When an object is being moved at constant velocity by a force, the power developed by the force is:

\[ P = Fv \]

*P* is the power developed in W,
*F* is the constant force in N,
*v* is the velocity in m s\(^{-1}\).
[Chapter 5]

**power for a wind generator**
The following equation calculates the total power (in W) available to a wind turbine as a result of the kinetic energy of wind. In practice, all this power cannot be harnessed.

\[ \text{power} = \frac{1}{2} A \rho v^3 \]

*\( A \)* is the area ‘swept out’ by the blades of the turbine in m\(^2\),
*\( \rho \)* is the density of the air in kg m\(^{-3}\),
*\( v \)* is the velocity of the air in m s\(^{-1}\).
[Chapter 22]
power per unit length
The following equation calculates the total power per unit length (in W m\(^{-1}\)) available as a result of the kinetic energy of waves. This assumes a rectangular profile for the waves and in practice all this power cannot be harnessed.

\[
power \text{ per unit length} = \frac{1}{2} A^2 \rho g v
\]

\(A\) is the amplitude of the waves in m,
\(\rho\) is the density of the water in kg m\(^{-3}\),
\(g\) is the gravitational field strength (10 N kg\(^{-1}\)),
\(v\) is the velocity of the wave in m s\(^{-1}\).

[Chapter 22]

precision
A precise reading is one with a small random error, i.e. the uncertainty is small.
[Chapter 2]

pressure
Pressure is the force per unit normal area (i.e. the area at right angles to the force).

\[P = \frac{F}{A}\]

\(P\) is the pressure in N m\(^{-2}\) (Pa),
\(F\) is the force in N,
\(A\) is the area at right angles to the force in m\(^2\).

[Chapter 10]

progressive (travelling) waves, energy transfer by
Progressive (travelling) waves transfer energy. This transfer is achieved by oscillations of the medium through which the wave travels but there is no net motion of the medium. In many examples the oscillations of the particles are simple harmonic.

[Chapter 8]

projectile motion
The vertical and the horizontal components of a projectile’s velocity in a uniform field are independent of one another.

[Chapter 6]

proton number, \(Z\)
The proton number, \(Z\), is the total number of protons in a given nuclide
[Chapter 16]

Q
quantum efficiency
The quantum efficiency of a pixel is the ratio of the number of photoelectrons emitted to the number of photons incident on the pixel. Improving the quantum efficiency of a CCD would allow images of dimmer sources of light to be recorded, but the quality will not be affected.

[Chapter 24]
radioactive decay
Radioactive decay is the spontaneous emission of ionizing radiations (alpha, beta, or gamma) from an unstable nucleus. It is a random and spontaneous process. As a result, the rate of decay decreases exponentially with time.
[Chapter 16]

radioactive decay law (as exponential)
Radioactive decay is exponential
\[ N = N_0 e^{-\lambda t} \]
\( N \) is the number of atoms in the sample still available to decay,
\( N_0 \) is the original number of atoms in the sample,
e is the number 2.718,
\( \lambda \) is the decay constant in s\(^{-1}\); this constant is the probability of decay of a nucleus per unit time,
\( t \) is the time taken in s,
\( \lambda \) and \( t \) can take other units providing they are complementary (e.g. \( \lambda \) in hr\(^{-1}\) \( t \) in hr).
[Chapter 17]

radioactive half-life
The time taken for the number of nuclei that are available to decay to halve to its original value is known as the half-life.
Equivalent definitions are possible in terms of other quantities, as the result of exponential decay is that many quantities (number of nuclei available to decay, activity, rate of decay etc.) reduce to half their initial value in a fixed constant time known as the half-life.
[Chapter 16]

random error
Random errors are errors in experimental readings resulting from, for example, the readability of the instrument, the observer being less than perfect, or effects of a change in the surroundings. They can be reduced by repeating readings.
[Chapter 2]

range of magnitude of distances
Distances range in magnitude from \( 10^{-15} \) m (sub-nuclear particles) to \( 10^{+25} \) m (extent of the visible universe)
[Chapter 2]

range of magnitude of masses
Masses range in magnitude from \( 10^{-30} \) kg (an electron) to \( 10^{+50} \) m (mass of the visible universe)
[Chapter 2]

range of magnitude of times
Times range in magnitude from \( 10^{-23} \) s (time light takes to cross a nucleus) to \( 10^{+18} \) s (age of the universe).
[Chapter 2]

rarefaction
Rarefactions are the points on a longitudinal wave where all the particles are ‘far apart’ (low pressure).
[Chapter 8]
Rayleigh criterion
Two sources will be just resolvable if the first minimum of the diffraction pattern from one source is located on top of the central maximum of the diffraction pattern from the other source.
[Chapter 9]

reflection at a boundary
A wave reflected at the boundary between two media stays in its original medium. Its direction of travel is such that the incident angle (the angle between the incident ray and the normal) and the reflected angle (the angle between the reflected ray and the normal) are equal.
[Chapter 8]

refractive index
The refractive index of a medium is the ratio between the speed of the wave in a vacuum and the speed of the wave in the medium.
[Chapter 8]

renewable energy sources
Renewable energy sources are those that cannot be used up.
[Chapter 18]

resistance
Resistance is defined as the ratio between p.d. and current:
\[ R = \frac{V}{I} \]
\( V \) is the p.d. in V,
\( I \) is the current in A,
\( R \) is the resistance in \( \Omega \).
[Chapter 12]

resistance and power (peak and average) vs peak values
The equations relating resistance and power (peak and average) to peak values are as follows:
\[ R = \frac{V_0}{I_0} = \frac{V_{\text{rms}}}{I_{\text{rms}}} \]
\[ P_{\text{max}} = I_0 V_0 \]
\[ P_{\text{av}} = \frac{1}{2} I_0 V_0 \]
\( R \) is the resistance in \( \Omega \),
\( P_{\text{max}} \) is the maximum power dissipation in the resistor in W,
\( P_{\text{av}} \) is the average power dissipation in the resistor in W,
\( I_{\text{rms}} \) is the rms value of the current in A,
\( I_0 \) is the peak value of the current in A,
\( V_{\text{rms}} \) is the rms value of the voltage in V,
\( V_0 \) is the peak value of the voltage in V.
[Chapter 15]

resistivity equation
The resistance of a sample of material is calculated using:
\[ R = \frac{\rho L}{A} \]
\( \rho \) is the resistivity in \( \Omega \) m,
\( L \) is the length in m,
\( A \) is the cross-sectional area in \( m^2 \),
\( R \) is the resistance in \( \Omega \).[Chapter 12]
resistors in series and parallel
The total resistance of a combination of resistors depends on whether they are connected in series or in parallel.
Series: 
\[ R = R_1 + R_2 + \ldots \]
Parallel: 
\[ R = \frac{1}{R_1} + \frac{1}{R_2} + \ldots \]
\( R \) is the total resistance of the circuit in \( \Omega \), 
\( R_1, R_2, \) etc. are the resistances in the circuit in \( \Omega \).
[Chapter 12]

resolution
Two points on an object may just be resolved on a CCD if the images of the points are at least two pixels apart.
[Chapter 24]

resolution of vectors
Any vector can be split into two or more different vectors that would add together to give the same effect. This process is called resolution, and the vector is said to have been resolved in different directions. It is often useful to resolve vectors in two mutually perpendicular (and thus independent) directions (e.g. horizontally and vertically).
[Chapter 3]

resonance
Resonance occurs when a system is subject to an oscillating force at exactly the same frequency as the natural frequency of oscillation of the system. The amplitude of the oscillations at resonance will be large.
[Chapter 7]

resultant force
The single force that would have the same affect on an object as a combination of forces is called the resultant force.
[Chapter 4]

root mean squared (r.m.s.) value
The r.m.s. value of an alternating current (or voltage) is that value of the direct current (or voltage) that dissipates power in a resistor at the same rate. The r.m.s. value is also known as the rating.
[Chapter 15]

rotating coil
The e.m.f. induced in a coil rotating within a uniform magnetic field is sinusoidal if the rotation is at constant speed. Changing the speed of rotation will change the maximum value of e.m.f. induced and the frequency of the alternating e.m.f.
[Chapter 15]
Sankey diagrams
Sankey diagrams are pictorial representations of energy conversions. An arrow (left to right) represents the energy changes taking place. The width of the arrow represents the power or energy involved at a given stage. Degraded energy is shown with an arrow up or down. [Chapter 18]

Scalars
Scalars are quantities that only have magnitude, for example mass, time, distance, speed, etc. [Chapter 3]

Schrödinger model of hydrogen atom
The Schrödinger model of the hydrogen atom assumes that electrons in the atom may be described by wavefunctions. The electron has an undefined position, but the square of the amplitude of the wavefunction gives the probability of finding the electron at a particular point. [Chapter 17]

Second law of thermodynamics
The second law of thermodynamics implies that thermal energy cannot spontaneously transfer from a region of low temperature to a region of high temperature. An equivalent statement is that the total entropy of the universe must always stay the same or increase. [Chapter 11]

Sensors
Electrical circuit can be designed to respond to external physical inputs if they include devices whose resistance varies as a result of external factors. Such devices are called sensors. Examples include light-dependent resistors, thermistors, and strain gauges. [Chapter 12]

Simple harmonic motion (SHM)
Simple harmonic motion (SHM) is motion where the acceleration of an object is always directed towards a fixed point and is proportional to its displacement from that fixed point. Mathematically:

\[ a = -\omega^2 x \]

The negative sign indicates that the acceleration and the displacement are in opposite directions.

- \( a \) is the acceleration in m s\(^{-2}\),
- \( x \) is the displacement in m,
- \( \omega^2 \) is a constant in rad\(^2\) s\(^{-2}\),
- \( \omega \) is angular frequency in rad s\(^{-1}\). [Chapter 7]
simple harmonic motion (SHM) energy equations
When undergoing SHM, an object’s energy will interchange between kinetic energy and potential as given by:

\[ E_p = \frac{1}{2} mw^2 x^2 \]
\[ E_k = \frac{1}{2} mw^2 (x_0^2 - x^2) \]
\[ E_t = E_{k(max)} = \frac{1}{2} mw^2 x_0^2 \]

\( E_p \) is the potential energy in J,
\( E_k \) is the kinetic energy in J,
\( E_t \) is the total energy in J,
\( E_{k(max)} \) is the maximum kinetic energy in J,
\( m \) is the mass in kg,
\( \omega \) is the angular frequency in rad s\(^{-1}\),
\( x \) is the displacement in m,
\( x_0 \) is the maximum displacement (the amplitude) in m.

[Chapter 7]

simple harmonic motion (SHM) equations for displacement and velocity
Two matching pairs of equations specify how the displacement and the velocity vary with time for an object undergoing SHM. An alternative equation allows for the velocity to be calculated from the displacement.

Either
\[ x = x_0 \sin \omega t \quad \text{and} \quad v = v_0 \cos \omega t \]
or
\[ x = x_0 \cos \omega t \quad \text{and} \quad v = -v_0 \sin \omega t \]

and
\[ v = \pm w \sqrt{(x_0^2 - x^2)} \]

\( x \) is the displacement in m,
\( x_0 \) is the maximum displacement (the amplitude) in m,
\( \omega \) is angular frequency in rad s\(^{-1}\),
\( t \) is the time in s.

[Chapter 7]

sinusoidal currents and voltages (peak and r.m.s.)
The relationship between peak and r.m.s. values for sinusoidal currents and voltages is given by the following relationships:

\[ I_{\text{rms}} = \frac{l_0}{\sqrt{2}} \]
\[ V_{\text{rms}} = \frac{V_0}{\sqrt{2}} \]

\( I_{\text{rms}} \) is the r.m.s. value of the current in A,
\( l_0 \) is the peak value of the current in A,
\( V_{\text{rms}} \) is the r.m.s. value of the voltage in V,
\( V_0 \) is the peak value of the voltage in V.

[Chapter 15]
**Snell’s law**

When a wave is refracted between two media, the ratio of the angle of incidence to the angle of refraction is a fixed constant that depends on the speeds of wave in each media.

\[ \frac{n_1}{n_2} = \frac{\sin \theta_2}{\sin \theta_1} = \frac{v_2}{v_1} \]

- \( n_1 \) is the refractive index of medium 1 (no units),
- \( n_2 \) is the refractive index of medium 2 (no units),
- \( \theta_1 \) is the angle of incidence (the angle between the incident ray and the normal) in medium 1 measured in ° or rad,
- \( \theta_2 \) is the angle of refraction (the angle between the refracted ray and the normal) in medium 2 measured in ° or rad,
- \( v_1 \) is the speed of the wave in medium 1 in m s\(^{-1}\),
- \( v_2 \) is the speed of the wave in medium 2 in m s\(^{-1}\).

[Chapter 8]

**solar heating panel**

A solar heating panel is designed to capture as much thermal energy as possible. Typically this directly heats water that is flowing through the panels which can then be used domestically. For example, some houses have solar panels on their roofs to save on the use of electrical energy.

[Chapter 22]

**specific heat capacity**

Specific heat capacity is the energy required to raise a unit mass of a substance by 1 K.

\[ Q = mc\Delta T \]

- \( Q \) is the energy transferred in J,
- \( m \) is the mass in kg,
- \( c \) is the specific heat capacity in J kg\(^{-1}\) K\(^{-1}\),
- \( \Delta T \) is the temperature change in K.

[Chapter 10]

**specific latent heat**

The specific latent heat of a substance is defined as the amount of energy per unit mass absorbed or released during a change of phase. The change of phase from solid to liquid is called fusion. The change of phase from liquid to gas is called vaporization.

\[ Q = mL \]

- \( Q \) is the energy transferred in J,
- \( m \) is the mass in kg,
- \( c \) is the specific latent heat in J kg\(^{-1}\).

[Chapter 10]

**speed**

The speed of an object is its rate of change of distance travelled. It is equal to the gradient of a distance–time graph and the area under an acceleration–time graph.

[Chapter 3]
standing (stationary) waves
Standing waves are formed when two waves of identical amplitude and frequency which are travelling in opposite directions meet. The result is a wave pattern whose shape does not travel through space. In one half of the wave, all the points along the wave are moving in phase to one another. In the other half they are also in phase with one another but in anti-phase to those in the first half. The amplitude of the wave varies along the length of the wave. No energy is being transmitted. Examples include the waves on a guitar string when a note is being played or the waves in the column of air inside the pipes of an organ.
[Chapter 8]

Stefan–Boltzmann law
The equation for the total power radiated in black-body radiation is:

\[ P = \sigma AT^4 \]

\( P \) is the total power radiated by the black body in W,
\( \sigma \) is the Stefan–Boltzmann constant \( (5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}) \),
\( A \) is the surface area in m\(^{-2}\),
\( T \) is the absolute temperature of the black body in K.
[Chapter 19]

strain gauges
A strain gauge is a device whose output voltage depends on any small extension or compression that occurs which results in a small change of length.
[Chapter 12]

superposition, principle of
The principle of superposition states that when two waves of the same type meet, the resulting disturbance at any point and at any time where the waves meet is just the vector sum of the disturbances that would have been produced by each of the individual waves.
[Chapter 8]

surface heat capacity
The surface heat capacity is the energy required to raise the temperature of unit area of a planet’s surface by one degree.

\[ c_s = \frac{Q}{A\Delta T} \]

\( c_s \) is the surface heat capacity in J m\(^{-2}\) K\(^{-1}\),
\( Q \) is the energy absorbed by the surface in J,
\( A \) is the surface area in m\(^{-2}\),
\( T \) is the absolute temperature of the surface in K.
[Chapter 19]

systematic error
Systematic errors are errors in experimental readings resulting from an instrument with zero error, an incorrect calibration of the instrument, or the observer making the same mistake every measurement. Repeating readings does not affect systematic errors.
[Chapter 2]
**temperature**
The temperature of two objects determines the direction of thermal energy transfer between the two objects (it measures the 'hotness' on an object on a scale). Thermal energy naturally flows from the hotter object to the cooler object. When two objects have reached a constant temperature, they are said to be in thermal equilibrium. It turns out that temperature is a measure of the average kinetic energy of the molecules in a substance.

[Chapters 9 and 10]

**temperature, internal energy and thermal energy (heat)**
Thermal energy (heat) is the non-mechanical transfer of energy between a system and its surroundings.

[Chapter 10]

**thermal capacity**
Thermal capacity is the energy required to raise its temperature by 1 K

\[ Q = C \Delta T \]

Q is the energy transferred in J,
C is the thermal heat capacity in J K\(^{-1}\),
\( \Delta T \) is the temperature change in K.

[Chapter 10]

**thermal energy conversion**
Thermal energy may be completely converted to work in a single process but that continuous conversion of this energy into work requires a cyclical process and the transfer of some energy from the system.

[Chapter 18]

**thermistors**
A thermistor is a device whose resistance depends on its temperature. Most common devices have a negative temperature coefficient (NTC), which means an increase in temperature causes a decrease in resistance.

[Chapter 12]

**translational equilibrium, condition for**
An object will be in translational equilibrium if the resultant force on the object is zero. An object in translational equilibrium is either at rest or moving with constant (uniform) velocity in a straight line.

[Chapter 4]

**transmission at a boundary**
A wave transmitted across the boundary between two media moves from one medium into the other. Its direction of travel changes as a result of refraction as calculated by Snell’s law.

[Chapter 8]

**transverse waves**
Transverse waves involve oscillations that are perpendicular to the direction of energy transfer. Light waves (all EM waves) are transverse. Transverse waves that involve oscillations of particles cannot be propagated in fluids (liquids or gases).

[Chapter 8]

**trough**
The trough is the lowest point of a transverse wave (the point of maximum negative displacement).

[Chapter 8]
uncertainty in addition/subtraction
If \( y = a \pm b \), then
\[
\Delta y = \Delta a + \Delta b
\]
If \( y \) is a quantity that is calculated from two (or more) other quantities, \( a \) and \( b \), by addition or subtraction the absolute uncertainty in \( y \) is the sum of the uncertainty in \( a \) and the uncertainty in \( b \).
\( \Delta a \) is the absolute uncertainty in \( a \),
\( \Delta b \) is the absolute uncertainty in \( b \),
\( \Delta y \) is the absolute uncertainty in \( y \).
[Chapter 2]

uncertainty in multiplication / division
If \( y = \frac{ab}{c} \), then
\[
\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}
\]
If \( y \) is a quantity that is calculated from two (or more) other quantities, \( a, b, \) and \( c \), by multiplication or division the fractional uncertainty in \( y \) is the sum of the fractional uncertainty in \( a \), the fractional uncertainty in \( b \), and the fractional uncertainty in \( c \). The same is true of the percentage uncertainties.
\( \frac{\Delta a}{a} \) is the fractional uncertainty in \( a \).
\( \frac{\Delta b}{b} \) is the fractional uncertainty in \( b \).
\( \frac{\Delta c}{c} \) is the fractional uncertainty in \( c \).
\( \frac{\Delta y}{y} \) is the fractional uncertainty in \( y \).
[Chapter 2]

uncontrolled nuclear fission
Uncontrolled nuclear fission takes place in nuclear weapons where chain reactions result in a large amount of energy all being released at once.
[Chapter 23]

unified atomic mass unit
The unified atomic mass unit, \( u \), is a unit appropriate for nuclear mass calculations. 1 \( u \) is approximately the mass of one proton or one neutron but is defined to be exactly one twelfth the mass of a carbon-12 atom.
\[ 1u = 1.66 \times 10^{-27} \text{ kg} \]
[Chapter 16]

uses of polarization
Polarized light can be used in the determination of the concentration of certain solutions that are optically active. It can also be used in stress analysis where bright coloured lines are observed in regions of stressed plastic which have been illuminated by polarised white light.
[Chapter 9]
**V**

**vectors**
Vectors are quantities that have magnitude and direction, for example, displacement, velocity, acceleration, force, etc.
[Chapter 3]

**velocity**
The velocity of an object is its rate of change of displacement in a particular direction. It is a vector quantity.
[Chapter 3]

**W**

**wave equation**
The wave equation is
\[ v = f \lambda \]
\( v \) is the wave velocity in m s\(^{-1}\),
\( f \) is the frequency in Hz,
\( \lambda \) is the wavelength in m.
[Chapter 8]

**wave speed**
The wave speed (in m s\(^{-1}\)) is the speed at which the wave pattern passes a stationary observer (i.e. the speed of energy transfer by the wave).
[Chapter 8]

**wavelength**
The wavelength \( \lambda \) is the shortest distance (in m) between two points that are in phase with one another (for example, the distance between adjacent crests on a transverse wave or adjacent compressions on a longitudinal wave).
[Chapter 8]

**weight**
Weight is the pull of gravity on an object.
\[ W = m g \]
\( W \) is the weight in N,
\( m \) is the mass in kg,
\( g \) is the gravitational field strength in N kg\(^{-1}\).
(On average, \( g = 10 \) N kg\(^{-1}\) on the Earth’s surface.)
[Chapter 4]

**weightlessness in orbital motion, free fall, and in deep space**
An object on the surface of the Earth experiences a contact force between it and the surface of the Earth as a result of the gravitational attraction on it. Only in deep space (i.e. far away from any other masses) might it be possible for the resultant gravitational attraction to be zero. Objects that are in orbital motion around a planet and objects falling down towards the surface of a planet are both in free fall. In these situations, the gravitational attraction is causing acceleration. There will be no ‘extra’ contact force between them and another object that is following the same motion. They will thus appear weightless.
[Chapter 14]
work
The work done by a force acting on an object is the product of the force and the component of the displacement of the point of application of the force on the object that is in the same direction as the force.
\[ W = F s \cos \theta \]
W is the work done in J,
F is the force in N,
s is the displacement in m,
\( \theta \) is the angle between the line of action of the force and the object’s displacement.
Work done is a scalar.
[Chapter 5]

work done in a volume change of a gas at constant pressure
The work done in a volume change of a gas at constant pressure is:
\[ W = P \Delta V \]
W is the work done by the gas in J,
P is the constant pressure of the gas in Pa,
\( \Delta V \) is the volume increase of the gas in m\(^3\).
[Chapter 11]
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