National 5 Physics

Dynamics and Space

Summary Notes

Section 1 – Kinematics

Average Speed

Average speed is the distance travelled per unit time.

distance (m)

average speed (m/s)

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

time (s)

SI unit of average speed is m/s (metres per second) since the SI unit for distance is metres (m) and SI unit for time is seconds (s).

Examples of alternative units for average speed are kilometres per hour (km/h) or miles per hour (mph).

Measurement of average speed

To measure an average speed, you must:

- measure the distance travelled with a measuring tape, metre stick or trundle wheel
- measure the time taken with a stop clock
- calculate the average speed by dividing the distance by the time

Calculations involving distance, time and average speed

Note: care must be taken to use the correct units for time and distance.

Example

Calculate the average speed in metres per second of a runner who runs 1500 m in 5 minutes.

Solution

s = 1500 m

t = 5 minutes = 5 × 60 seconds = 300 s

v = ?

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

$$= \frac{1500}{300}$$

$$= 5\ m/s$$

Instantaneous speed

The instantaneous speed of a vehicle at a given point can be measured by finding the average speed during a **very short time interval** as the vehicle passes that point.

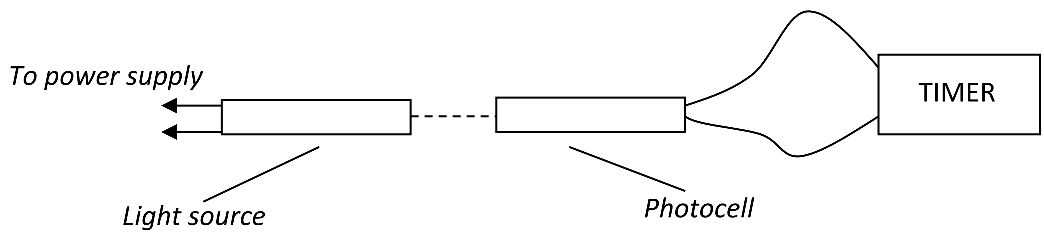
Average speed and instantaneous speed are often very different e.g. the average speed for a car over an entire journey from Glasgow to Edinburgh could be 40 mph, but at any point in the journey, the instantaneous speed of the car could be 30 mph, 70 mph, 60 mph or 0 mph if the car is stationary at traffic lights.

Measuring Instantaneous Speed

To measure instantaneous speeds, it is necessary to measure **very** short time intervals.

With an ordinary stop clock, human reaction time introduces large uncertainties. These can be avoided by using electronic timers. The most usual is a **light gate.**

A light gate consists of a light source aimed at a photocell. The photocell is connected to an electronic timer or computer.

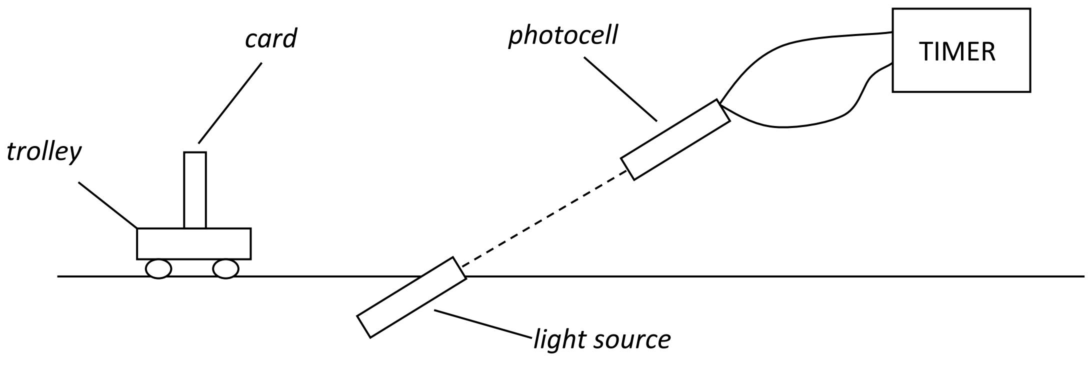


The timer measures how long an object takes to pass through the light beam.

The distance travelled is the length of the object which passes through the beam.

Often a card is attached so that the card passes through the beam.

Procedure to measure the instantaneous speed of a trolley



- Set up apparatus as shown
- Measure length of card
- Push trolley through light beam
- Timer measures time taken for card to pass through light gate
- Calculate instantaneous speed by

$$instantaneous\ speed = \frac{length\ of\ card}{time\ to\ pass\ through\ light\ beam}$$

Example

In the above experiment, the following measurements are made:

Length of card: 10 cm

Time on timer: 0.25 s

Calculate the instantaneous speed of the vehicle

Solution

Length of card = 10 cm = 0.1 m

Time on timer = 0.25 s

$$instantaneous\ speed = \frac{length\ of\ card}{time\ to\ pass\ through\ light\ beam}$$

$$= \frac{0.1}{0.25}$$

$$= 0.4\ m/s$$

<u>**Vector and Scalar Quantities**</u>

A **scalar quantity** is fully described by its magnitude (size) and unit, e.g.

unit

quantity *time = 220 s*

magnitude

A **vector quantity** is fully described by its magnitude, unit, **and direction,** e.g.

unit

quantity *Force = 800 N upwards* direction

magnitude

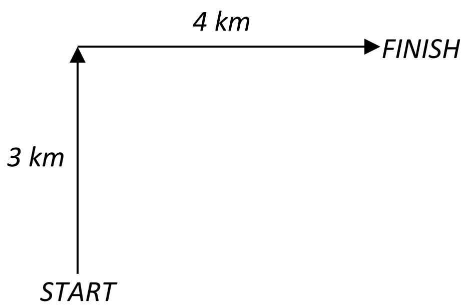
<u>Distance and Displacement</u>

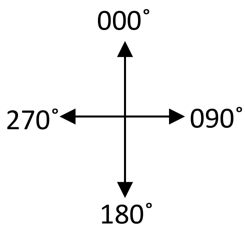
Distance is a **scalar** quantity. It measures the total distance travelled, no matter in which direction.

Displacement is a **vector** quantity. It is the length measured from the starting point to the finishing point in a straight line. Its **direction** must be stated.

Example

A girl walks 3 km due north then turns and walks 4 km due east as shown in the diagram.





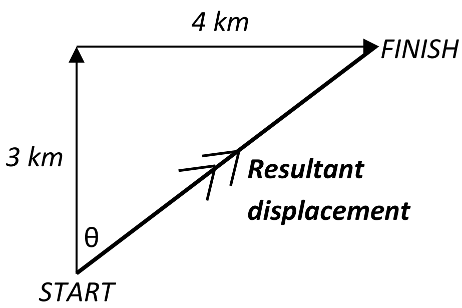
Calculate

(a) The total distance travelled
(b) The girl's final displacement relative to her starting position.

Solution

(a) Total distance = 3 km + 4 km
= 7 km

(b) ***(to calculate displacement, we need to draw a vector diagram)***
(this solution involves using Phythagoras and trig functions (SOH-CAH=TOA), but you can also solve these types of problems using a scale diagram).



Magnitude of displacement = $\sqrt{3^2 + 4^2}$

= *5 km*

$tan\theta = \frac{4}{3}$

Θ= 53˚

Resultant displacement = 5 km at 053˚

Speed and Velocity

Speed is a **scalar** quantity. As discussed above, speed is the **distance** travelled per unit time.

$$\boxed{(average)speed = \frac{distance}{time}}$$

Velocity is a **vector** quantity (the vector equivalent of speed). Velocity is defined as the **displacement** per unit time.

$$\boxed{(average)velocity = \frac{displacement}{time}}$$

Since velocity is a **vector,** you **must** state its direction.

The direction of velocity will be the same as the displacement.

Example

The girl's walk in the previous example took 2.5 hours.

Calculate

(a) The average speed
(b) The average velocity for the walk, both in km/h

Solution

(a) Distance = 7 km

Time = 2.5 hours

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

$$= \frac{7}{2.5}$$

$$= 2.8\ km/h$$

(b) Displacement = 5 km (053˚)

Time = 2.5 hours

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

$$= \frac{5}{2.5}$$

$$= 2\ km/h \text{ at } 053^{\circ}$$

(When performing calculations on speed and velocity like the above, it is best to write the equations in words as shown, to avoid confusion with symbols. This communicates your understanding in the clearest way).

<u>Acceleration</u>

Acceleration is defined as the **change in velocity per unit time.**

$$a = \frac{\Delta v}{t}$$

The change in velocity can be given by the moving object's final velocity (v) – initial velocity (u)

$$\Delta v = v - u$$

Therefore we can write our equation for acceleration as

Final velocity (m/s)

Initial velocity (m/s)

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

Acceleration (m/s²)

Metres per second per second

Time (s)

Acceleration is a **vector** quantity. If the final speed is less than the initial speed, the acceleration is in the opposite direction to motion and will be **negative.** This indicates a **deceleration.**

The equation for acceleration can be rearranged in terms of the final velocity, v

$$\boxed{v = u + at}$$

Example

A car is travelling with an initial velocity of 15 m/s. The driver presses the accelerator pedal and the car accelerates at a rate of 2 m/s² for 4 s. Calculate the final velocity of the car.

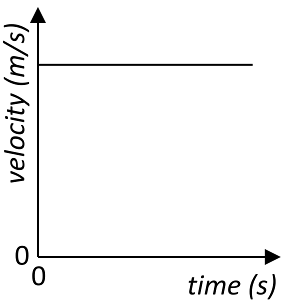
v = ?	*v = u + at*
u = 15 m/s	*= 15 + (2x4)*
a = 2 m/s²	*= 23 m/s*
t = 4 s	

Velocity-time graphs

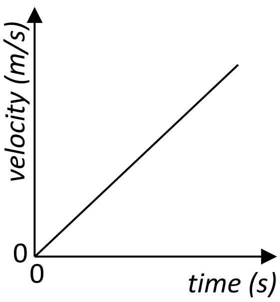
Velocity-time graphs provide a useful way of displaying the motion of an object.

They can be used to:

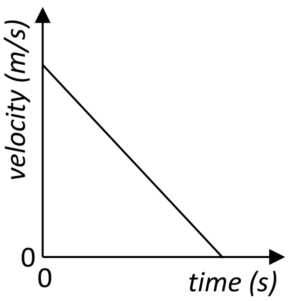
1) Describe the motion of the object in detail.
2) Calculate values for accelerations and decelerations using **gradients**.
3) Calculate distances travelled and resultant displacements **using area under graph**.
4) Calculate the average velocity for a journey.



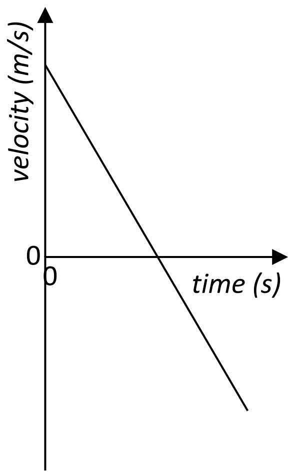
constant velocity



constant acceleration



constant deceleration

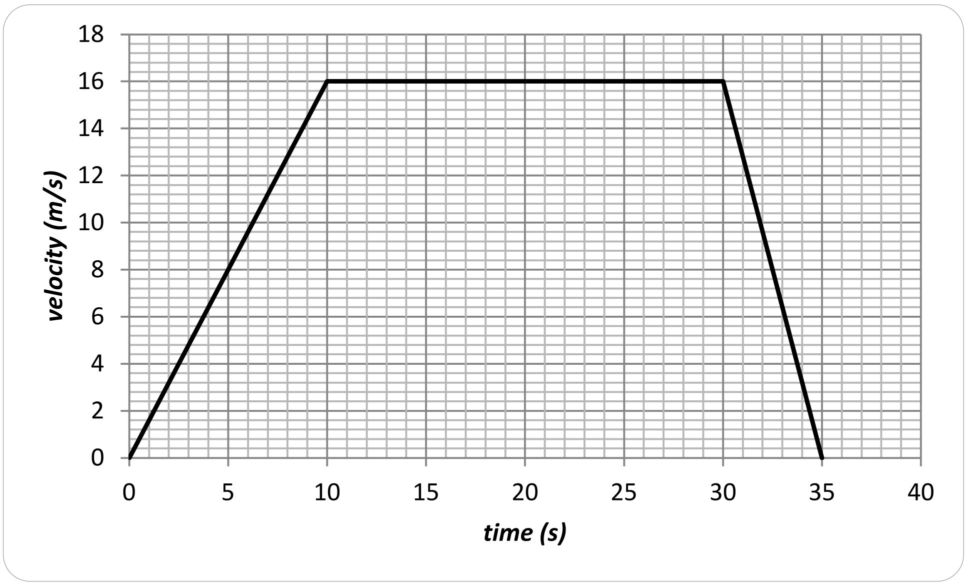


constant deceleration to rest, then constant acceleration in the opposite direction

(Note: Speed-time graphs are also used, but a speed-time graph would not show any change in direction).

Example

The graph below shows the motion of a car over 35 seconds.



(a) *Describe the motion of the car during the 35 seconds*
(b) *Calculate the acceleration between 0 and 10 seconds*
(c) *Calculate the acceleration between 30 and 35 seconds*
(d) *Calculate the final displacement of the car from the starting position*
(e) *Calculate the average velocity during the 35 seconds.*

Solution

(a) *0→10 seconds:* *constant acceleration from rest to 16 m/s*
10→30 seconds: *constant velocity of 16 m/s*
30→35 seconds *constant deceleration from 16 m/s to rest.*

(b) *a = ?* $a = \frac{v-u}{t}$

v = 16 m/s $= \frac{16-0}{10}$

u= 0 $= 1.6\ m/s^2$

t = 10 s

(c) *a = ?* $a = \frac{v-u}{t}$

v = 0 m/s $= \frac{0-16}{5}$

u= 16 m/s $= -3.2\ m/s^2$

t = (35-30)=5 s

(d) displacement = area under v-t graph

= (½ x 10 x 16) + (20 x 16) + (½ x 5 x 16)

= 80 + 320 + 40

= 440 m

(e) average velocity = ?

displacement = 440 m

time = 35 s

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

$$= \frac{440}{35}$$

= 12.6 m/s

Section 2 – Newton's Laws

Effects of Forces

We can't see forces themselves, but we can observe the effects that they have.

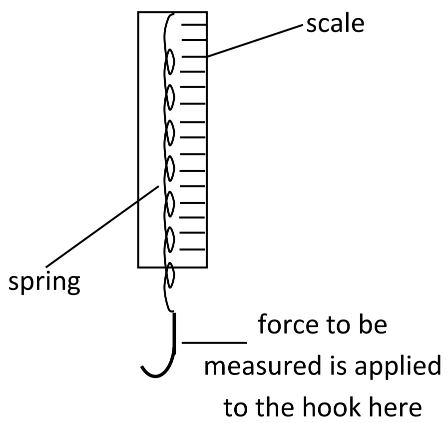
Forces can change:

- the shape of an object
- the speed of an object
- the direction of travel of an object

Measuring Force

The unit of force is the Newton.

The size of a force can be measured using a device called a **Newton Balance.**



A force is applied to the hook and the spring is stretched.

The greater the force applied, the greater the extension of the spring.

The size of the force is read from the scale.

Mass and Weight

Mass and Weight mean different things!

Mass is a measure of the amount of matter that an object is made of. The units of mass are kilograms (kg).

Weight is the size of the **force** that gravity exerts on an object. The units of weight are Newtons (N) since weight is a force.

Gravitational field strength

Gravitational field strength is the **weight per unit mass,** i.e. gravitational field strength is the amount of force that gravity exerts on every kilogram of an object.

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

Therefore the units of gravitational field strength are **Newtons per kilogram (N/kg).**

This can be rearranged to give:

mass (kg)

weight (N) $\boxed{W = m\,g}$ gravitational field strength (N/kg)

Example

The gravitational field strength on the surface of Earth is 10 N/kg.

The gravitational field strength on the surface of the Moon is 1.6 N/kg.

Calculate the weight of an astronaut of mass 60 kg

(a) on the surface of the Earth
(b) on the surface of the Moon

Solution

(a) W=? | *W = m g*
m=60 kg | *= 60 x 10*
g=10 N/kg | *= 600 N*

(b) W=? | *W = m g*
m=60 kg | *= 60 x 1.6*
g=1.6 N/kg | *= 96 N*

Friction

Friction is a **resistive** force, which opposes the motion of an object. This means that it acts in the **opposite** direction to motion. Friction acts between any two surfaces in contact. When one surface moves over another, the force of friction acts between the surfaces and the size of the force depends on the surfaces, e.g. a rough surface will give a lot of friction.

Friction caused by collisions with particles of air is usually called **air resistance**. It depends mainly on two factors:

- the shape and size of the object
- the speed of the moving object.

Air resistance **increases** as the speed of movement increases.

Increasing and Decreasing Friction

Where friction is making movement difficult, friction should be reduced.

This can be achieved by:

- lubricating the surfaces with oil or grease
- separating the surfaces with air, e.g. a hovercraft
- making the surfaces roll instead of slide, e.g. use ball bearings
- streamlining to reduce air friction.

Where friction is used to slow an object down, it should be increased.

This can be achieved by:

- choosing surfaces which cause high friction e.g. sections of road before traffic lights have higher friction than normal roads
- increasing surface area and choosing shape to increase air friction, e.g. parachute.

Force is a vector

Force is a vector quantity. The direction that a force acts in will dictate the effect that it has.

Balanced Forces

Two forces acting in opposite directions are said to be **balanced**. The effect is equivalent to **no force** acting on the object at all.

Newton's First Law

"An object will remain at rest or move at a constant velocity in a straight line unless acted on by an unbalanced force".

This means that if the forces acting on an object are balanced, then the object will remain stationary if it was already stationary. For a moving object, if the forces acting on it are balanced, then it will continue to move in a straight line at a constant velocity.

balanced forces ↔ Object at rest OR object moving at a constant velocity in a straight line

Newton's Second Law

If an overall resultant (or unbalanced) force is applied to an object, then the object will accelerate in the direction of the unbalanced force.

- The greater the resultant force, the greater the acceleration.
- The smaller the mass, the greater the acceleration.

These two relationships are combined to give

acceleration (m/s^2)

(resultant or unbalanced) force (N)

$$\boxed{F_{un} = m\,a}$$

mass (kg)

This equation shows that a force of 1 N is the force needed to accelerate a mass of 1 kg at a rate of 1 m/s^2

Example

A trolley of mass 2 kg accelerates at a rate of 2.5 m/s^2.

Calculate the resultant force acting on the trolley.

Solution

$F_{un}=?$	$F_{un} = m\,a$
$m=2kg$	$= 2 \times 2.5$
$a=2.5\ m/s^2$	$= 5\ N$

Free Body Diagrams and Newton's Second Law

"Free body diagrams" are used to analyse the forces acting on an object. The **names** of the forces are labelled on the diagram. (It is also useful to mark the **sizes** of the forces on the diagram).

This enables us to calculate the resultant force, and then apply F_{un}=ma.

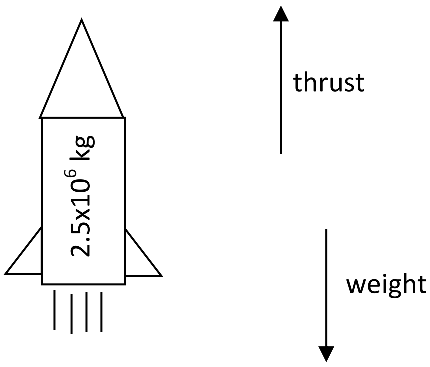
Example

A space rocket of mass $2.5\text{x}10^6$ kg lifts off from the earth with a thrust of $3.5\text{x}10^7$ N.

(a) Draw a free body diagram of the rocket at lift-off
(b) Calculate the resultant force acting on the rocket
(c) Calculate the initial acceleration of the rocket.

Solution

(a)



(Initially, no air resistance will act on the rocket at the instant it lifts off. Air resistance will only begin to act once the rocket starts moving).

(b)

F_{un} = thrust – weight

$= 3.5\text{x}10^7 - 2.5\text{x}10^7$

$= 1.0 \text{ x } 10^7$ N

W = mg

$= 2.5\text{x}10^6 \text{ x } 10$

$= 2.5\text{x}10^7$ N

(c)

$F_{un} = 1 \text{ x}10^7$ N

m = $2.5\text{x}10^6$ kg

a = ?

$$F_{un} = m\,a$$

$$a = \frac{F_{un}}{m}$$

$$= \frac{1\times10^7}{2.5\times10^6}$$

= 4 m/s^2

Forces at Right Angles

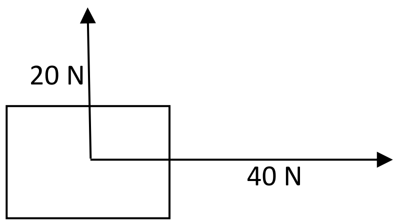
The resultant force arising from two forces acting at right angles can be found by

(a) Drawing the force vectors "nose-to-tail"
(b) Calculating the magnitude using Pythagoras
(c) Calculate the direction using trigonometry (SOH-CAH-TOA)

(Alternatively, you could draw the vectors "nose-to-tail" as a scale diagram. Then find the magnitude using a ruler and your chosen scale, and the direction using a protractor).

Example

Two forces act on an object at right angles to each other as shown.

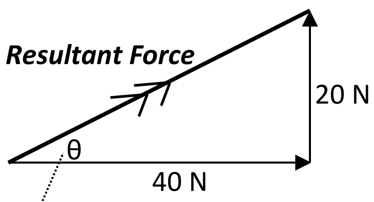


Calculate

(a) The magnitude of the resultant force
(b) The direction of the resultant force, relative to the 40 N force.

Solution

(arrange vectors "nose-to-tail" and draw resultant from tail of first to nose of last)



(question asks for direction relative to 40 N force)

(a) Magnitude of resultant force = $\sqrt{40^2 + 20^2}$

= 44.7 N

$(b) tan\theta = \frac{20}{40}$

Θ= 26.6˚

Resultant force = 44.7 N at 26.6˚ to 40 N force

Acceleration Due to Gravity and Gravitational Field Strength

Recall from pages 12-13 that **weight** is the **force** which causes an object to accelerate downwards and has the value mg, where g is the gravitational field strength.

The value of the acceleration caused by weight can be calculated from Newton's second law, using F_{un} = ma where F is now the weight W, and W = mg.

$$a = \frac{F_{un}}{m}$$

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

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

$$a = g$$

This shows that the acceleration due to gravity and the gravitational field strength are **numerically equivalent.**

Therefore the acceleration due to gravity on Earth is 10 m/s^2 since the gravitational field strength is 10 N/kg.

The acceleration due to gravity on the moon is 1.6 m/s^2 since the gravitational field strength is 1.6 N/kg.

Example

An astronaut drops a hammer on the Moon where the gravitational field strength is 1.6 m/s^2.

The hammer lands on the surface of the Moon 2.2 s after being dropped.

Calculate the velocity of the hammer at the instant it strikes the surface of the Moon.

Solution

(a) u=0	*v = u + at*
v= ?	*= 0 + (1.6x2.2)*
a=1.6 m/s^2	*= 3.52 m/s*
t=2.2 s	

Free-fall and Terminal Velocity

An object falling from a height on Earth will **accelerate** due to its weight. This is called **free-fall.**

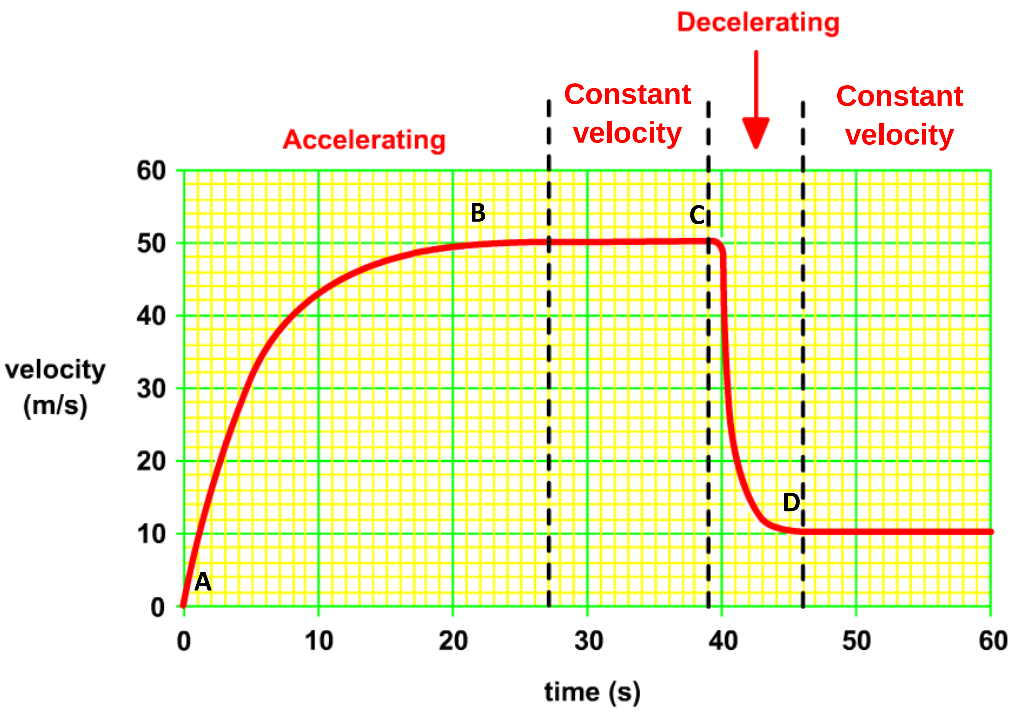
As the velocity increases, the air resistance acting on the object will increase.

This means that the unbalanced force on the object will decrease, producing a smaller acceleration.

Eventually, the air resistance will balance the object's weight, meaning that the object will fall with a **constant velocity.**

This final velocity is called **terminal velocity.**

The velocity-time graph shown below is for a parachutist undergoing free-fall before opening her parachute.



Point A – parachutist jumps from plane and undergoes acceleration due to gravity (free-fall)

*Point B – air resistance has increased to balance weight – constant velocity: **terminal velocity 1***

Point C – parachutist opens parachute – increased air resistance causes deceleration

*Point D – weight and air resistance balanced again so new slower constant velocity reached: **terminal velocity 2***

Newton's Third Law

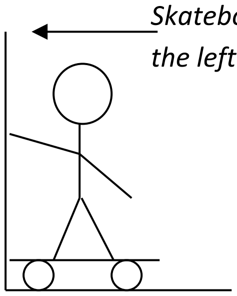
"For every action, there is an equal and opposite reaction".

Newton noticed that forces occur in pairs. He called one force the **action** and the other the **reaction**. These two forces are always **equal in size, but opposite in direction**. They do not both act on the same object.

If an object A exerts a force (the action) on object B, then object B will exert an equal, but opposite force (the reaction) on object A.

Examples

Skateboarder pushes wall to the left (action force)



Wall pushes skateboarder to right (reaction force)

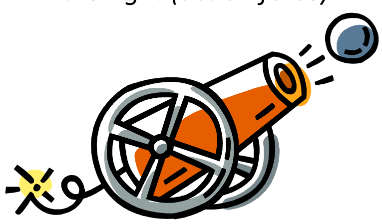
Water pushes swimmer to left (reaction force)

Swimmer pushes water to right (action force)

Fuel forces rocket upwards (reaction force)

Rocket forces fuel downwards (action force)

Cannon fires cannonball to the right (action force)

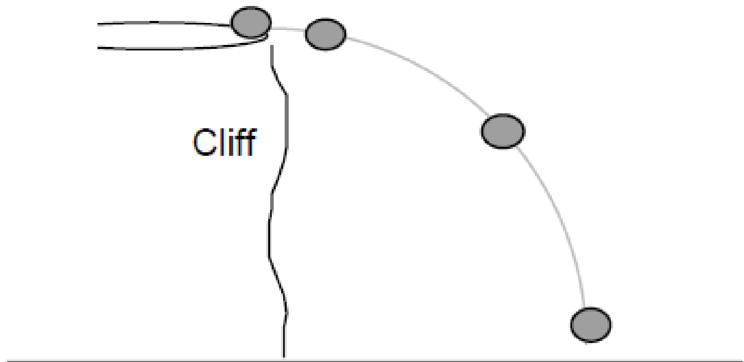


Cannonball forces cannon back to the left (reaction force)

These action and reaction forces are also known as **Newton Pairs.**

Section 3 – Projectile Motion

A projectile is an object which has been given a forward motion through the air, but which is also pulled downward by the force of gravity. This results in the path of the projectile being curved.



A projectile has two **separate** motions at right angles to each other.

Each motion is **independent** of the other.

The **horizontal** motion is at a **constant velocity** since there are no forces acting horizontally (air resistance can be ignored).

horizontal velocity (m/s)

So *horizontal distance (m)* $\boxed{d_h = v_h t}$ *time (s)*

The **vertical** motion is one of **constant acceleration**, equal to g (10 m/s^2 on earth).

For projectiles which are projected horizontally, the initial vertical velocity is zero.

For vertical calculations, use *time (s)*

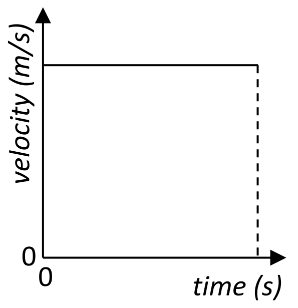
final vertical velocity (m/s) $\boxed{v_v = u_v + at}$ where $u_v = 0$ and $a = g$

initial vertical velocity (m/s)

acceleration due to gravity (m/s^2)

Velocity time graphs for horizontal and vertical motion

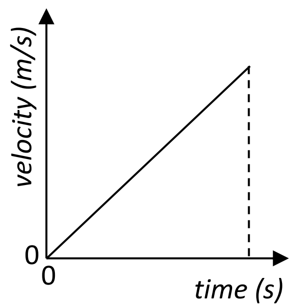
Horizontal motion



constant velocity

horizontal distance can be found using area under graph (equivalent to $d_h=v_ht$)

Vertical motion



constant acceleration from rest

vertical height can be found from area under graph (equivalent to $h=½\ v_{max}t$)

Example

An aircraft flying horizontally at 200 m/s, drops a food parcel which lands on the ground 12 seconds later.

Calculate:

a) the horizontal distance travelled by the food parcel after being dropped

b) the vertical velocity of the food parcel just before it strikes the ground

c) the height that the food parcel was dropped from.

Solution

(a useful layout is to present the horizontal and vertical data in a table)

(then select the data you need for the question, and clearly indicate whether you are using horizontal or vertical data).

Horizontal	*Vertical*
$d_h = ?$	$u_v = 0$
$v_h = 200\ m/s$	$v_v = ?$
$t = 12\ s$	$a = 10\ m/s^2$
	$t = 12\ s$

initial vertical velocity always 0 for a projectile launched horizontally

acceleration due to gravity

time of flight the same for both horizontal and vertical

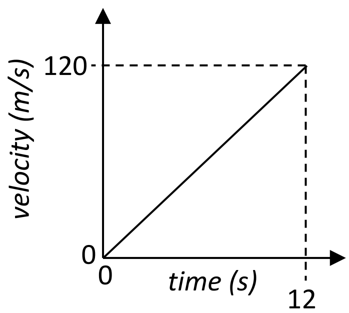
(a) Horizontal :

$d_h = ?$	$d_h = v_h\, t$
$v_h = 200$ m/s	$= 200 \times 12$
$t = 12$ s	$= 2400$ m

(b) *Vertical:*

$u_v = 0$	$v_v = u_v + at$
$v_v = ?$	$= 0 + 10 \times 12$
$a = 10$ m/s^2	$= 120$ m/s
$t = 12$ s	

(c) *(Draw a velocity time graph of* ***vertical*** *motion)*



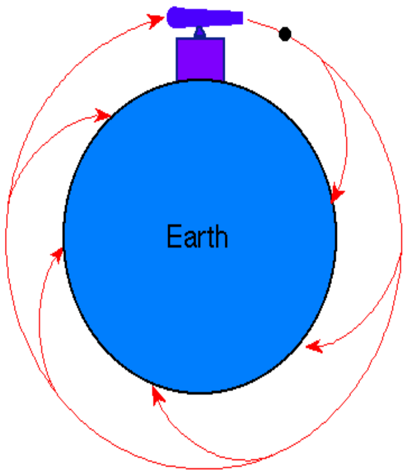
height $= $ *area under v-t graph*

$= \frac{1}{2} \times 12 \times 120$

$= 720$ m

<u>Satellites and Projectile Motion</u>

Newton's Thought Experiment



Newton's thought experiment allowed us to understand satellite orbits.

If a projectile is launched with sufficient horizontal velocity, it will travel so far that the curvature of the Earth must be taken into account.

Now imagine a projectile launched with such a great horizontal velocity that it never reaches the ground! It will continue to circle the Earth until its horizontal velocity decreases.

The satellite orbits around the Earth because it is in constant free-fall due to the Earth's gravity.

Apparent Weightlessness

Astronauts in orbit around the Earth are in a constant state of free-fall. The spaceship, the astronauts and everything inside are all accelerating towards the Earth due to gravity.

This is known as apparent weightlessness. The effects are because of gravity, and **not** because they have escaped from the gravitational field of the Earth.

Section 4 – Space Exploration

Current understanding of the universe

What we know about the Universe is a result of humankind's continual curiosity about our existence. This has led to a remarkable understanding of our Universe which is continually developing. Much of this can be attributed to our continual observation of space along with our exploration of the Solar System and beyond.

Big Bang Theory

(http://big-bang-theory.com)

- The Big Bang theory is an effort to explain what happened at the very beginning of our universe.
- Discoveries in astronomy and physics have shown beyond a reasonable doubt that our universe did in fact have a beginning. Prior to that moment there was nothing; during and after that moment there was something: our universe.
- Our universe sprang into existence as a "singularity" around 13.7 billion years ago.
- Singularities are zones which defy our current understanding of physics. They are thought to exist at the core of Black Holes.
- Black holes are areas of intense gravitational pressure. The pressure is thought to be so intense that finite matter is compressed into infinite density.
- Our universe is thought to have begun as an infinitesimally small, infinitely hot, infinitely dense singularity.
- After its initial appearance, the universe inflated, expanded and cooled, going from very, very small and very, very hot, to the size and temperature of our current universe.
- It continues to expand and cool to this day and we are inside of it!
- There is currently debate as to whether the universe will continue expanding, or whether it will start to contract.

Big Bang Theory - Evidence for the Theory

- Galaxies **appear to be moving away from us** at speeds proportional to their distance. This is called "Hubble's Law," named after Edwin Hubble (1889-1953) who discovered this phenomenon in 1929. This observation supports the expansion of the universe and suggests that the universe was once compacted.
- **"Doppler red-shift"** also provides evidence that **galaxies are moving away from us.** The light from galaxies appears to be more red than it should be, and the decreased frequency of the light tells us that the galaxies are moving away from us.
- If the universe was initially very, very hot as the Big Bang suggests, we should be able to find some remnant of this heat. In 1965, Arno Penzias and Robert Wilson discovered a 2.725 degree Kelvin (-270.425 degree Celsius) **Cosmic Microwave Background radiation (CMB)** which pervades the observable universe. This is thought to be the remnant which scientists were looking for. Penzias and Wilson shared in the 1978 Nobel Prize for Physics for their discovery.
- The **abundance of the "light elements" Hydrogen and Helium** found in the observable universe are thought to support the Big Bang model of origins.

Space exploration and our understanding of the Earth

Satellites have allowed us to make observations of the Earth.

Important observations of the environment have been made using monitoring satellites in orbit around the Earth, including:

- reduction of rainforest
- melting of polar icecaps

Technologies arising from space exploration

Some examples include

- Weather forecasting
- GPS and Sat Nav
- Global communication
- Satellite TV
- Protective paints

NASA has a website called "Spin-off" which shows how technologies developed in their Space Programme have benefits in everyday life –

http://spinoff.nasa.gov/index.html

http://spinoff.nasa.gov/Spinoff2008/tech_benefits.html

http://www.nasa.gov/externalflash/nasacity/index2.htm

For any technology that you provide, you must be able to describe the impact that it has on our everyday life.

Re-entry into the atmosphere

- When a spacecraft re-enters the Earth's atmosphere, it is travelling at a velocity of around 11 000 m/s.
- The force of air resistance from the Earth's atmosphere is huge at these velocities.
- Air resistance does **work** on the spacecraft which changes the **kinetic** energy to **heat** **($E_k \rightarrow E_h$)**.
- The heat absorbed can cause a temperature increase of around 1300 °C

Heat Shield Design

Case Study – the Shuttle

The Shuttle was the first (and only) reusable spacecraft. The first Shuttle mission was launched in 1981 and the final mission was in July 2011.

The part of the Shuttle that returns to Earth is called the *Orbiter* and its shape resembles an aircraft.

(For more information, see http://www.nasa.gov/mission_pages/shuttle/main/index.html).

- The Shuttle Orbiter is made from aluminium alloy covered in special tiles to protect it from the intense heat generated during re-entry.
- The Shuttle needs around 34 000 thermal protection tiles (all of different shapes and sizes).
- The tiles are made of a material called silica, which has a high specific heat capacity and a high melting point *(c=1040 J/kg ℃, melting point = 1610 ℃).*
- The tiles are painted black so that heat is lost to the surroundings. The air around the shuttle heats up. The temperature increase of the shuttle is therefore not as great.

Protection by vapourisation

Heat shields are also designed with coatings that vapourise. The temperature of the craft is stabilised since the coating absorbs heat at a constant temperature while it melts and boils (E_h=ml).

Example

A heat shield on a spacecraft has a mass of 50 kg.

The spacecraft is travelling at 1000 m/s. On re-entry into the Earth's atmosphere, the velocity of the spacecraft is reduced to 200 m/s.

(a) *Calculate the change in kinetic energy of the heat shield.*
(b) *Calculate the change in temperature of the heat shield. (Assume all of the kinetic energy is changed to heat in the heat shield material).*

Specific heat capacity of heat shield material = 1040 J/kg ℃

Solution

(a)

$m = 50$ kg

$u = 1000$ m/s

$v = 200$ m/s

Change in $E_k = \text{initial } E_k - \text{final } E_k$

$= (½mu^2) - (½mv^2)$

$= (½ \times 50 \times 1000^2) - (½ \times 50 \times 200^2)$

$= 2.5 \times 10^7 - 1.0 \times 10^6$

$= 2.4 \times 10^7$ J

(b)

$\Delta E_h = \Delta E_k = 2.4 \times 10^7$ J

$c = 1040$ J/kg ℃

$m = 50$ kg

$\Delta T =$

$E_h = cm\Delta T$

$2.4 \times 10^7 = 1040 \times 50 \times \Delta T$

$\Delta T = \frac{2.4\times10^7}{1040\times50}$

$= 460$ °C

Section 5 - Cosmology

The Light Year

- The "light year" is a measurement of **distance.**
- 1 light year is the distance that light travels in 1 year.

Example

(a) Calculate the number of metres in 1 light year.

(b) Proxima Centauri, the next closest star after the Sun, is 4.3 light years from the Earth. Calculate this distance in metres.

Solution

(a) $d = ?$

$s = 3\times10^8$ m/s

$t = 1$ year

$= 365.25\times24\times60\times60$ s

$d = st$

$= 3\times10^8\times(365.25\times24\times60\times60)$

$= 9.47\times10^{15}$ m

(b)

1 light year $= 9.47\times10^{15}$ m

4.3 light years $= 4.3\times9.47\times10^{15}$ m

$= 4.07\times10^{16}$ m

Proxima Centauri is 4.07×10^{16} m from Earth

Age of the universe

Current thinking dates the age of the universe as approximately **14 billion years.**

Observable universe

- The **universe** consists of many galaxies separated by empty space.
- A **galaxy** is a large cluster of stars (e.g. theMilky Way).
- A **star** is a massive ball of matter that is undergoing nuclear fusion and emitting light and heat. The Sun is a star.
- The sun and many other stars have a solar system. A **solar system** consists of a central star orbited by planets.
- A **planet** is a large ball of matter that orbits a star (e.g. Earth or Jupiter). Planets do not emit light themselves.
- Many planets have moons. A **moon** is a lump of matter that orbits a planet (e.g. the Moon orbits the Earth. Deimos and Phobos orbit Mars.

These are features of the **observable** universe. The universe also contains matter that cannot be observed directly, e.g. **dark matter.**

Electromagnetic Spectrum

increasing wavelength →

Gamma rays X-rays Ultraviolet Visible light Infrared Microwaves Radio + TV

← *increasing frequency*

Radiation from space

The main types of radiation received from space (being emitted from stars, galaxies, etc.) are

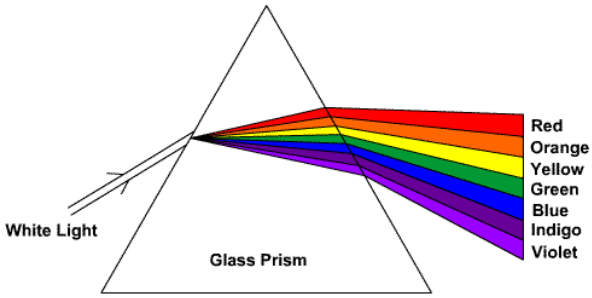
- Electromagnetic radiation (across the entire spectrum from radio to gamma)
- Cosmic rays (mainly energetic protons)
- Neutrinos (tiny elementary particles with no charge)

Detectors of electromagnetic radiation

Radiation	Detector
Gamma rays	Geiger-Müller tube
X-rays	Photographic film
Ultraviolet	Fluorescent paint
Visible light	Photographic film
Infrared	Charge-coupled diode (CCD)
Microwaves	Diode
Radio + TV Waves	Aerial

<u>Spectra</u>

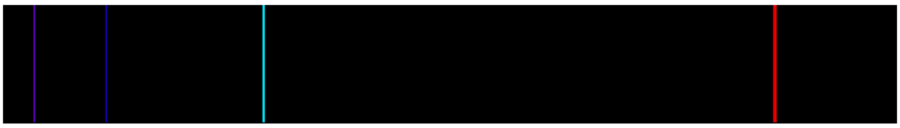
- White light is made up of a range of colours.
- These colours can be separated by splitting white light with a **prism** to obtain a **spectrum**.



- A spectrum can also be produced using a **diffraction grating.**

- A **line absorption spectrum** consists of a complete (continuous) spectrum with certain colours missing which appear as black lines in the spectrum.

- A **line emission spectrum** consists of lines of light of distinct colours rather than a continuous 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 help to identify the type, distance, age or speed of a star.