Dynamics & Space

Motion

Summary

Speed is a measure of the distance travelled by an object in a unit of time.

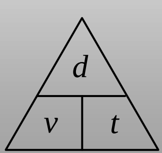
Speed is measured in metres per second (m s^{-1}).

Speed, Distance and Time

m

$$speed = \frac{distance}{time}$$

m s^{-1} s



$$v = \frac{d}{t}$$

$$d = vt$$

$$t = \frac{d}{v}$$

Average speed, $\bar{v}$, is a measure of the average of the speed for an entire journey.

- measure distance travelled with a ruler
- measure time taken to travel with a stop clock
- average speed = $\frac{\text{distance travelled}}{\text{time taken}}$

Instantaneous speed, v, is the speed at one point during the journey.

- measure length of card attached to vehicle with a ruler
- measure time taken for card to pass through a light gate with an electronic timer
- instantaneous speed = $\frac{\text{length of card}}{\text{time through light gate}}$

Scalar quantities only have a magnitude (size)

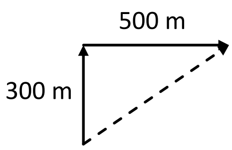
Distance and speed are scalar quantities; as are time, frequency, energy and mass.

Vector quantities have both magnitude (size) and direction

Velocity and displacement are vector quantities; as are acceleration and force.

When adding vector quantities they must be added "nose-to-tail". This can be done by scale diagram or using trigonometry

e.g. A displacement of 300 m North then 500 m East



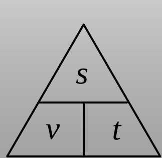
resultant = 583 m @ 059

Velocity, Displacement and Time

m

$$velocity = \frac{displacement}{time}$$

m s^{-1} s



$$v = \frac{s}{t}$$

$$s = vt$$

$$t = \frac{s}{v}$$

Acceleration is a measure of the rate of change of velocity of an object.

Acceleration is measured in metres per second per second (m s^{-2}).

Acceleration can be calculated by dividing the change in velocity by the time taken for the change.

The two velocities can be determined experimentally by using either:

- a single card and two light gates connected to an electronic timer

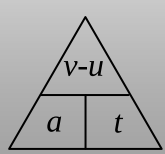
  or
- a double card and a single light gate connected to an electronic timer

Acceleration, Velocity and Time

m s^{-2} m s^{-1}

$$acceleration = \frac{final\ velocity - initial\ velocity}{time}$$

s

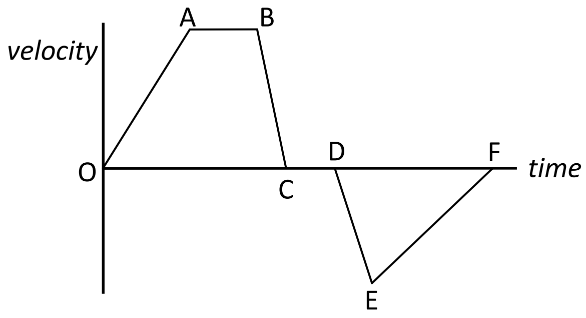


$$a = \frac{v-u}{t}$$

$$v - u = at$$

$$t = \frac{v-u}{a}$$

A **velocity-time graph** shows how the velocity of a moving object varies with time.



OA – constant acceleration

AB – constant velocity

BC – constant deceleration

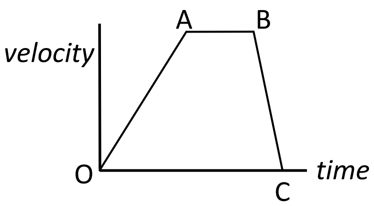
CD – at rest (zero velocity)

DE – constant acceleration in the opposite direction

EF – constant deceleration in the opposite direction

The acceleration of the object is equal to the gradient of the graph.

e.g.



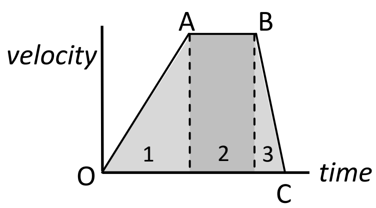
$$acceleration = gradient\ of\ graph$$

$$= \frac{change\ in\ velocity}{time}$$

Note: negative gradients represent negative accelerations

The displacement of the object is equal to the area under the graph.

e.g.



$$displacement = area\ under\ graph$$

$$= area\ 1 + area\ 2 + area\ 3$$

Note: areas under the velocity-time graphs represent negative displacements (displacements in the opposite direction)

Dynamics & Space

Forces

Summary

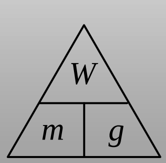
Forces have the ability to change the shape, speed and direction of an object.

Force is measured in newtons (N).

Forces can be measured with a newton balance (or a spring balance or force-meter).

Weight, Mass and gravitational field strength

$$\underbrace{weight}_{\mathrm{N}} = \underbrace{mass}_{\mathrm{kg}} \times \overbrace{gravitational\ field\ strength}^{\mathrm{N\ kg^{-1}}}$$



$$W = mg$$

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

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

Mass, m, is the amount of matter in an object and is measured in kilograms (kg). The mass of an object is the same, no matter where it is in the Universe.

Weight, W, is the force of gravity on an object and is measured in newtons (N). The weight of an object depends on both its mass and the strength of gravity.

Gravitational field strength, g, is the weight per unit mass and is measured in newtons per kilogram (N kg^{-1}). The gravitational field strength is different at different places in the Universe. On Earth g has a value of 9·8 N kg^{-1}. The value of g decreases with distance from the planet's surface.

Friction is the force that opposes motion. Friction arises when surfaces rub together. When there is friction, heat is produced.

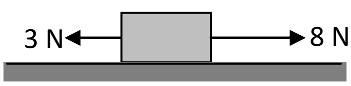
Situations in which friction is reduced include: lubricating a bicycle wheel with oil, using rollers on a conveyor belt, wearing swimsuits made of vey smooth materials and waxing skis.

Situations in which friction is increased include: pressing brake pads onto a bake disc, using chalk to absorb moisture when rock climbing, using rubber on car tyres to increase 'grip'.

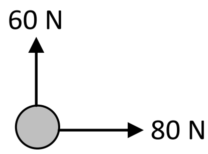
Air resistance, or drag, is a form of friction. Air resistance increases with speed. Air resistance can be reduced by **streamlining**.

Forces are vector quantities and therefore have both a magnitude (size) and direction.

e.g.



resultant force = 5 N right



resultant force = 100 N @ 54° to vertical

Equal forces acting in opposite directions are known as balanced forces. When the forces on an object are balanced the object remains at rest or continues to move at a constant speed in a straight line. This is known as **Newton's First Law of Motion**.

When the forces on an object are unbalanced the object will accelerate. The acceleration of an object depends on the mass of the object and the size of the unbalanced force:

Acceleration is directly proportional to the unbalanced force on the object.

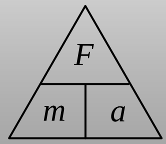
Acceleration is inversely proportional to the mass of the object.

The relationship between unbalanced force, mass and acceleration is known **as Newton's Second Law of Motion**.

To accelerate an object upwards the lifting force must be greater than its weight, so there is an unbalanced upward force (e.g. rockets)

Force, Mass and Acceleration

$$\underbrace{unbalanced\ force}_{\text{N}} = \underbrace{mass}_{\text{kg}} \times \overbrace{acceleration}^{\text{m s}^{-2}}$$



$$F = ma$$

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

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

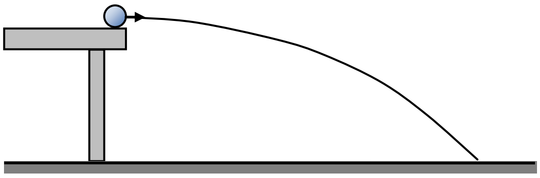
When an object is dropped it initially accelerates due to the force of gravity. As it travels faster air resistance increases, the unbalanced force decreases and the acceleration decreases. Eventually the weight and air resistance become balanced; at this point the object falls at a constant velocity known as its **terminal velocity**.

Dynamics & Space

Space Travel

Summary

When an object is projected in a gravitational field (e.g. when a ball is thrown on Earth) it will follow a curved path. This is known as **projectile motion**.



Projectile motion because the only force acting on the object is the force of gravity (weight) acting vertically downwards. This results in a constant downward acceleration. Whereas there are no horizontal forces so the object continues to move with a constant horizontal speed.

The horizontal and vertical motion of a projectile can be treated separately:

horizontal motion : constant velocity using $s = vt$

vertical motion : constant downward acceleration using $a = \frac{v-u}{t}$

(Note: on Earth a = 9·8 m s^{-2})

A **satellite** is a projectile that remains in orbit because its horizontal velocity sufficiently large that, as it accelerates toward the surface of the Earth, the surface 'curves away' from it. Satellites orbit the Earth above the atmosphere (>160 km) so that there is no air resistance to slow them down.

When an object is in freefall it appears to be weightless. For example the astronauts inside a spacecraft appear to be weightless because both the astronauts and the spacecraft are falling towards the Earth at the same rate.

The greater the altitude of a satellite the greater the period of the satellites orbit

e.g.

Satellite(s)	Altitude (km)	Period
International Space Station	420	92 minutes
Galileo (navigation)	23 200	14 hours
Astra (Sky TV)	35 800	24 hours

Satellites that orbit the equator with a period of 24 hours are **geostationary**. Geostationary satellites remain above the same point on the Earth's surface at all times.

Satellites have many uses including: telecommunications (satellite phones, satellite television etc.), meteorology (weather mapping and prediction), positioning (GPS), environmental monitoring (vegetation, geology, temperature, atmospheric chemicals etc.), imaging (mapping and surveillance) and scientific (experiments and telescopes).

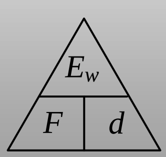
Work done, Force and Distance

m

$$Work\ done = force \times distance$$

J N

$$E_w = Fd$$



$$F = \frac{E_w}{d}$$

$$d = \frac{E_w}{F}$$

Work done is a measure of the energy transferred during an energy change.

Work done is measured in Joules (J).

The work done by a force to an object is equal to the force applied multiplied by the distance travelled.

Note : When an object is lifted the force applied to lift the object at constant speed is equal to its weight (W=mg) and the distance it travels is equal to the height, h. Therefore the work done in lifting the object is equal to mg multiplied by h. This means the gain in gravitational potential energy is equal to mgh ($Ep = mgh$).

When an object enters the Earth's atmosphere it experiences friction with the atmosphere. The work done by friction changes kinetic energy into heat. To protect spacecraft returning from space heat shielding is required. There are two main types of heat shielding:

dissipation – Some heat shields (e.g. on the Space Shuttle) absorb the heat using insulating tiles which then re-radiate the heat back into the atmosphere. These tiles have a high specific heat capacity and a high melting point.

ablation – Some heat shields (e.g. those on Apollo and Soyuz spacecraft) use the heat to vaporise the heat shield and carry away the energy. The materials used in these heat shields have a high specific latent heat.

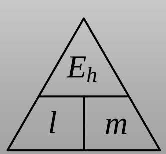
Specific Latent Heat

J kg^{-1} kg

$$Heat\ energy = \begin{matrix} specific \\ latent \\ heat \end{matrix} \times mass$$

J

$$E_h = lm$$



$$l = \frac{E_h}{m}$$

$$m = \frac{E_h}{l}$$

The heat energy required to change the state of one kilogram of a substance is known as its **specific latent heat**.

Specific latent heat is measured in joules per kilogram (J kg^{-1}).

When a substance change state from a solid to a liquid or a liquid to a gas latent heat is absorbed (taken in).

When a substance changes state from a gas to a liquid or a liquid to a solid latent heat is released (given out).

Specific latent heat of fusion is the amount of heat energy required to change one kilogram of a substance from a solid at its melting point to a liquid at the same temperature

Specific latent heat of vaporisation is the amount of heat energy required to change one kilogram of a substance from a liquid at its boiling point to a gas at the same temperature.

During a change of state there is no change in temperature.

Dynamics & Space

Cosmology

Summary

The **Universe** consists of many galaxies separated by empty space.

A **galaxy** is a large cluster of stars (e.g. the Milky Way).

A **star** is a large ball of matter that is undergoing nuclear fusion and emitting light. The Sun is a star (as are Sirius, Rigel and Proxima Centauri).

A **planet** is a large ball of matter (rounded by its own gravity) that orbits a star (e.g. Earth or Jupiter). Planets do not emit light themselves.

The Sun and many other stars have a **solar system**. A solar system consists of a central star orbited by planets. Planets orbiting stars other than the Sun are known as **exoplanets**.

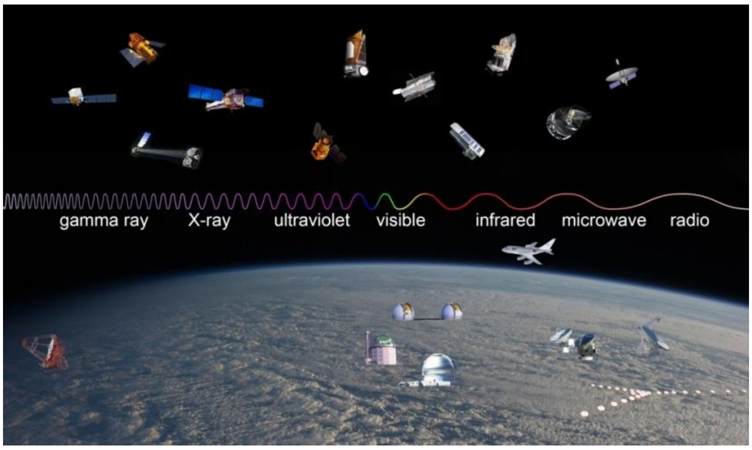
Many planets have moons. A **moon** is a lump of matter that orbits a planet (e.g. the Moon orbits the Earth and Deimos and Phobos orbit Mars).

The Universe is thought to have begun in an event, known as the **Big Bang**, around 13·8 billion years ago when all matter, and even space and time itself, came into existence. The universe began at a single point in space-time, known as a singularity; since then the universe has expanded and (according to observations) will continue to expand.

Distances in space are so enormous that we use units known as light-years to measure them. A **light-year** (ly) is the distance travelled by light in one year (around $9{\cdot}5 \times 10^{15}$ m).

For example: Proxima Centauri (the nearest star, apart from the Sun) is 4·3 light-years away; our galaxy (the Milky Way) is around 100 000 light-years across and the next nearest spiral galaxy (Andromeda) is 2·5 million light-years away.

Our current understanding of the Universe comes from observations of it using **telescopes**.



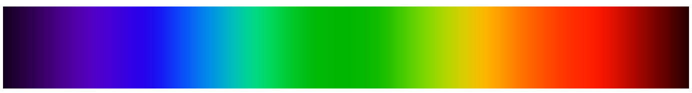
Today we use telescopes which cover all parts of the **electromagnetic spectrum** to investigate astronomical objects:

e.g.

Part of Spectrum	Examples of telescopes	Observations made
radio	Arecibo Joddrell Bank Very Large Array (VLA)	• discovery of pulsars and quasars • studying plasma clouds • studying the Sun's magnetic field
microwaves	Holmdel Horn Antenna Cosmic Background Explorer (COBE)	• the existence of cosmic microwave background radiation – evidence of the Big Bang
infrared	Spitzer Herschel	• studying nebulae, gas clouds and the formation of stars • identification of exoplanets
visible light	Hooker Kepler Very Large Telescope (VLT) Hubble Space Telescope	• observations of galactic redshift – evidence of the expanding Universe • imaging planets, stars and galaxies
ultraviolet	Galaxy Evolution Explorer (GALEX)	• studying star formation • measurement of distances to distant galaxies
X-rays	Solar and Heliospheric Observatory (SOHO) Chandra	• studying the Sun's atmosphere • studying supernovae
gamma rays	Fermi	• evidence of supermassive black holes at centres of galaxies • studying gamma ray bursts – probably due to hypernovae

One of the techniques used in astronomy is **spectroscopy**

A complete (continuous) spectrum is made up of all the colours of the spectrum (red, orange, yellow, green, blue, indigo and violet).



A line spectrum consists of a complete (continuous) spectrum with certain colours missing which appear as black line in the spectrum. Every element produces a unique line spectrum.

Studying line spectra allows the elements present in a light source (e.g. a star) to be identified. This can allow the type, distance, age or speed of a star to be identified.