Physics Highlights

MATHS TALK

NUMBERS

How to write numbers

- Numbers can be written as symbols (10) or words (ten).
- In formal writing use symbols for large amounts and words for everything else.
- A decimal point is written as a "dot", not a comma.
  - **example** 6.5 six point five
- A comma can be used to separate hundreds from thousands, from millions,….
  - **example** 3,498,570
  - The word "million" can be expressed by the letter "m".

How to read numbers

- Numbers after the decimal dot, are read separately.
- The "zero" before a dot can be read as "nought" or not be read at all.
  - **example** 0.25 (nought/zero) point two five (**not** twentyfive)
- When reading a big number, do not use plural for "million", "thousand" and "hundred"
  - **example** 6,200 six thousand two hundred (**not** thousands, **not** hundreds)
- One difference between British English (BrE) and American English (AmE) is the use of "and" when reading big numbers.
  - **example** 5,370 five thousand three hundred and seventy (in BrE, in AmE there is no "and")

Scientific notation

- Numbers in scientific notation are written as:
  $a \times 10^b$ ("a times ten to the power of b")
  The exponent b is an integer, and the coefficient a is a real number called the significant or mantissa.

Expressions

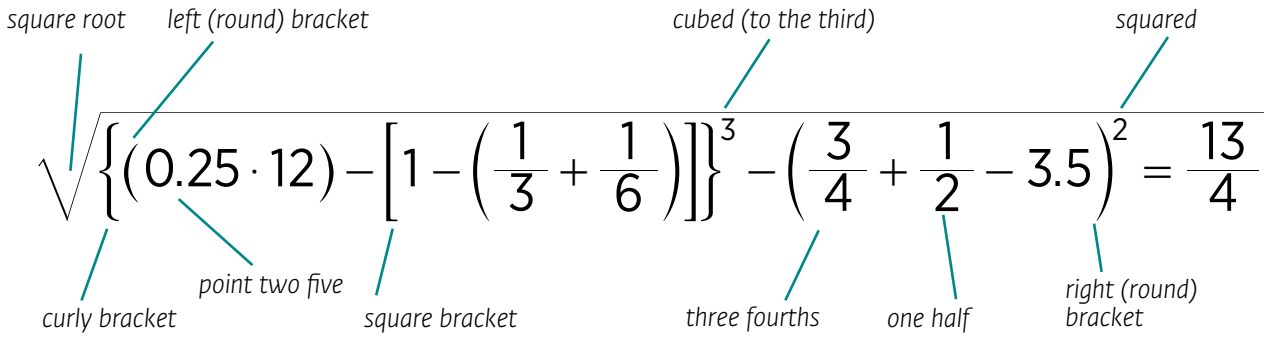
- In mathematics, an **expression** is a finite combination of symbols and numbers.
  - Mathematical expressions are calculated, solved or evaluated.

Grouping

- If there is more than one level in a mathematical expression, brackets can be used in order to group the levels.
  - ( ) left and right (round) brackets (parentheses, in AmE)
  - [ ] square brackets (brackets, in AmE)
  - { } curly brackets (curly braces, in AmE)

▸ **example** $\{[(3-4)-7-0.5]:2\}$ open curly, square and round brackets, three minus four, close round brackets, plus seven minus point five, close square brackets, all divided by two, close curly brackets.

- Expressions within parentheses are called *nested* expressions.



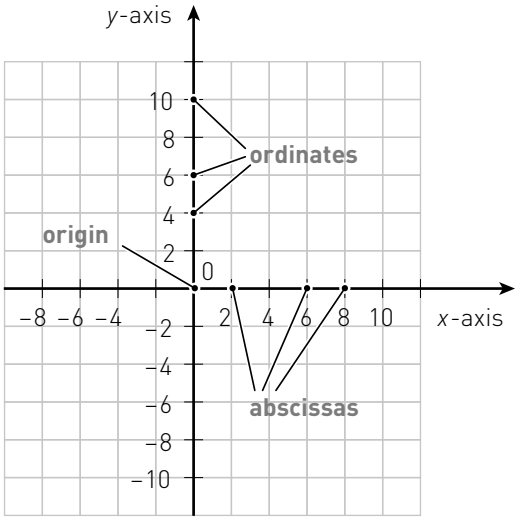
$$\sqrt{\left\{(0.25\cdot 12)-\left[1-\left(\frac{1}{3}+\frac{1}{6}\right)\right]\right\}^3-\left(\frac{3}{4}+\frac{1}{2}-3.5\right)^2}=\frac{13}{4}$$

SYMBOLS

IN SYMBOLS	IN WORDS	EXAMPLES	
+	plus, add	$a+b$	a *plus* b
−	minus, take away, substract	$a-b$	a *minus* b
±	plus or minus		
⋅	times, multiplied by	$a \cdot b$	ab, a *times* b
¨ (dot product)		$a \¨ b$	ab, a *times* b
/	divided by	$\frac{a}{b}$	a *over* b, a *divided by* b
			a is called the *numerator*
			and *b* the *denominator*
		how to read fractions	
⋯ / ⋯ (*vinculum* or *fraction bar*)		$\frac{1}{2}, \frac{5}{2}, \frac{2}{3}, \frac{7}{10}, \frac{\pi}{4}\cdots$	one half, five halves, two thirds, seven tenths, pi over four, ...
=	is equal, equals, is	$a=b$	a *equals* b or a *is equal to* b
		1 1 2 1 3	one plus 2 *is* (*equals*) b
≈	is approximately equal to		
≠	is not equal to	$a \neq b$	a is *different from* b, a is *not equal to* b
<	inequality signs	$a<b$	a is (strictly) *less than* b
>		$a>b$	a is (strictly) *greater than* b
≪		$a \ll b$	a is *much less than* b
≫		$a \gg b$	a is *much greater than* b
≥		$a \geq b$	a is *greater than or equal to* b
≤		$a \leq b$	a is *less than or equal to* b
%	percent	5 %	five *percent*

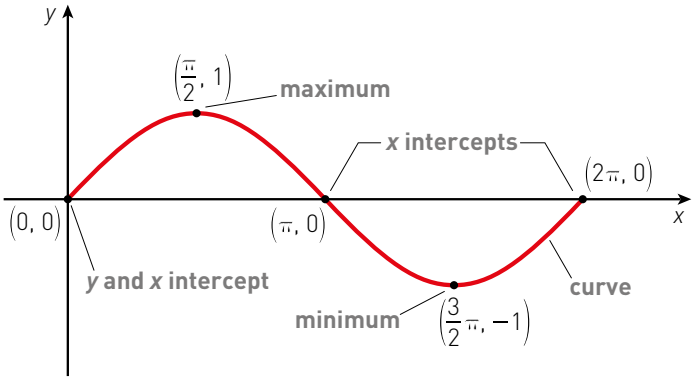
GRAPHS

Cartesian plane



- In mathematics, the graph of a function *f* is the collection of all ordered pairs $(x, f(x))$.
- Graphing on a Cartesian plane is sometimes referred to as to *plot* or *draw* a curve.
- A *curve* is a set of points that form or can be joined by a continuous line on a graph.
- To *plot* means to place a point on a coordinate plane using its *x*-coordinate and *y*-coordinate.

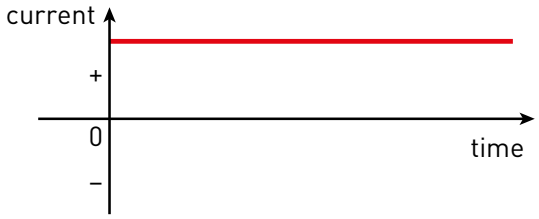
Main features of the graph of a function



- *Range*: the *y*-coordinates of the set of points on a graph. In the example above, the *range* is [−1;1] (minus one; one)
- *x-intercept*: the point where the graph crosses the *x*-axis. In the example, there are three *x-intercepts*, corresponding to $x = 0$, $x = \pi$ and $x = 2\pi$
- *y-intercept*: the value on the *x*-axis where a graph crosses the *y*-axis. In the example, the only *y-intercept* is the origin of the Cartesian plane (0; 0)
- *Domain*: the set of *x*-coordinates corresponding to the points on a graph. In the example, the *domain* is [0; 2π] (zero; two pi).
- *Asymptote*: a line that a curve approaches as it heads towards infinity. The *asymptotes* can be horizontal, vertical and oblique.

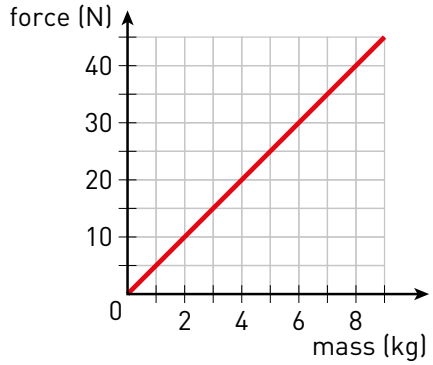
GRAPHS

Describe a trend of a graph



Stays the same/is flat/remains unchanged

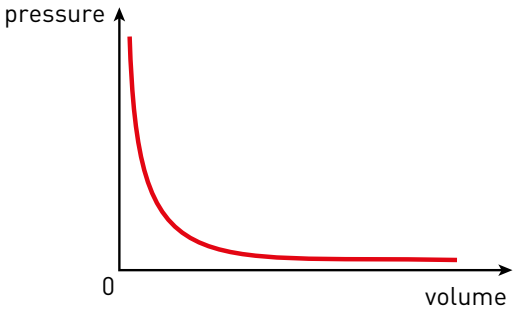
The current remains unchanged over time.



Rises/increases/grows

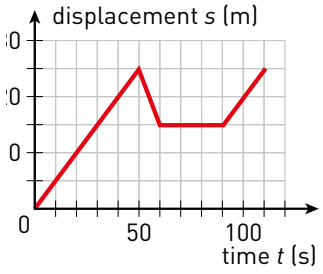
The force increases as the mass increases.

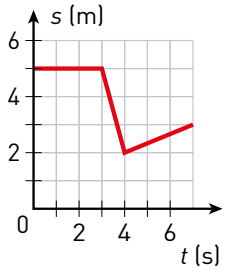
The force increases with the mass.



Falls/drops/declines/decreases

The pressure decreases as the volume increases.





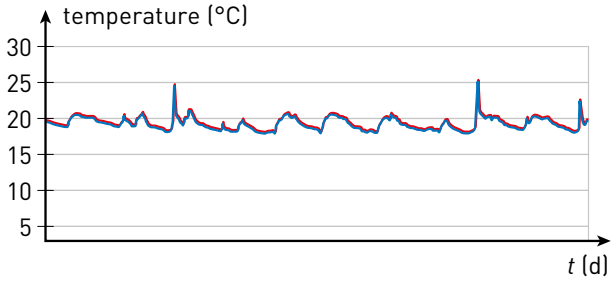
Peaks/reaches a peak

Hits a low

The peak and the low are *stationary points*, *maximum* and *minimum*, respectively.

In the graph on the left, displacement reaches a peak when time is 50 s.

In the graph on the right, displacement hits a low when time is 4 s.



Fluctuates

In these two graphs, temperature fluctuates around a mean value over time.

NEWTON'S LAWS OF MOTION

■ A change in the velocity of any body is caused by a force. Forces are vector quantities: they have both magnitude and direction.

■ The SI unit for forces, the newton, is the unit for mass, the kilogram, times the unit for acceleration, metres per second squared.

■ Dynamics deals with the effects that forces have on motion. When two or more forces act upon a body, the net force is the vector sum of the forces.

1 **Newton's first law of motion**, or **law of inertia**.

If no net force acts on a body, the body's velocity cannot change.

2 **Newton's second law of motion**.

The net force on a body is equal to the product of the body's mass and its acceleration:

$$\vec{F} = m\vec{a}$$

This vector equation tells us that acceleration has the same direction as the force that causes it.

3 **Newton's third law of motion**, or **action-reaction law**.

When two objects A *and* B *interact, the force exerted by* A *on* B *is equal in magnitude to the force exerted by* B *on* A*, but the two forces point in opposite directions:*

$$\vec{F}_{A\to B} = -\vec{F}_{B\to A}$$

■ A very common example of force is weight, given by the mass of an object multiplied by the acceleration due to gravity $\vec{g}$:

$$\vec{W} = m\vec{g}$$

■ Reference frames in which Newton's laws are valid are called inertial reference frames. The **principle of relativity** states that

the laws of physics are the same in every inertial reference frame.

GLOSSARY AND RELEVANT EXPRESSIONS

change in ▶ variazione di (anche inteso come Δ, es. Δt = change in time)
vector quantity ▶ grandezza vettoriale (quantity = grandezza fisica)
unit ▶ unità di misura
times ▶ volte, per
per ▶ al, su (implica un quoziente e non va confuso con l'italiano «per»)
magnitude ▶ modulo o intensità
direction ▶ direzione e verso (si usa un unico termine per esprimere 2 informazioni)
velocity ▶ vettore velocità («speed» indica esclusivamente il modulo del vettore «velocity»)
force ▶ forza (a force acts on/upon a body, a force is exerted on a body)
net force ▶ forza risultante
due to ▶ dovuto a, di
inertial reference frame ▶ sistema di riferimento inerziale

Activities

1 Complete the following definitions with the words listed below.

force • equal • net • acting • exerts • frame • velocity • resultant • direction • acceleration • magnitude • opposite

- A vector quantity is a quantity that has both ..... and ..... .
- Speed is just the magnitude of a vector called ..... .
- The net force is the vector sum, or ....., of all the forces ..... simultaneously on a body.
- An action-reaction pair is a couple of forces that have ..... magnitudes and ..... directions.
- An inertial reference ..... is one in which Newton's first law is valid.
- The mass of a body is the characteristic of that body that relates the body's ..... to the ..... force causing the acceleration.
- The weight of an object is the gravitational ..... that the Earth ..... on the object.

2 The following sentences about Newton's three laws all contain some mistakes. Rewrite them correctly.

- In the absence of an unbalanced force, an objects remains at rest if it is initially at rest, or moves in a straight line with constant acceleration if it is in motion.
- Acceleration is a vector unit and points in the same direction as the force.
- For every action there is an equal and opposite reaction, but action-reaction pairs act on the same objects and so they can be added.
- If no net force acts on a body, the body's position cannot change. That is, the body cannot move.
- For a given net force, the magnitude of the acceleration is directly proportional to the mass.
- Whenever an object acts a force on a second object, the second object exerts a force of equal intensity on the first object but in the opposite direction.

3 Choose the correct option in the following sentences.

- Mass changes / does not change as an object is moved from one location to another.
- Weight can / cannot vary, depending on how far the object is from the Earth's surface.
- Weight is a scalar / vector quantity while mass is a scalar / vector quantity.
- Weight always acts / exerts toward the centre of the Earth.

WORK AND ENERGY

■ Work is done on an object when an external force acts on the object whilst it moves through some displacement. Work is the scalar product of the force and the displacement.

■ The kinetic energy of an object is one half the product of its mass and the square of its speed. The SI unit of work is the joule (J), or newton metre (N·m), the same as energy.

■ When a net force performs work on an object, the kinetic energy of the object changes, as stated by the **work-energy theorem**:

the work done by the net force on an object equals the change in the object's kinetic energy.

■ A force is conservative when the work it does on a moving object is independent of the path between the object's initial and final positions. For conservative forces, such as the gravitational and the elastic force, the change in potential energy is equal to the negative of the work done by the force.

■ Mechanical energy, that is the sum of an object's kinetic and potential energy, obeys a very important **law of conservation**:

in an isolated system where only conservative forces act, mechanical energy is conserved.

■ The rate at which work is done, or energy is expended, is called power.

GLOSSARY AND RELEVANT EXPRESSIONS

work ▶ lavoro
to do work, to perform work ▶ fare lavoro
to state ▶ enunciare, stabilire
path ▶ percorso
rate ▶ ritmo, velocità

Activities

1 Complete the following definitions with the words listed below.

change • non-conservative • friction • divided • converted • closed • drag • transferred

- A force is conservative when it does no net work on an object moving around a ..... path.
- A force that is not conservative, such as the kinetic ..... force or the ..... force, is called a non-conservative force.
- The work-energy theorem relates work to ..... in kinetic energy.
- The concept of potential energy is not defined for a ..... force.
- The law of conservation of energy states that energy can be ..... from one object to another or ..... from one form to another, but it cannot be destroyed or created.
- Power is the change in energy ..... by the time during which the change occurs.

2 Match the first and second parts of the following sentences dealing with work as a scalar product.

1. A scalar product is the product of the magnitude of one vector and the component of the second vector
2. Work depends
3. Only the component of the force
4. If the force is parallel to the displacement, then
5. If the force is perpendicular to the displacement, then
6. Work can be positive or negative, depending

a. the force does no work at all.
b. work simplifies to force times distance.
c. along the displacement can do work on the object.
d. along the direction of the first vector.
e. on the angle between the directions of force and displacement.
f. on whether a component of the force points in the same direction as the displacement or in the opposite direction.

3 Complete the following sentences with the correct form of energy.

- ..... is associated with moving objects.
- ..... is a form of energy waiting to be released.
- ..... is a non-negative scalar quantity and is independent of the direction of motion.
- ..... is conserved for any object on which only conservative forces act.
- ..... is zero if an object is stationary.
- Adding ..... and ..... gives the ..... .
- The greater the height of a body relative to an arbitrary zero level, the greater its ..... .

LINEAR MOMENTUM

■ The linear momentum of a body is a vector quantity defined as the product of the body's mass and velocity. It is important because a new conservation law can be stated in terms of it, the **principle of conservation of linear momentum**:

the total linear momentum of an isolated system is conserved. An isolated system is one for which the vector sum of the average external forces acting on the system is zero.

■ The following relations are equivalent expressions of Newton's second law of motion:

$$\vec{F} = \frac{\Delta \vec{p}}{\Delta t} \qquad \vec{F} = m\vec{a}$$

■ The conservation of linear momentum is useful in describing collisions, when the colliding objects constitute an isolated system. Collisions are often classified according to whether the total kinetic energy remains constant (elastic) or changes (inelastic) during the collision.

■ The impulse of a force is the product of the average force and the time interval during which the force acts. It is related to momentum by the **impulse-momentum theorem**:

when a net average force acts on an object over a time interval, the impulse of this force is equal to the change in momentum of the object.

GLOSSARY AND RELEVANT EXPRESSIONS

linear momentum or momentum ▶ quantità di moto
to state ▶ enunciare, stabilire
in terms of ▶ in funzione di
average ▶ medio
collision ▶ urto

Activities

1 Complete the following definitions with the words listed below.

conservation • average • kinetic • vector • inelastic • velocities • collision • before • divided • direction • linear-momentum

- Elastic/inelastic collision: one in which the total ..... energy of the system after the ..... is equal/not equal to the total kinetic energy ..... the collision.
- According to the ..... equation $\vec{p} = m\vec{v}$, momentum and velocity must always have the same ....., because mass is a scalar positive quantity.
- If a system is isolated so that no external force acts on it, then its ..... must be constant even if there are internal changes.
- A one-dimensional collision is one in which the ..... of the objects all point along a single line before and after contact.
- For an isolated system in which a two-dimensional collision occurs, the ..... of momentum must be applied along each axis.
- If the colliding objects stick together, the collision is called completely ..... and the bodies have the same final velocity.
- The net force applied to an object is equal to the change in that object's momentum ..... by the time during which the change in momentum occurs.
- The centre of mass of a system is a point that represents the ..... location for the total mass of the system.

2 For each of the following phrases write an analogous one based on the suggestion.

- Impulse is a vector quantity and has the same direction as the force.
  Linear momentum .....
- Internal forces are exerted by objects within a system on each other.
  External forces .....
- Internal forces cannot change the total linear momentum of a system.
  External forces .....
- An increase in speed increases momentum proportionally.
  An increase in mass .....
- In an elastic collision, the total kinetic energy of the system is the same before and after the collision.
  In an inelastic collision, ...

3 Match the first and second parts of the following sentences.

1. Because the momentum of an isolated system does not change with time, we can use
2. Using the idea of momentum constancy, we can analyse situations involving non-constant forces, without any
3. It is often difficult to measure directly the impulse of a net average force during a time interval, but we can get

a. information about the forces involved.
b. information about the net force indirectly by calculating the momentum change.
c. information about the momentum at one instant to determine the momentum at a later instant.

ROTATIONAL DYNAMICS

■ In the motion of rotation, a rigid object turns about an axis. The variables for rotation are analogous to those for one-dimensional motion: angular displacement, angular velocity, angular acceleration.

■ Mass must be replaced by moment of inertia, force by torque, linear momentum by angular momentum.

■ By substituting angular quantities for the linear ones, the laws of rotational dynamics can be derived from the laws of linear dynamics.

■ **Rotational analogue of Newton's second law**

The net torque acting on a rigid body is given by the body's moment of inertia multiplied by the resulting angular acceleration about the rotation axis.

■ **Law of conservation of angular momentum**

The angular momentum of a body remains constant if the net external torque acting on the body is zero.

■ **Requirements of equilibrium**

The vector sum of all the external forces that act on the body must be zero and also the vector sum of all the external torques that act on the body, measured about any possible point, must be zero.

GLOSSARY AND RELEVANT EXPRESSIONS

to turn about, to rotate about ▶ girare, ruotare attorno a
to turn or to rotate through an angle ▶ ruotare di un angolo
angular momentum ▶ momento angolare
moment of inertia or rotational inertia ▶ momento d'inerzia
torque ▶ momento di una forza
requirements ▶ condizioni
to undergo ▶ essere soggetto a (è un verbo transitivo molto usato nell'inglese scientifico)
variables ▶ variabili, incognite

Activities

1 Complete the following definitions with the words listed below.

inertia • arm • about • angular • action • moment • square • axis • limit • displacement • instantaneous • angular • approaches • about • ratio • through

- A body that rotates about a rotation axis, changing its ..... position from θ_1 to θ_2, undergoes an angular ..... $\Delta\theta = \theta_2 - \theta 1$.
- If a body rotates ..... an angular displacement $\Delta\theta$ in a time interval Δt, its instantaneous angular velocity ω is the limit of the ..... $\Delta\theta / \Delta t$ as Δt approaches zero, and its ..... angular acceleration α is the ..... of the ratio $\Delta\omega / \Delta t$ as Δt ..... zero.
- A rigid body is a body that can rotate ..... an ..... with all its parts locked together with no change in shape.
- The perpendicular distance between the rotation axis and the line of ..... of the force is called the moment (or lever) arm of the force $\vec{F}$.
- The torque acting on a body rotating ..... an axis is the product of the moment ..... and the force.
- Kinetic rotational energy is one-half the product of the object's ..... of inertia and the ..... of its angular velocity.
- The angular momentum of a rigid body rotating about a fixed axis is the product of the body's rotational ..... and its ..... velocity.

2 Complete the following sentences.

- The ..... of angular velocity is the radian per second. The ..... of ..... is the newton metre.
- Since all points within a rigid body have the same ..... velocity, points with greater radius have greater ..... velocity.
- The tangential component of the linear acceleration of a point a_t is tangent to the ..... of the point in question and is responsible for changes in the ..... of the linear velocity. The .... component of the linear acceleration a_c is directed radially inward and is responsible for changes in the ..... of the linear velocity.
- For a body moving in a circular path, both angular velocity and angular acceleration are directly proportional to the ..... .

3 Match the first and the second parts of the following sentences.

1. The equations of rotational dynamics can be derived from
2. The moment of inertia of a body with respect to its axis of rotation tells us
3. The ability of a force to rotate a body depends not only on its magnitude but also on
4. The net external torque is proportional to
5. A rigid body is in equilibrium if it has
6. The mathematical form of angular momentum is analogous to that of linear momentum, with the mass and the linear velocity being replaced with

a. zero translational acceleration and zero angular acceleration.
b. the angular acceleration.
c. how far from the axis of rotation the force is applied.
d. how the mass of the rotating body is distributed about the axis of rotation.
e. their rotational counterparts, the moment of inertia and the angular velocity.
f. the corresponding linear equations, substituting angular quantities for the linear ones.

GRAVITATION

■ Gravity is a universal attractive force that acts between any two masses. It is described by **Newton's law of universal gravitation**:

Between any two objects there is an attractive force that is proportional to their masses and inversely proportional to the square of the distance between them, and whose line of action always lies along the line connecting the interacting objects. The proportionality constant G is a universal constant.

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

■ As a consequence of the fact that gravity is a conservative force, the gravitational potential energy can be defined, for any two-particle system, as proportional to the product of the masses and inversely proportional to their separation.

■ The law of universal gravitation also includes, as special cases, the **three Kepler's laws**.

1 **Law of orbits**: *all planets move in elliptical orbits with the Sun at one focus.*

2 **Law of areas**: *a line joining a planet to the Sun sweeps out equal areas in equal time intervals.*

3 **Law of periods**: *the square of the period of any planet is proportional to the cube of the semi-major axis of its orbit.*

■ The law of universal gravitation also describes the motion of any satellite.

GLOSSARY AND RELEVANT EXPRESSIONS

two-particle system ▶ coppia di particelle
to attract ▶ attrarre
to lie ▶ giacere
escape speed ▶ velocità di fuga
to double ▶ raddoppiare
to orbit ▶ orbitare

Activities

1 Complete the following definitions with the words listed below.

exerts • accelerations • force • gravitational • Earth • line • any • mass • magnitude • initial

- The force of gravity is an attraction between all objects that have ..... .
- A central force is one that always acts along the ..... joining the interacting objects.
- The weight of an object is the ..... force that the Earth ..... on the object.
- Gravitational acceleration *g* is the acceleration due to gravity at the .....'s surface.
- The universal gravitational constant *G* is needed to calculate the ..... acting between ..... two objects.
- The gravitational force on particle 2 due to particle 1 has the same ..... as the force on particle 1 due to particle 2 but they may produce very different ..... .
- The escape speed is the minimum ..... speed that will cause a projectile to move upwards forever.

2 Choose the correct option from the pairs of words.

- The gravitational force exerted on particle 2 by particle 1 has / has not the same magnitude as the force on particle 1 due to particle 2 but the same / opposite direction. They form an action-reaction pair, according to Newton's first / third law.
- If we double the distance between the two objects, the force of gravity between them becomes smaller / greater by a factor of four / two.
- The gravitational potential energy of a one-particle / a two-particle system approaches zero as *r* approaches infinity and is negative / positive for any value of *r*.

3 State whether the following statements are true or false. Rewrite the false ones in their correct form.

- The gravitational forces that two spheres exert on each other are the same as if their entire masses were concentrated at their centre, at a distance *r* between the surfaces of the spheres.
- Free-fall acceleration *g* is independent of an object's mass. It only depends on the Earth's mass and radius.
- The ratio T^2 / a^3 has essentially the same value for every planetary orbit around a given massive body.
- Acceleration due to gravity *G* decreases as the distance *r* increases.

4 Complete the following sentences with one or more words

- An object will escape the gravitational attraction of an astronomical body if the object's speed near the body's surface is at least equal to ..... .
- For a given distance between a satellite and its central body, there is only one ..... at which the satellite can remain in orbit.
- When a satellite orbits Earth in an elliptical path, both its speed and its distance from the centre of Earth vary. Thus, both its ..... energy and ..... vary, but its ..... remains constant.
- For a given orbit, a satellite with a large mass has ..... orbital speed as a satellite with a small mass.

FLUIDS

- A fluid is a substance that can flow. It conforms to the shape of any container in which it is placed.
- Fluids are conveniently described by such quantities as density and pressure.
- In a static fluid, the pressure at a point at a given depth due to the fluid's weight is directly proportional to the fluid's density and to the depth.
- **Pascal's principle** states that

if an external force causes a change in the pressure applied to an enclosed fluid, this change is transmitted to all parts of the fluid and to the walls of its container.

- When an object is immersed in a fluid, **Archimedes' principle** applies:

the fluid applies a buoyant force that equals the weight of the fluid that the object displaces.

- The behaviour of fluids in motion is described by the **equation of continuity**:

the product of the velocity of an ideal fluid and the cross-sectional area through which it flows is constant.

This is a consequence of the fact that mass is conserved.

- In the steady flow of an ideal fluid, the pressure at a point at a given depth is related not only to the depth in the fluid but also to the speed, according to **Bernoulli's equation**. This is a consequence of the principle of conservation of mechanical energy.

GLOSSARY AND RELEVANT EXPRESSIONS

to flow ▶ fluire
depth ▶ profondità
cross-sectional area ▶ sezione
steady flow ▶ flusso stazionario
buoyant force ▶ spinta idrostatica (buoy = boa)
streamline ▶ linea di flusso
flow rate ▶ portata

Activities

1 Complete the following definitions with the words listed below.

incompressible • tangent • perpendicular • change • volume • exerted • acts • per

- The density of a substance is its mass divided by its ..... .
- Pressure is defined as the magnitude of the force acting ..... to a surface divided by the area over which the force ..... .
- The buoyant force is the net upward force ..... by a fluid of an object.
- In steady or laminar flow the velocity of the moving fluid at any fixed point does not ..... with time.
- A streamline is the path followed by an individual fluid particle, and the velocity vector of the particle is ..... to the streamline at every point.
- The volume/mass of fluid ..... second that flows through a tube is called the volume/mass flow rate.
- An ideal fluid is an ..... and non-viscous fluid.

2 State whether the following statements are true or false. Where false, rewrite them correctly.

- Pressure is a scalar quantity and has no directional characteristics.
- The force generated by the pressure of a static fluid is always tangent to the surface that the fluid is in contact with.
- Most liquids are incompressible; that is, the density of a liquid increases as the pressure changes.
- Gases are normally highly incompressible.
- A mercury barometer can be used to measure atmospheric pressure, while an open-tube manometer is used for measuring the pressure of a confined gas.
- In a hydraulic lever, the ratio of the forces equals the inverse of the ratio of the surfaces.

3 Choose the correct option in the following sentences.

- The buoyant force acting on a body exists because the pressure of the surrounding water increases / decreases with depth below the surface.
- When a body floats in a fluid, the magnitude of the upward / downward buoyant force on the body is equal to / greater than the magnitude of the upward / downward gravitational force on the body.
- A floating body displaces its own mass / weight of fluid.
- An object sinks if the buoyant force acting on it does not exist / is not large enough to balance its weight.

4 Match the first and second parts of the following sentences.

1. In steady flow, the pattern of
2. The equation of continuity is an expression of the fact that
3. Bernoulli's equation is obtained by applying
4. If the speed of a fluid element increases as the element travels along a horizontal streamline, the pressure of
5. Where velocity is high, and

a. the fluid must decrease, and conversely pressure increases when speed decreases.
b. the mass flow rate has the same value everywhere in the tube, that is, mass is conserved as the fluid flows.
c. streamlines are therefore close together, pressure is low. The converse also holds.
d. streamlines is steady in time and no two streamlines cross one another.
e. the principle of conservation of mechanical energy to the flow of an ideal fluid.

TEMPERATURE

■ Temperature is a base SI quantity, and in the SI system it is measured on the Kelvin scale, which is graduated in units called kelvins. Temperature is defined and measured as a consequence of the **zeroth law of thermodynamics**:

two systems individually in thermal equilibrium with a third system are in thermal equilibrium with each other.

■ All objects change size with changes in temperature, that is, they undergo linear and volume thermal expansion. The change in any linear dimension is proportional to the change in temperature and also to the initial length. The behaviour of water between 0 °C and 4 °C constitutes a notable exception to this law.

■ All gases exhibit changes in pressure and volume with changes in temperature, as expressed by Gay-Lussac's and Boyle's laws and as summarised by the **ideal gas law**:

The pressure of an ideal gas is directly proportional to the Kelvin temperature and the number of moles of the gas and is inversely proportional to the volume of the gas. The coefficient of proportionality is R, the universal gas constant.

GLOSSARY AND RELEVANT EXPRESSIONS

degrees ▶ gradi (0 °C si legge «zero degrees Celsius», 0 K si legge «zero kelvin»)
thermodynamics ▶ termodinamica
thermal expansion ▶ dilatazione termica

Activities

1 Complete the following definitions with the words listed below.

amount • related • volumes • equal • per • any • zero • law

- The temperature of ..... body has a lower limit: this limiting low temperature is the ..... of the Kelvin scale and is called absolute zero.
- When two bodies are in thermal equilibrium their temperatures are ..... .
- The mole is the SI base unit for expressing the ..... of a substance. The number of atoms ..... mole is called Avogadro's number.
- An ideal gas is one for which pressure, volume and temperature are ..... by the ideal gas ..... .
- Equal ..... of different types of gas, when at the same temperature and pressure, contain the same number of gas particles.

2 Fill the table: for each law, write the corresponding formula and the substances and/or requirements for which it is valid. Then write the formula in words and read it aloud.

Formulas:

$\Delta V = \alpha V_0 \Delta T$ • $\Delta L = \lambda L_0 \Delta T$ • $pV = nRT$ • $pV = \text{constant}$ • $V = V_0(1 + \alpha \Delta T)$ • $p = p_0(1 + \alpha T)$

Substances and requirements:

gases • solids • liquids • constant temperature • constant volume • constant pressure

	Formula	Substances / Requirements
Ideal gas law		
Boyle's law		
Gay-Lussac's first law		
Gay-Lussac's second law		
Linear expansion		
Volume expansion		

3 Complete the following sentences.

- Different materials with the same initial length expand and contract by different amounts as the temperature changes, so the ..... depends on the nature of the material.
- Objects at different temperatures come to a thermal ..... when they are placed in contact with each other.
- Between 0 °C and about 4 °C, water contracts with increasing temperature. Thus, at about 4 °C, the ..... of water passes through a maximum.
- One mole is the number of ..... contained in 12 grams of carbon-12.
- An ideal gas is an idealised ..... for real gases that have sufficiently low densities.
- A ..... contains a working substance with a measurable property that changes in a regular way as the substance becomes hotter or colder.

KINETIC THEORY OF GASES

■ The kinetic theory of gases relates the macroscopic properties of gases to the microscopic properties of their constituent atoms and molecules. These particles are in constant, random motion, colliding with each other and with the walls of the container and moving in a straight line at constant speed between collisions.

■ The velocities possessed by the particles are different from one another, and their probability distribution at a given temperature is described by **Maxwell's speed distribution law**.

■ The pressure that a gas exerts on the walls of a container is due to the force exerted by the gas molecules when they collide with the walls. The temperature of a gas can also be expressed in terms of microscopic properties, as stated by the significant equation

$$E_c = \frac{3}{2} k_B T$$

where E_c is the mean translational kinetic energy of the molecules, T is the absolute temperature of the gas and k_B is the Boltzmann constant.

■ A thermal energy can be defined for any gas as an internal energy comprising the sum of the kinetic energy associated with the random motion of the atoms and molecules of the gas and the potential energy due to their mutual attraction for one another.

GLOSSARY AND RELEVANT EXPRESSIONS

root-mean-square speed ▶ velocità quadratica media
most probable speed ▶ velocità più probabile
mean, average ▶ medio
to collide ▶ urtare
collision ▶ urto

Activities

1 Complete the following definitions with the words listed below.

square • independent • molecules • atoms • mean • values • random • energy • Brownian motion • root • length

- ..... can be observed through a microscope with pollen grains suspended in water or with fine smoke particles in the air.
- Thermal energy is the sum of kinetic energy, due to the ..... motion of the molecules, and potential energy, due to forces that act between the ..... of a molecule and between ..... .
- Maxwell's distribution allows us to know how the possible ..... of speed are distributed among the molecules.
- To determine the root-mean-square speed, ... each speed, find the ..... of all these squared speeds, and then take the square ..... of that mean.
- The mean free path is the average path ..... travelled by a molecule between collisions.
- Degrees of freedom are ..... ways in which the molecule can store energy.
- Each degree of freedom has associated with it, on average, an ..... of $(1/2)k_B T$.

2 Order the following snippets of text in order to form a paragraph about Maxwell's speed distribution.

- Maxwell's distribution describes the distribution of
- the «most probable speed», but some molecules will have speeds that are
- the translational kinetic energy of its molecules. At a given temperature, all ideal gas molecules, no matter what their mass, have the same
- slow process. The greater part of the molecules have speeds close to
- many times the «most probable speed». Such molecules lie in
- average translational kinetic energy. The root-mean-square speeds are commonly so
- the repeated collisions with other molecules. Therefore, diffusion is a relatively
- high that air molecules often travel faster than bullets. Nevertheless, they travel very slowly because of
- the high-speed tail of the distribution curve.
- speeds within a large collection of molecules of an ideal gas at a constant temperature. When we measure the temperature of a gas, we are also measuring

HEAT

■ Heat is energy that flows from one object to another because of a temperature difference between them. Heat can be measured in Joules or in calories: 1 cal = 4.186 J.

■ Heat can be transferred via three different mechanisms: conduction in solids; convection in fluids; and radiation, which also acts through a vacuum. All bodies continuously radiate in the form of electromagnetic waves: according to the **Stefan-Boltzmann law**, the radiant power is proportional to the fourth power of the absolute temperature of the emitting object.

■ The greenhouse effect is due to the electromagnetic waves (infrared waves) that the Earth's surface radiates, but which cannot carry energy into space because they are reflected back by greenhouse gases.

■ When heat is absorbed or lost by a solid or a fluid, a change in temperature may occur, that is proportional to the heat. But also a phase change may occur, during which the temperature remains constant.

GLOSSARY AND RELEVANT EXPRESSIONS

heat ▶ calore
greenhouse effect ▶ effetto serra
vacuum ▶ vuoto
heat transfer mechanisms ▶ modalità di propagazione del calore
phase change ▶ cambiamento di fase
mass or bulk movement ▶ correnti convettive
equilibrium vapour pressure ▶ pressione di vapore saturo

Activities

1 Complete the following definitions with the words listed below.

transferred • mechanism • phase • temperature • equilibrium • change • proportionality • kelvin

- The heat capacity of a system is the ..... constant between the heat that the object absorbs or loses and the resulting temperature ..... of the object.
- Specific heat is the amount of heat required to raise the temperature of one gram of a substance by one .....
- The equilibrium vapour pressure of a liquid is the pressure of the vapour that coexists in ..... with the liquid.
- Conduction is a heat transfer mechanism occurring in a solid due to a ..... difference with no displacement of matter.
- Convection is the heat transfer ..... by which heat is carried from place to place by the mass movement of a fluid.
- Radiation occurs when energy is ..... by means of electromagnetic waves.
- Latent heat is the heat per kilogram associated with a ..... change.

2 Form short sentences with the groups of words provided below.

- Solid, liquid, heat, to melt, to add.
- Liquid, gas, heat, to condense, to take away.
- Solid, liquid, heat, to freeze, to remove.
- Rapid evaporation, to form, to boil, bubbles, liquid.
- Liquid, gas, heat, to evaporate, to supply.
- Solid, gas, directly, to provide, to sublime, heat.

3 Find the direct and inverse proportionalities existing between the elements of the first and the second groups.

1. The rate of conductive heating from the hot side of a material to the cool side
2. Convection occurs in fluids such as air or water because their weight
3. The amount of radiant energy increases markedly with increasing temperature because the thermal radiation emitted by all objects

a. the cross sectional area across which the thermal energy flows
b. the temperature
c. the temperature difference between the two sides
d. the density, which
e. the thermal conductivity of the material
f. the fourth power of the Kelvin temperature
g. the distance that the thermal energy travels

4 Find the mistake present in each of the following sentences and rewrite them correctly.

- Those materials that conduct heat poorly are called thermal conductors.
- The heat that must be supplied or removed to change the phase of a mass of substance equals the product of the mass and the specific heat capacity of the substance.
- When energy is absorbed as heat by a solid or a liquid, its temperature necessarily increases.
- A substance can never exist at equilibrium in more than one phase at the same time.
- Liquid, solid and vapour can coexist in thermal equilibrium at only one set of values of density and temperature.

FIRST LAW OF THERMODYNAMICS

■ A system's energy can change not only when external objects exert forces and do work on it, but also when heat is exchanged between the system and its environment: thermodynamics deals with such exchanges.

■ A typical thermodynamic system consists of a gas confined to a cylinder with a movable piston. Work can be done, on the system or by the system, through movement of the piston. Heat can flow between the system and an adjacent thermal reservoir.

■ Work done and heat exchanged are related to the change in the system's internal energy according to the law of conservation of energy, as stated by the **first law of thermodynamics**:

the change in internal energy of a system during any thermodynamic process is given by heat minus work.

■ This change depends on the initial and final states of the system and does not depend on the process or path that produces the final state. Thus, the internal energy of a thermodynamic system is a function of state.

■ The first law of thermodynamics finds application in several special cases such as, for example, isothermal, isochoric, isobaric, and adiabatic processes.

GLOSSARY AND RELEVANT EXPRESSIONS

to supply ▶ fornire
to exchange ▶ scambiare;
exchange ▶ scambio
environment, the surroundings ▶ ambiente, universo
thermal reservoir ▶ termostato
thermodynamic process ▶ trasformazione termodinamica
to exceed ▶ superare

Activities

1 Complete the following definitions with the words listed below.

states • volume • amount • transfer • constant • initial • thermal • occurs • by

- A quasi-static process is one in which changes occur slowly, so that every part of the system is always in ..... equilibrium.
- An isothermal process takes place at ..... temperature.
- An isobaric process is one that ..... at constant pressure.
- An adiabatic process takes place without the ..... of heat.
- An isochoric process is one that occurs at constant ..... .
- A cyclical processes is one in which, after certain interchanges of heat and work, the system is restored to its ..... state.
- A function of state depends only on the initial and final ..... of a system.
- The molar heat is the amount of energy required to raise the temperature of one mole of a substance ..... one kelvin.
- For a monoatomic gas the molar specific heat at constant pressure exceeds the molar specific heat at constant volume by an ..... equal to R.

2 Choose the correct options in the following paragraph concerning energy exchanges.

The principle of energy conservation applies to isolated / closed systems, i.e., systems for which energy / no energy enters or leaves the system. The first law of thermodynamics is a special case / an extension of that principle to systems that are / are not isolated. In such cases, energy may be transferred into or out of the system as either potential or kinetic energy / work or heat. The internal energy of a system tends to decrease / increase if energy is added as heat and tends to decrease if energy is lost / supplied as work done by / on the system. The work done on a system is always the negative / same of the work done by a system. When a system changes from a given initial state to a given final state, both the work and the heat do not depend / depend on the nature of the process, but their sum / difference is the same for all processes.

3 Complete the following sentences with the appropriate forms of energy (internal energy, work, heat).

- For any kind of process, ... is the area under a pressure-volume graph.
- In an adiabatic process, ... cannot enter or leave the system because of insulation. The change in ..... is totally converted into ..... .
- When a system performs work isothermally the ..... does not change and the ..... done equals the ..... that has been supplied to the system.
- If the volume of a system is held constant, the system can do no ..... . Thus, if ..... is absorbed/lost, the ..... must increases/ decrease by the same amount.
- In an isobaric process the ..... done is simply the product of the constant pressure and the change in volume.

SECOND LAW OF THERMODYNAMICS

■ A heat engine is any device that uses heat to perform work. Heat is supplied to the engine at a high input temperature from a hot reservoir, but part of the heat is always rejected into a cold reservoir.

■ The efficiency of a heat engine is defined as the ratio of the work done by the engine to the input heat.

■ A reversible process is one in which both the system and its environment can be returned to exactly the same states as before the process occurred. According to **Carnot's principle**,

all reversible engines operating between two reservoirs at constant temperatures have the same efficiency, but no irreversible engine operating between the same temperatures can have a greater efficiency.

■ The **second law of thermodynamics** can be stated in a number of equivalent forms.

1 **Clausius' statement** is about the spontaneous flow of heat:

no series of processes is possible whose only result is the transfer of energy as heat from a reservoir at a given temperature to a reservoir at a higher temperature.

2 **Lord Kelvin's statement** is about efficiency:

no series of processes is possible whose only result is the transfer of energy as heat from a thermal reservoir and the complete conversion of this energy into work.

3 The third statement is about a new function of state, called **entropy**. This function can be defined both in terms of thermodynamic quantities (heat and temperature) and in terms of probability, that is, by counting the ways in which the molecules that make up a system can be arranged:

the total entropy of the universe does not change when a reversible process occurs, and increases when an irreversible process occurs.

■ The relationship between the entropy of a configuration and the multiplicity of that configuration is described by **Boltzmann's entropy equation**.

GLOSSARY AND RELEVANT EXPRESSIONS

heat engine ▶ macchina termica
device ▶ dispositivo (è un termine molto usato nell'inglese scientifico)
hot/cold reservoir ▶ termostato caldo/freddo
efficiency ▶ rendimento
power plant ▶ centrale per la produzione di energia elettrica
to deliver ▶ produrre, fornire

Activities

1 Complete the following definitions with the words listed below.

configuration • distribution • reservoirs • flow • ratio • microstates • device • cycle • temperature • increases • divided

- The second law of thermodynamics is a statement about the tendency of heat to ..... from hot to cold.
- A heat engine is a ..... that extracts energy as heat from a high-temperature reservoir and does a certain amount of useful work.
- The efficiency of a reversible engine depends only on the temperatures of the hot and cold .....
- A Carnot engine is a reversible engine in which all input heat originates from a hot reservoir at a single ....., and all rejected heat goes into a cold reservoir at a lower single temperature.
- A refrigerator is a device that, operating in a ....., uses energy from the environment in order to extract heat from a low-temperature reservoir.
- The coefficient of performance of a refrigerator or air conditioner is defined as the ..... of the amount of heat it removes to the amount of work it uses.
- When a system exchanges heat at a constant temperature, this heat ..... by the Kelvin temperature gives the system's change in entropy.
- A reversible process does not alter the total entropy of the universe, while any irreversible process ..... the entropy of the universe.
- For identical molecules, each possible ..... of molecules is called a microstate of the system.
- All equivalent ..... are grouped into a configuration of the system. The number of microstates in a configuration is the multiplicity of the .....

2 Match the first and second parts of the following sentences.

1. The area enclosed in a pressure-volume diagram for a cycle represents
2. Only part of the energy extracted as heat from the high-temperature reservoir is
3. The amount of energy that any power plant throws away to the cold reservoir is
4. If some form of energy is
5. In a refrigerator or an air conditioner, work is

a. always greater than the amount of energy that it delivers in useful form.
b. used to remove heat from the cold reservoir and deposit heat into the hot reservoir.
c. available to do work, the rest is rejected to the low-temperature reservoir.
d. provided, heat can flow from cold to hot.
e. the work per cycle done by a Carnot engine.

3 Complete the following sentences with the words reversible or irreversible.

- Processes that occur spontaneously are always ..... .
- The entropy of one part of the universe may change because of a ..... process, but if so, the entropy of another part changes in the opposite way by the same amount.
- When an ..... process occurs and entropy of the universe increases, the energy available for doing work decreases.
- The direction in which an ..... process proceeds is set by the change in entropy of the system undergoing the process.
- In the real word all processes are ..... to some extent because of friction, turbulence and other factors.
- ..... processes in which the system's entropy remains constant are always idealisations.