National 5 Physics

Dynamics and Space

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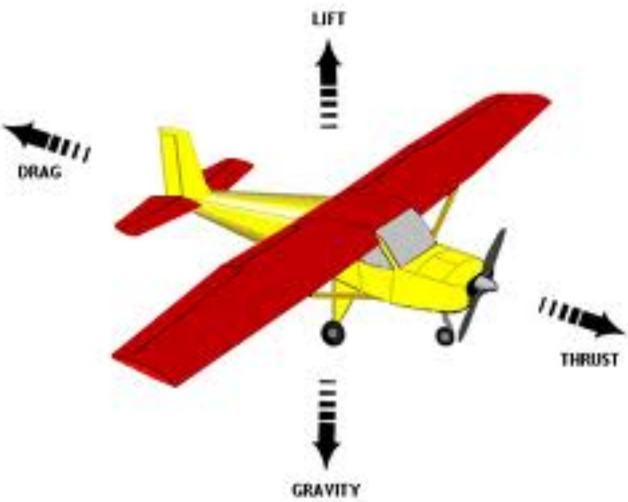

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Prefixes and Scientific Notation

Throughout the course, appropriate attention should be given to units, prefixes and scientific notation.

tera	T	10^{12}	x 1,000,000,000,000
giga	G	10^{9}	x 1,000,000,000
mega	M	10^{6}	x 1,000,000
kilo	k	10^{3}	x 1,000
centi	c	10^{-2}	/100
milli	m	10^{-3}	/1,000
micro	μ	10^{-6}	/1,000,000
nano	n	10^{-9}	/1,000,000,000
pico	p	10^{-12}	/1,000,000,000,000

In this section the prefixes you will use most often are centi(c) milli (m), micro (μ), kilo (k), mega (M) and giga (G). It is essential that you use these correctly in calculations.

In Physics, the standard unit for time is the **second (s)** and therefore if time is given in milliseconds (ms) or microseconds (μs) it must be converted to seconds.

Example 1
A car takes 2 ms to pass a point in the road. How many seconds is this?

2 ms = 2 milliseconds = 2 x 10^{-3} s = 2/1 000 = 0.002 seconds.

In Physics, the standard unit for distance is the **metre (m)** and therefore if distance is given in kilometres (km) it must be converted to metres.

Example 2
A car travels 15.6 km in ten minutes. How far in metres has it travelled?

15.6 km = 15.6 kilometres = 15.6 x 10^{3} m = 15.6 x 1 000 = 15 600 metres.

Example 3
An object experiences a force of 15 kN. How many Newton is this?

15 kN = 15 kiloNewtons = 15 x 10^{3} N = 15 x 1000 = 15 000 Newtons

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Contents

1. Velocity and Displacement - Vectors and Scalars

1.1 Vector and scalar quantities: force, speed, velocity, distance, displacement, acceleration, mass, time and energy.

1.2 Calculation of the resultant of two vector quantities in one dimension or at right angles.

1.3 Determination of displacement and/or distance using scale diagram or calculation. Use of appropriate relationships to calculate velocity in one dimension.

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

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

Velocity and displacement – Vectors and Scalars

Physical quantities can be divided into two groups:

- a **scalar** quantity is completely described by stating its **magnitude** (size).
- a **vector** quantity is completely described by stating its **magnitude** and **direction**.

The following table lists some of the scalars and vectors quantities that will be encountered in this course.

Scalars	Vectors
Energy	Velocity
Temperature	Weight
Pressure	Acceleration
Time	Displacement
Mass	Momentum
Current	Force
Speed	
Volume	
Voltage	
Distance	
Area	
Resistance	
Frequency	

Vectors

A vector is often drawn with an arrow to indicate its size and direction. The starting point of the arrow is called the "tail" and the arrow end is called the "tip".

Adding Vectors

Example

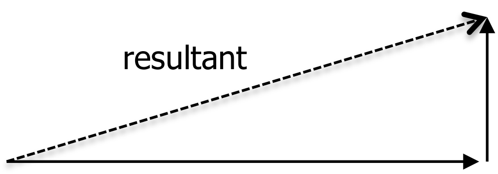
Two forces are applied to a box as shown below

Resultant = 12 – 8 = 4 N to the right

When adding more than one vector they must be added "tip to tail". That means that the tip of the first vector must point at the tail of the next vector.

In some cases that means that the two vectors have to be redrawn so that they are being added "nose/tip to tail". See example below.

Then join a line from the tail of the first vector to the nose/tip of the second vector. This is the **resultant** vector.

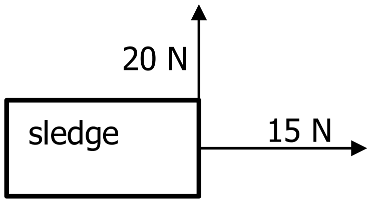


There are two possible methods for finding the size and direction of the resultant of two vectors acting at right angles to each other.

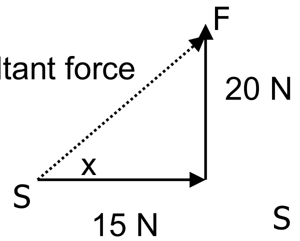
- Draw a scale diagram
- Use Pythagoras and trig functions.

Example 1

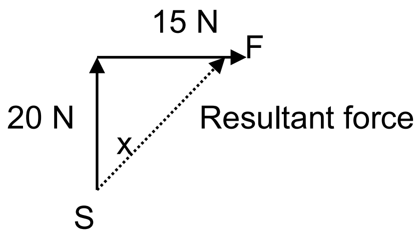
If there are two forces pulling a sledge (see diagram below) then calculate the resultant force acting on the sledge.



Step 1
Redraw the diagram with the vectors 'tip to tail'. The first way to do this is below.



OR



S = Start
F = Finish

Step 2
Do the calculation using Pythagoras to find the resultant force.

Resultant = $\sqrt{(15^2 + 20^2)} = \sqrt{(225 + 400)} = 25$ N

Step 3
BUT resultant force must have a direction. This can be found by drawing a scale diagram.

Rules for Drawing A Scale Diagram
1. Select a scale which will allow you to draw a diagram that fits on about half a page.
2. Mark North and the starting point.
3. Draw the two vectors and the resultant.
4. Measure the angle between the first vector and the displacement.
   This is the direction.

Angle x = 53^0

(Trigonometry can also be used

$\tan x = 4/3 \Rightarrow x = \tan^{-1}(4/3) = 53.1^o$)

Displacement is 5 m in a direction of 53 ^{o} East of North or at a bearing of 053^o.

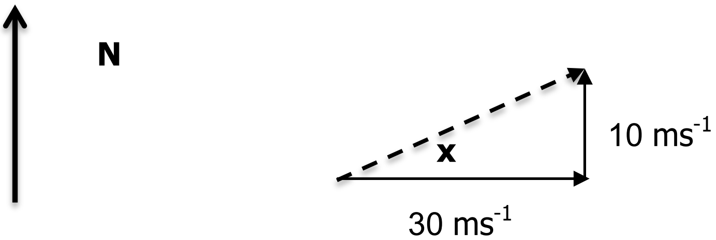
Step 4
Write down the full answer.

Resultant force is 25 N at 53^0 North of East or at a bearing of (037).

Example 2

A strong wind blows at 30 ms^{-1} Eastward. What is the resultant velocity of a plane flying due North at 10 ms^{-1}?

Scale Diagram



Velocity = 31.6 m/s 18^0 north of east or at bearing of (072).

Trigonometry

Velocity = $\sqrt{(30^2 + 10^2)}$ = 31.6 ms^{-1}

tan x = 10/30 => x = $\tan^{-1}(10/30)$ = 18^0 => direction is 18^0 north of east or at a bearing = (072)

Velocity = 31.6 ms^{-1} at bearing of (072) or 18^0 north of east

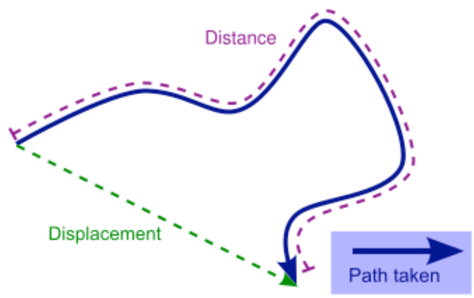
Distance and Displacement

Distance is a measure of how far a body has actually travelled in any direction.
Distance is a scalar as it only requires a magnitude

Displacement is the measurement of how far an object has travelled in a straight line from the start to the finish of its journey.
Displacement is a vector and so a magnitude and a direction is required.

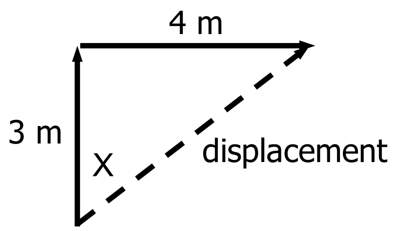
Example

1.



A walker has followed a path through a forest as shown. The distance travelled is much larger than their displacement from the starting position.

2.



A skateboarder travels 3 m due North, then turns and travels due East for 4 m.

They have travelled a distance of 3 + 4 = 7 m

The displacement is calculated as follows:

$(\text{Displacement})^2 = 3^2 + 4^2 = 25 \quad \Rightarrow \text{displacement} = \sqrt{25} = 5\text{ m}$

BUT displacement must have a direction. This can be found by drawing a scale diagram.

Rules for Drawing A Scale Diagram

1. Select a scale which will allow you to draw a diagram that fits on about half a page.
2. Mark North and the starting point.
3. Draw the two vectors and the resultant.
4. Measure the angle between the first vector and the displacement.
   This is the direction.

Angle x = 53^0

Trigonometry can also be used

$\tan x = 4/3 \Rightarrow x = \tan^{-1}(4/3) = 53.1^o$

Displacement is 5 m in a direction of 53 ^{o} East of North or at a bearing of 053^o.

Speed

Speed is described by the equation below. Speed is a scalar quantity.

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

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

Symbol	Definition	Unit	Unit symbol
v	speed	metre per second	ms^{-1}
d	distance	metre	m
t	time	second	s

Velocity

Velocity is described by the equation below. Velocity is a vector quantity. The direction of the velocity will be the same as the direction of the displacement.

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

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

Symbol	Definition	Unit	Unit symbol
v	velocity	metre per second	ms^{-1}
s	displacement	metre	m
t	time	second	s

If the velocity is measured over the whole journey then it is known as **average velocity**, with the symbol $\bar{v}$**.**

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

Symbol	Definition	Unit	Unit symbol
$\bar{v}$	Average velocity	metre per second	ms^{-1}
s	total displacement	metre	m
t	time	second	s

Example

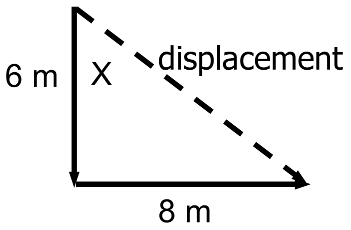
A remote control toy car goes 6 m due South and then 8 m due East. It takes two minutes to do this journey.

a) Find the distance it travelled and its displacement.

b) Calculate its average speed and velocity.

Solution

First draw a diagram to help.



a) Distance = 6 + 8 = 14 m

$(\text{Displacement})^2 = 6^2 + 8^2 = 100 \Rightarrow \text{displacement} = \sqrt{100} = 10\text{ m}$

Direction: Angle x can be calculated using trigonometry

tan x = 8/6 => x = $\tan^{-1}(8/6) = 53^{0}$

or by scale diagram

Displacement is 10 m in a direction of 53° East of South or at a bearing of (127)

.

b) Average Speed

d = 14 m	v = d/t
t = 2 minutes = 2 x 60 = 120 s.	v = 14/120
v = ?	v = 0.1166
	v = 0.12 ms^{-1}

Velocity

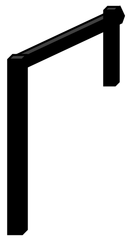
s = 10 m	v = s/t
t = 2 minutes = 2 x 60 = 120 s.	v = 10/120
v = ?	v = 0.083 ms^{-1}

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** as the vehicle passes that point. Average speed and instantaneous speed are often very different e.g. the average speed of a runner during a race will be less than the instantaneous speed as the winning line is crossed.

Measuring Instantaneous Speeds

To measure instantaneous speeds, it is necessary to be able to measure **very** short times. With an ordinary stopclock, human reaction time introduces large errors. These can be avoided by using electronic timers. The most usual is a light gate**.**



Light gate used in class

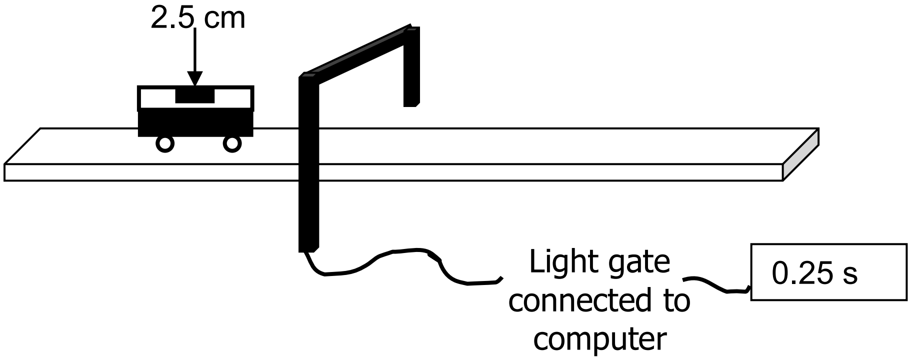
A light gate consists of a light source aimed at a photocell. The photocell is connected to an electronic timer or computer. The timer measures how long an object takes to cut the light beam. The distance travelled is the length of the object which passes through the beam. Often a card is attached so that the card passes through the beam. The length of the card is easy to measure. The instantaneous speed as the vehicle passes through the light gate is then calculated using:

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

Symbol	Definition	Unit	Unit symbol
v	Speed of vehicle	metre per second	ms^{-1}
d	length of card	metre	m
t	time	second	s

Example

A vehicle moves through a light gate as shown in the diagram. Using the data from the diagram, calculate the instantaneous speed of the vehicle as it passes the light gate.



Solution

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

$$v = \frac{0.025}{0.25}$$

$$v = 0.1\ ms^{-1}$$

2. Velocity – Time graphs

2.1 Velocity–time graphs for objects from recorded or experimental data.
2.2 Interpretation of velocity – time graph to describe the motion of an object.

$$\text{Displacement} = \text{area under v} - \text{t graph}$$

3. Acceleration

3.1 Acceleration of a vehicle between two points using appropriate relationships with initial and final velocity and time of change.
3.2 Acceleration from a velocity–time graph.

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

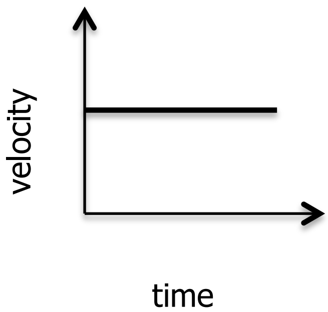
$$a = \frac{v - u}{t}$$

Velocity-Time Graphs

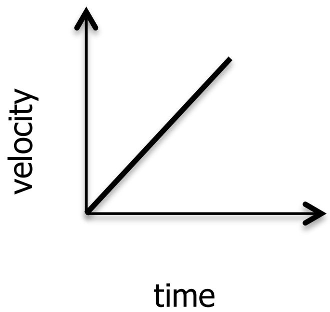
A velocity-time graph is a useful way to describe the motion of an object. Time is always plotted along the x-axis, and velocity is plotted along the y-axis.

The **shape** of the graph indicates whether the vehicle is accelerating, decelerating or moving at a constant velocity.

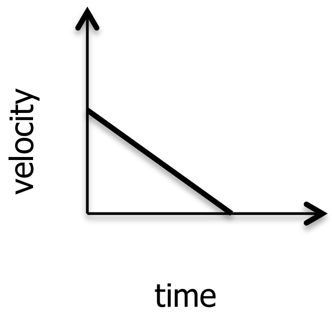
Constant velocity



Increasing velocity (acceleration)



Decreasing velocity (deceleration)



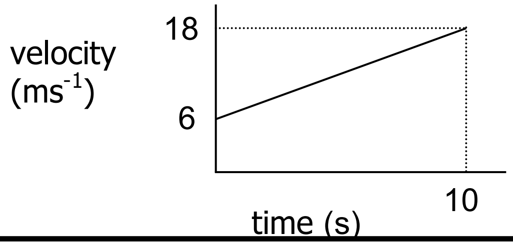
The slope (or gradient) of the line on a velocity-time graph indicates the acceleration.

While the slope is steady, the acceleration is constant.
If the line gets steeper, the acceleration (or deceleration) gets greater.
If the slope has zero gradient, and the line is flat, then the acceleration is zero and the velocity is constant.

Acceleration can be calculated using **data from the graph**. The **acceleration is equal** to the **gradient of the slope**.

Examples

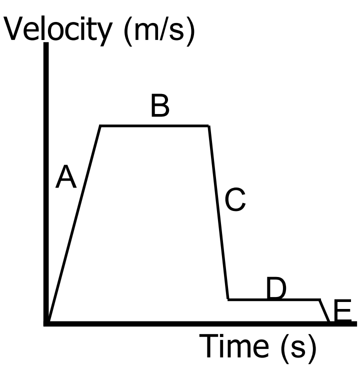
Calculate the acceleration shown in the graph below.



Answer
v=18; u=6; t=10

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

$$a = \frac{18 - 6}{10} = 1.2\ ms^{-2}$$



The graph opposite describes the motion of a vehicle. Explain in words the motion of the vehicle during each of the lettered stages.

A : Vehicle starts from rest and accelerates uniformly to its maximum velocity.

B : Vehicles travels at a constant velocity

C : Vehicle decelerates uniformly to its new lower velocity.

D : Vehicle travels at this new (lower) constant velocity.

E : Vehicle decelerates uniformly to rest.

Calculating Distance Travelled from a Velocity-Time Graph

If an object is accelerating it is often not possible to easily find its average speed. This in turn prevents the use of the equation distance = average speed x time to find the distance travelled.

Thankfully there is another way - we can use a velocity time graph

To find **displacement** travelled the **area under the velocity time graph is calculated.**

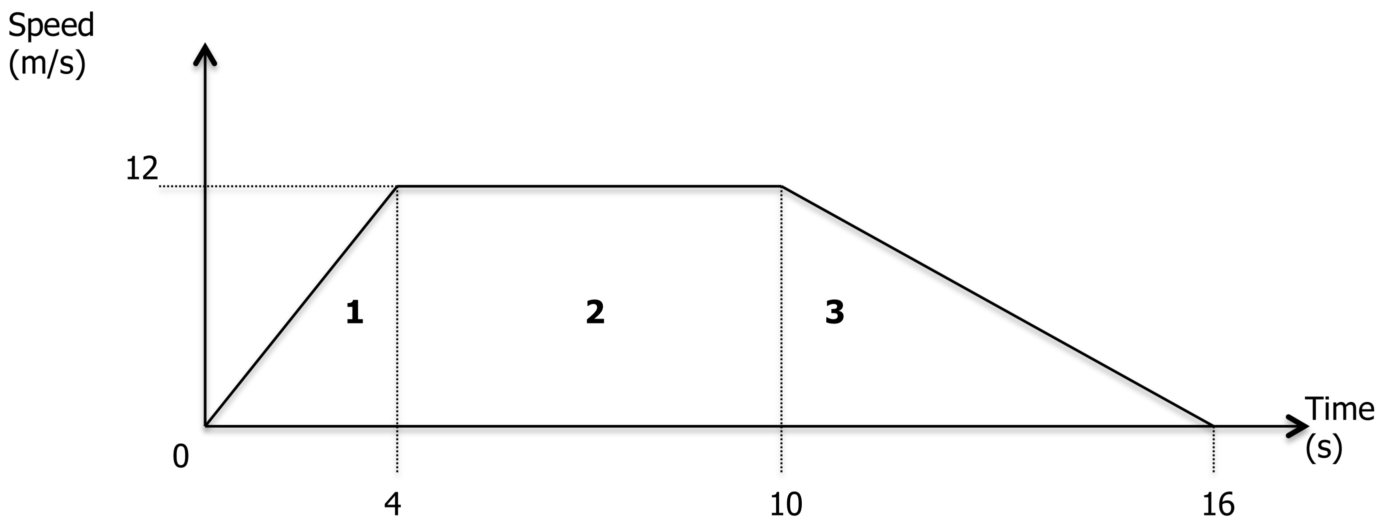
Distance gone = area under a speed-time graph

Displacement = area under a velocity-time graph

Remember that displacement and distance are not the same thing.
However, if the object is travelling in a straight line then they will be the same.

This rule applies to any shape of graph.

Example



It is best to split the area under the graph into rectangles and triangles. Calculate the area of each and then add them together. [Area of a triangle is ½ base x height]

Distance gone = area 1 + area 2 + area 3

Distance gone = (½ x 12 x 4) + (12 x 6) + (½ x 6 x12)

Distance gone = 24 + 72 + 36 = 132 m

Acceleration

Most vehicles do not travel at the same velocity all the time. If their velocity increases, they are said to accelerate. If they slow down, they decelerate. Acceleration describes **how quickly** velocity changes. Acceleration is a **vector** quantity. Only the acceleration of vehicles travelling in straight lines will be considered in this course.

Acceleration is the change in **velocity** in unit time.

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

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

Symbol	Definition	Unit	Unit symbol
v	final velocity	metre per second	ms^{-1}
u	initial velocity	metre per second	ms^{-1}
a	acceleration	metre	ms-^{2}
t	time	second	S

Units of Acceleration

The units of acceleration are the units of velocity (metres per second) divided by the units of time (seconds). The result is metres per second per second. This is usually called metres per second squared and is written $\mathbf{ms^{-2}}$.

An acceleration of 2 $\mathbf{ms^{-2}}$ means that every second, the velocity increases by 2 $\mathbf{ms^{-1}}$.

Note

If a vehicle is slowing down, the final velocity will be smaller than the initial velocity, and so the acceleration will be negative. **A negative acceleration is a deceleration**.

Examples

A train accelerates from rest to 40 m/s in a time of 60 s. Calculate the acceleration.

$u = 0\ ms^{-1}$
$v = 40\ ms^{-1}$
$t = 60\ s$

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

$$a = \frac{40-0}{60}$$

$$a = 0.67\ ms^{-2}$$

A car is moving at 15 m/s, when it starts to accelerate at 2 m/s^2. What will be its speed after accelerating at this rate for 4 seconds?

$u = 15\ ms^{-1}$
$a = 2\ ms^{-2}$
$t = 4\ s$

$$2 = \frac{v - 15}{4}$$

$$v = 8 + 15$$

$$v = 23\ ms^{-1}$$

Newton's Laws

4.1 Applications of Newton's laws and balanced forces to explain constant velocity, making reference to frictional forces.
4.2 Calculations involving the relationship between unbalanced force, mass and acceleration for situations where more than one force is acting.
4.3 Calculations involving the relationship between work done, unbalanced force and distance/displacement.
4.4 Calculations involving the relationship between weight, mass and gravitational field strength during interplanetary rocket flight.
4.5 Newton's second law and its application to space travel, including rocket launch and landing.
4.6 Newton's third law and its application to explain motion resulting from a 'reaction' force.
4.7 Use of Newton's laws to explain free-fall and terminal velocity.

$$\mathrm{F} = \mathrm{ma}$$

$$\mathrm{W} = \mathrm{mg}$$

$$\mathrm{E_W} = \mathrm{Fd}$$

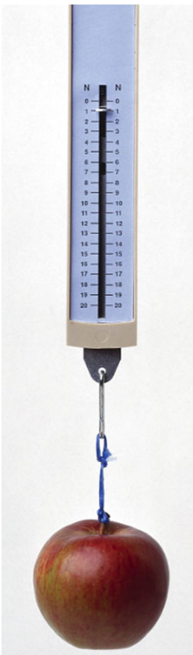
Newton's Laws

Forces

Effects of forces
Forces can only be detected by their effects.
They can change:
- the shape of an object (stretch it, squeeze it etc)
- the speed of an object
- the direction of movement of an object

Forces are vectors
A force is a vector quantity because to describe it properly direction and size are required.

Measurement of Forces
Forces are measured in units called **newtons** (N). (See later for definition).
Forces can be measured with a **newton balance** or **spring balance**. This instrument uses the effect of a force on the shape (length) of a spring. The extension of the spring is directly proportional to the force applied to it.
The scale is calibrated to measure the size of the force in newtons.



The force to be measured is applied to the hook, which is attached to the spring inside the spring balance. The force causes the spring to stretch. The bigger the force the more the spring stretches and the marker moves across the scale.

The Force of Friction

Friction is a **resistive** force, which opposes the relative motion of two surfaces in contact. This means that it acts in the **opposite** direction to the relative movement of the two surfaces.

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 is a very common force.

Friction between two solid surfaces depends on two factors:

- how **rough** the two surfaces are
- the size of the **force** between the two surfaces [how hard they are pressed together.]

Friction increases the rougher the two surfaces are and the bigger the force between them.

If there is no friction between surfaces then the surfaces can move easily over each other. This can be achieved by placing a layer of a different material between the surfaces.

An example of this is air being used in an air puck.

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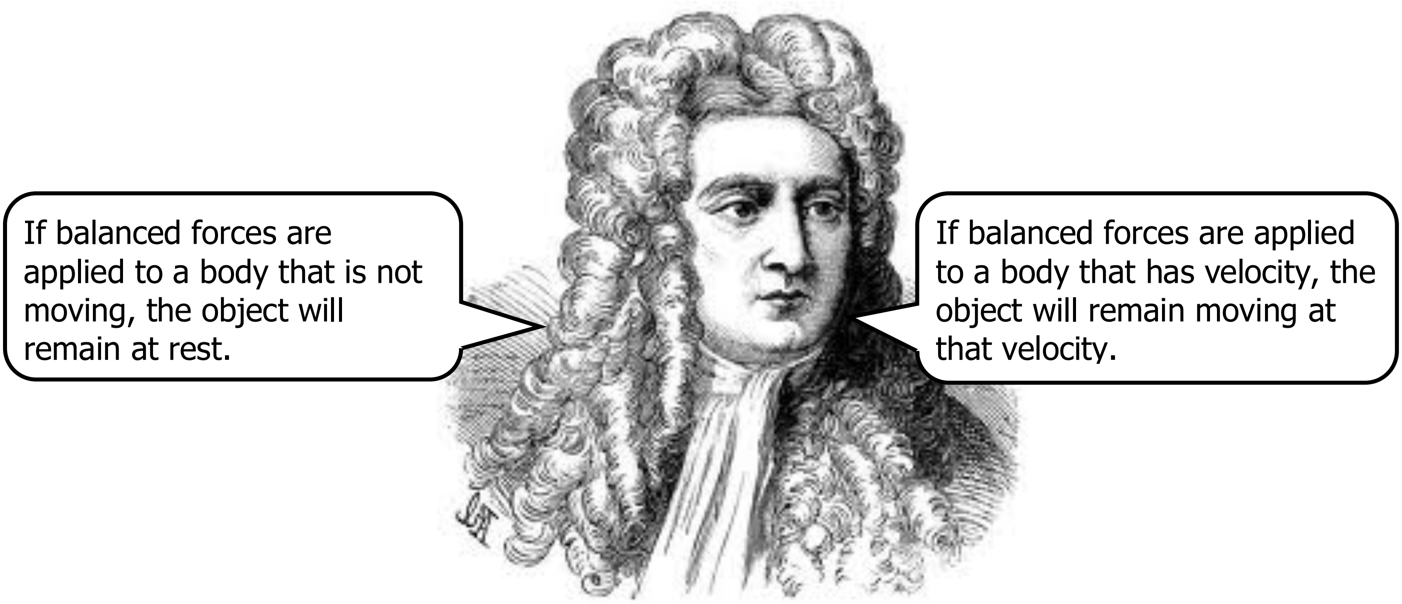
funcrate.com

Newton's First Law

Two forces which are equal in size but which act in opposite directions are called **balanced** forces.

Balanced forces have the same effect as **no force** at all. When the forces on an object are balanced (or when there are no forces at all), then neither the speed nor direction of movement will change.

Newton said :



philvaz.com

Newton’s First Law of Motion

If there are **no forces acting** on an **object or the forces are balanced** then the **object** will **remain at rest or travel at a constant speed in a straight line.**

This is why a passenger in a bus (not wearing a seat belt) will continue to move forward after the bus has applied its brakes. The force was applied to the bus and not to the passenger. Therefore the passenger will continue moving forwards until a force stops them (usually the backrest from the seat in front of them).

In everyday life it is unusual to have balanced forces.
If a pencil is pushed along a desk. Once the pushing force is removed, the pencil will come to a stop, as the force of friction acts against the motion.

Examples of balanced forces

www.photosearch.com

Citycigarblogspot.com

wallconvert.co

Force, Mass and Acceleration

Newton followed up his first law about balanced forces with a second law that describes how an object will accelerate if there is an unbalanced or resultant force acting on it. When the forces are balanced an object will remain at rest or travel at a constant speed in a straight line. But when the forces are not balanced the velocity cannot remain constant. It will change. The acceleration tells you how quickly the velocity is changing.

The acceleration of an object (produced by an unbalanced force) is:

- *directly proportional to the magnitude of the unbalanced force,*
- *in the same direction as the unbalanced force*
- *inversely proportional to the mass of the object.*

$$F = m\,a$$

Symbol	Definition	Unit	Unit symbol
F	force	newton	N
m	mass	kilograms	kg
a	acceleration	metres per second squared	m/s^2

This formula defines the newton.

One **newton** is defined as the **force** that makes a mass of **1 kg accelerate** at **1 ms^{-2}**

Example

A car of mass 1 000 kg has an unbalanced force of 1 600 N acting on it. What will be its acceleration?

F = 1 600 N
m = 1 000 kg

$$F = ma$$
$$1600 = 1000 \times a$$
$$a = \frac{1600}{1000}$$
$$a = 1.6\ ms^{-2}$$

Mass and Weight

Mass measures the amount of matter in an object. It is measured in **kilograms** (kg).
The value of mass does not change from place to place.

Weight is a force caused by gravity acting on an object's mass. On Earth, it measures the pull of the Earth on the object. It is measured in **newtons**.
Weight always acts vertically downwards. **Weight** depends on the **mass of the object**, and the **strength of the gravitational field** at that place.

The **strength of gravity** in a particular place is called **the gravitational field strength.**
This tells you the weight of 1 kilogram.
Its symbol is **g** and its unit is newtons per kilogram, **N/kg.** On Earth g is rounded to **10 N/kg.**

Mass and weight are connected by the following formula:-

$$W = mg$$

Symbol	Definition	Unit	Unit symbol
W	weight	newton	N
m	mass	kilograms	kg
g	gravitational field strength	newtons per kilogram	N/kg

The gravitational field strength is different for different planets within our solar system. Consequently, a 1 kg bag of sugar will have a mass of 1 kg everywhere, but its weight varies on different planets.

Example

Calculate the weight on Mars of a component for the Mar's Rover, if its mass on Earth is 5.6 kg.

Gravitational field strength on Mars is 3.8 N/kg

m = 5.6 kg
g = 3.8 N/kg

W = mg
W = 5.6 x 3.8
W = 21.28
W = 21 N

Resultant Forces

When several forces act on one object, they can be replaced by one force, which has the same effect. **This single force is called the resultant or unbalanced force.**

Combining forces in a straight line

To combine forces acting in one direction:

- draw a diagram of the object
- mark in all the forces acting - use an arrow to represent each force's direction.
  Do not forget weight, which is often not specifically mentioned in the question.

Use arithmetic to find the resultant by:

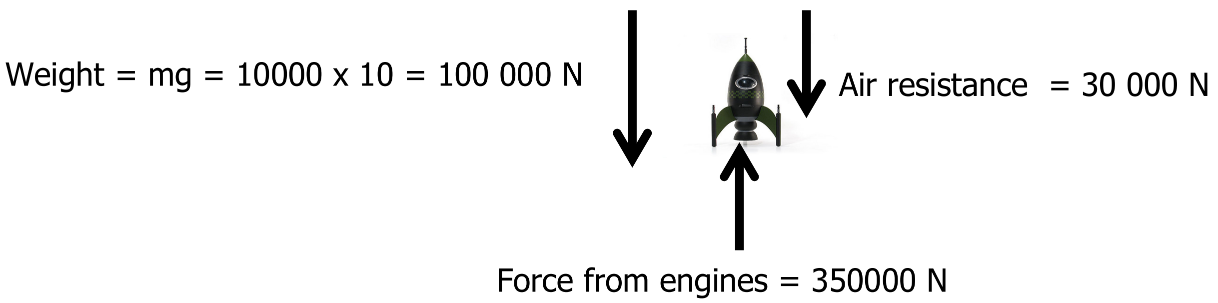
- **adding** together forces which act in the **same** direction
- **subtracting** forces which act in the **opposite** direction.

A diagram like this is called a **free body diagram**.

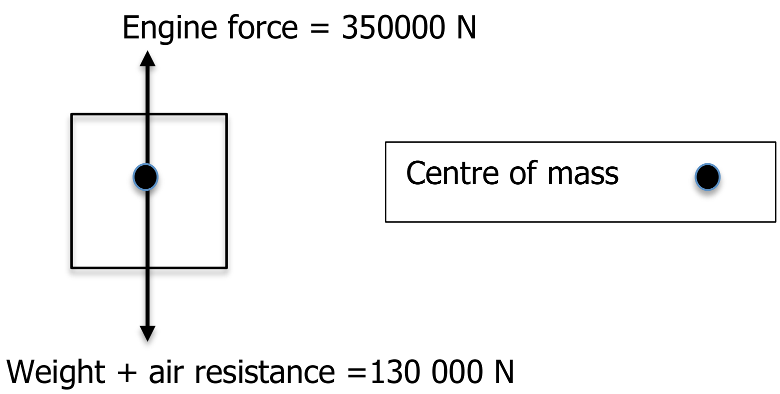
Example

A short time after take off, a rocket of mass 10 000 kg has a thrust of 350 000 N and experiences air resistance of 30 000 N. Draw a free body diagram and find the resultant force acting on the rocket.

This can be illustrated as follows



The free body diagram would be:



Resultant force = force from engine – (air resistance + weight)

Resultant force = 350 000 – (100 000 + 30 000) = 220 000 N upwards

Real Life Situation

Engineers working in the space industry use this type of calculation to find out the size of the engine force that is required to launch a spacecraft.

They also calculate the size of the engine force which would be required to slow the spacecraft down so that it can land in a safe, controlled manner.

Example

A landing specialist working at NASA is given the following information about a space craft landing on to Mars. He does some initial calculations and knows how to ensure that the space craft approaches the surface of the planet at the correct velocity.

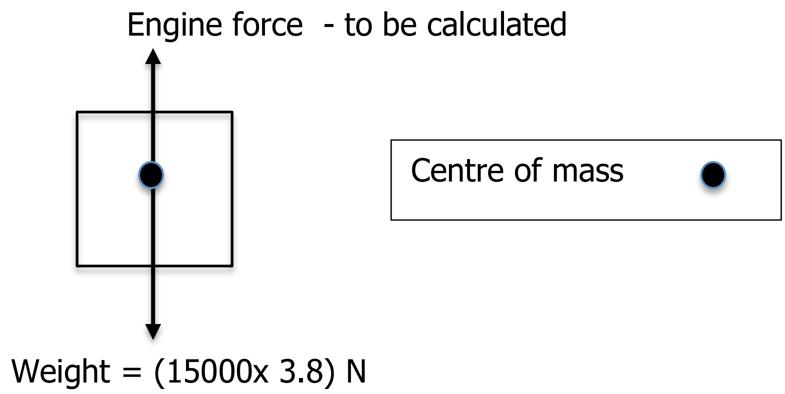
However he must now calculate the size of the force that the rocket engines must apply in order to maintain the constant velocity.
He uses the following information:

Mass of rocket 15 000 kg.
Gravitational field strength = 3.8 N/kg

Draw a free body diagram and calculate the size of the force that the rocket engines must produce.

Constant velocity means that there are **no unbalanced forces** acting on the space craft.

Free Body Diagram



Total downward force = weight

m = 15000 kg
g = 3.8 N/kg

$W = mg$

$W = 15\,000 \times 3.8$

$W = 57\,000$ N

Upwards force = weight

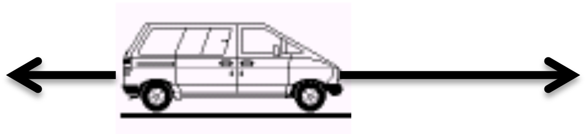
Force applied by rocket engines = 57 000 N upwards

Calculations Using F = ma For More Than One Force

If there is more than one applied force in a problem then draw a free body diagram and mark on all the known forces.
Use this to calculate the resultant force (F in the equation) before using the equation F = ma.

Examples

1. A car of mass 1 000 kg experiences friction equal to 500 N. If the engine force is 1 300 N, what will be the car's acceleration?



Resultant force = 1300 – 500 = 800 N

F = 800 N
m = 1 000 kg

$$F = ma$$
$$800 = 1000 \times a$$
$$a = \frac{800}{1000}$$
$$a = 0.8\ ms^{-2}$$

2. Given that the tank below has a mass of 6000 kg, calculate its acceleration.

Resultant force = 2000 – 1200 = 800 N

F = 800 N
m = 6 000 kg

$$F = ma$$
$$800 = 6000 \times a$$
$$a = \frac{800}{6000}$$
$$a = 0.8\ ms^{-2}$$

For revision see also example on page 38

Acceleration Due To Gravity And Gravitational Field Strength

Weight is the force which causes an object to accelerate downwards.
W = 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 the equation F = ma where F is now the weight W, and W = mg. (This assumes that friction is negligible).

$$\text{Acceleration due to gravity} = \mathrm{a}$$

Using Newton's Second Law:

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

In this case the force is weight so:

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

W = mg giving:

$$\mathrm{a} = \frac{\mathrm{mg}}{\mathrm{m}} = \mathrm{g} \text{ where } \mathrm{g} \text{ is in } \mathrm{m\ s^{-2}}$$

The numerical values of the acceleration due to gravity and gravitational field strength are equal. Their units, **N/kg** and **$\mathbf{m/s^2}$** are also equivalent.

Example

On the moon, where the gravitational field strength is 1.6 N/kg, a stone falls and takes 1.5 s to reach the surface. What is its velocity as it hits the surface of the moon?
(There is no atmosphere to cause any air resistance on the moon).

u = 0 m/s
g = 1.6 N/kg (=1.6 m/s^2)

t = 1.5 s

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

$$1.6 = \frac{v - 0}{1.5}$$

$$v = 1.6 \times 1.5$$

$$v = 2.4\ ms^{-1}$$

Free Fall

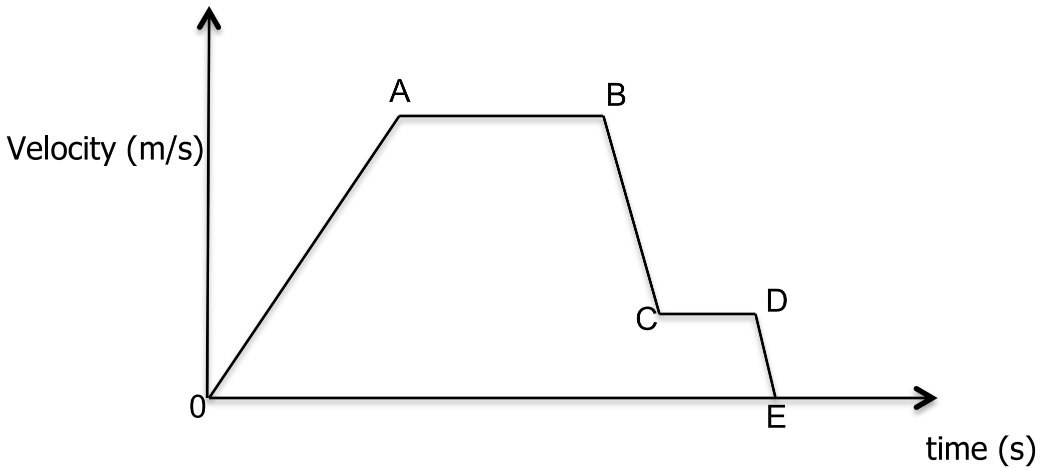
When an object is released from a height and allowed to fall vertically down under the influence of gravity then:

- the object's initial vertical velocity is zero.
- the vertical velocity increases as the object accelerates at 10 m/s^2

The object will continue to accelerate until the force acting downwards (weight) and the force acting upwards (air resistance) on the object are balanced.
When this happens the object will fall at a constant vertical velocity. This vertical velocity is known as the **terminal velocity.**

If an object is falling as described above and the only two forces acting on it are weight and air resistance then the object is said to be in **free fall.**

When a parachutist first jumps out of an aircraft they are in free fall until they open their parachute. This is best illustrated using a velocity time graph.



At O
The parachutist leaves the aircraft

OA
The parachutist accelerates towards the earth.
As their velocity increases, their air resistance also increases.
Air resistance will increase until the air resistance acting upwards is equal in size to the weight of the parachutist acting downwards.
When these two forces are balanced the parachutist has reached their **terminal velocity**.
(Point A on graph above)

AB
Parachutist falls at a constant velocity.

BC
At B, parachutist opens their parachute and they rapidly decelerate due to increased air resistance. Once the upward and downward forces are balanced again the parachutist will fall at their (new) **lower terminal velocity.** (Point C on graph above).

DE
Rapid deceleration as parachutist (safely) lands.

Weight, Mass, and Space

An object's mass does not change from place to place, but an object's weight does change because of the gravitational field strength.

As you already know W = mg.

For the space shuttle in low earth orbit, the weight is **not zero.** This is because at this orbit height there is still a gravitational force acting on the shuttle.

The "weightlessness" experienced by astronauts on board the Shuttle is caused by the free fall of all objects in orbit. The Shuttle is pulled towards the Earth because of gravity. The shuttle's high orbital speed causes the fall towards the surface to be exactly matched by the curvature of the Earth away from the shuttle. In essence, the shuttle is constantly falling around the Earth.

The gravitational field strength at the surface of the Earth (9.8 N/kg) is due to the mass of the Earth and the radius of the Earth. There are **different** gravitational field strengths for every planet in the solar system.

Example

Of particular interest for future Space Exploration is the gravitational acceleration of the moon which is 1/6 of the value on earth. This means that the engine thrust required to launch from the moon is much less than the thrust required to launch from the earth.

For more information please use:
http://exploration.grc.nasa.gov/education/rocket/rktwt1.html

Work Done and Energy

Energy

Energy cannot be created or destroyed, but it can be changed from one form into another. All forms of energy are measured in the same unit: the **joule (J).** When a force causes movement, some energy is changed from one form to another (it is **transformed**) and we say that **work is done**. For example, the force of friction causes kinetic energy to be transformed into heat.

Work Done

The work done is a measure of the energy transformed. It is equal to the force multiplied by the distance the force moves. The force and distance must be measured in the **same direction**. Work is measured in the same units as energy: joules. The symbol for work is E_W.

$$E_W = F\,d$$

Symbol	Definition	Unit	Unit symbol
E_W	energy	joules	J
F	force	newtons	N
d	distance	metres	m

Example

Calculate the work done by a gardener who uses a wheelbarrow to move 15 kg of soil a distance of 500 m.

m = 15 kg
g = 10 N/kg

$W = mg$
$W = 15 \times 10$
$W = 150$ N

The weight is equivalent to the force the gardener has to apply to move the wheelbarrow of soil.

F = W = 150 N
d = 500 m

$E_W = Fd$
$E_W = 150 \times 500$
$E_W = 75\ 000$ J

Newton's Third Law

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. Newton's Third Law can be stated as:

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

A footballer heading a ball.

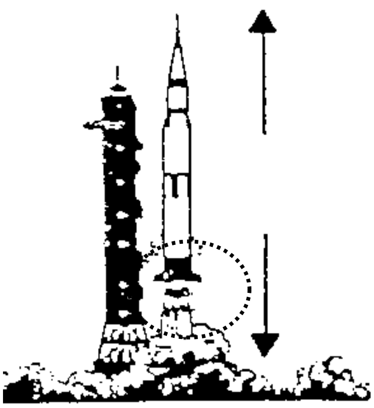
Object A is the head. Object B is the ball. When the player heads the ball, the head exerts a force to the right on the ball. The ball exerts a force on the head that is equal in size and opposite in direction.

Please note the deformation of the shape of the ball

Watch

http://www.youtube.com/watch?v=seg7eLmw5pY
for slow motion kicking of a rugby ball

http://www.youtube.com/watch?v=lBMA2wWuqh8
for slow motion kicking of a football



Object A is the rocket. Object B is the exhaust gases from the fuel. When the rocket takes off, the rocket exerts a force downwards on the exhaust gases. The exhaust gases exerts a force on the rocket that is equal in size and opposite in direction.

Tutorial Problems on Speed, Distance and Time

1. A runner completes a 200 m race in 25 s. What is his average speed in m/s?

2. A friend asks you to measure his average cycling speed along a flat road. Describe which measurements you would take and the measuring instruments you would use.

3. An athlete takes 4 minutes 20 s to complete a 1500 m race. What is the average speed?

4. On a fun run, a competitor runs 10 km in 1 hour. What is her average speed in:
   a) km/h
   b) m/s?

5. Describe how you could measure the average speed of a car as it passes along the road outside your school.

6. Concorde can travel at 680 m/s (twice the speed of sound). How far will it travel in 25 s at this speed?

7. A girl can walk at an average speed of 2 m/s. How far will she walk in 20 minutes?

8. How long will it take a cyclist to travel 40 km at an average speed of 5 m/s?

9. How long (to the nearest minute) will the Glasgow to London shuttle take if it flies at an average speed of 220 m/s for the 750 km flight?

10. How long, to the nearest minute, will a car take to travel 50 km if its average speed is 20 m/s?

11. Look at this timetable for a train between Edinburgh and Glasgow:

Station	Time	Distance from Glasgow
Glasgow	0800	0 km
Falkirk	0820	34 km
Linlithgow	0828	46 km
Edinburgh	0850	73 km

   a) What was the average speed for the whole journey in m/s?
   b) What was the average speed in m/s between Glasgow and Falkirk?
   c) Explain the difference in average speeds in a) and b).

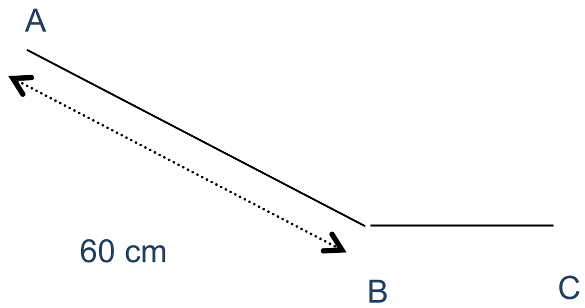
12. Describe how you would measure the instantaneous speed of a vehicle as it reached the bottom of a slope.

13. In an experiment to measure instantaneous speed, these measurements were obtained:
    Reading on timer = 0.125 s Length of car = 5 cm
    Calculate the instantaneous speed of the vehicle in m/s.

14. A trolley with a 10 cm card attached to it is released from A and runs down the slope, passing through a light gate at B, and stopping at C.
Time from A to B = 0.8 s.

Time on light gate timer = 0.067 s

a) What is the average speed between A and B?
b) What is the instantaneous speed at B?

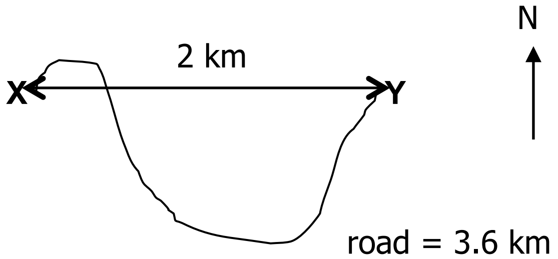


Tutorial Problems on Scalars and Vectors

1. What is the difference between a vector quantity and a scalar quantity?

2. Use your answer to question 1 to explain the difference between distance and displacement.

3. A man walks from X to Y along a winding road.

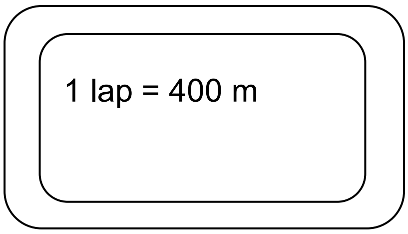


a) What is his displacement at the end of his walk?
b) What distance has he walked?

4. If the walker in question 3 took 40 minutes for his walk, what was
a) his average speed
b) his average velocity?

5. One complete lap of a running track is 400m. An athlete completes one lap in 48 s in the 400 m race. What is his

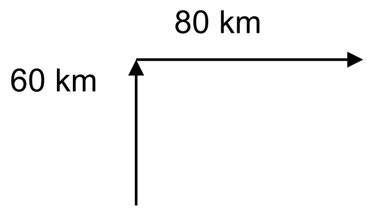
a) distance travelled
b) displacement
c) average speed
d) average velocity.



6. Repeat Q 5 for a runner in the 800 m race whose winning time was 1 min 54 s.

7. A car travels 40 km north, then turns back south for 10 km. The journey takes 1 hour. What is
   a) the displacement of the car
   b) the distance the car has travelled
   c) the average velocity of the car
   d) the average speed of the car?

8. A car drives 60 km north, then 80 km east, as shown in the diagram. The journey takes 2 hours.
   Calculate the
   a) distance travelled
   b) displacement
   c) average speed
   d) average velocity.



Tutorial Problems on Acceleration

1. A Jaguar can reach 27 m/s from rest in 9.0 s. What is its acceleration?

2. The space shuttle reaches 1000 m/s, 45 s after launch. What is its acceleration?

3. A car reaches 30 m/s from a speed of 18 m/s in 6 s. What is its acceleration?

4. A train moving at 10 m/s increases its speed to 45 m/s in 10 s. What is its acceleration?

5. A bullet travelling at 240 m/s hits a wall and stops in 0.2 s. What is its acceleration?

6. A car travelling at 20 m/s brakes and slows to a halt in 8 s. What is the deceleration?

7. Describe how you would measure the acceleration of a small vehicle as it runs down a slope in the laboratory.

8. On approaching the speed limit signs, a car slows from 30 m/s to 12 m/s in 5 s. What is its deceleration?

9. A bowling ball is accelerated from rest at 3 m/s^2 for 1.2 s. What final speed will it reach?

10. How long will it take a car to increase its speed from 8 m/s to 20 m/s if it accelerates at 3 m/s^2?

11. A cyclist can accelerate at 0.5 m/s^2 when cycling at 4 m/s. How long will she take to reach 5.5 m/s?

12. The maximum deceleration a car's brakes can safely produce is 8 m/s^2. What will be the minimum stopping time if the driver applies the brakes when travelling at 60 mph (27 m/s)?

13. The table below gives some performance figures for cars.

Car	Time for 0 - 60 mph	max. speed in mph
Mondeo 1.8 LX	10.2 s	122
Peugeot 106 XN 1.1	12.5 s	103
Renalt Clio RL	14.3 s	95
Nissan Micra 1.0 S	15.2 s	89
Porsche Boxster	6.5 s	139

a) Which car has the smallest acceleration?

b) Which car has the largest acceleration?

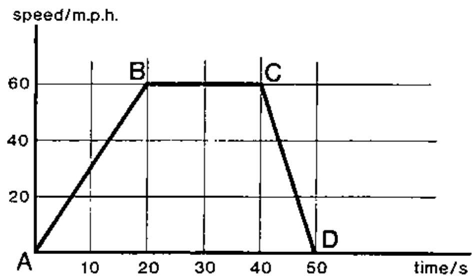
Speed m/s

Velocity-time Graphs

1. The graph shows how the speed of the car changes during a short journey.

   (a) What is the acceleration during AB?

   (b) What is the deceleration during CD?



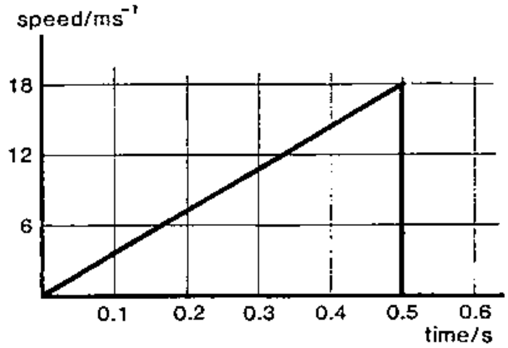
2. To test the strength of a nuclear waste container, it is fired along a track towards a concrete wall. The speed-time graph is shown opposite.

   (a) At what time did the container hit the wall?

   (b) How fast did it hit the wall?

   (c) How long was the test track?

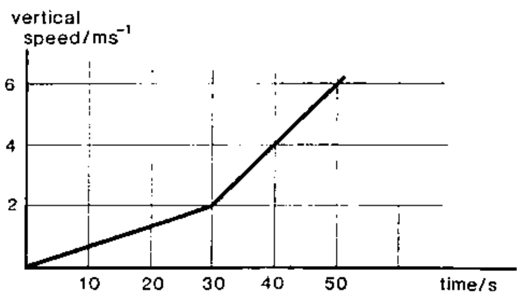
   (d) What was its acceleration?



3. A hot air balloon is released and accelerates upwards. During the lift, some of the sandbags are released and the acceleration increases. The graph shows its vertical motion during the first 50 seconds of its flight.

   (a) Calculate both accelerations.

   (b) At what height were the sandbags released?



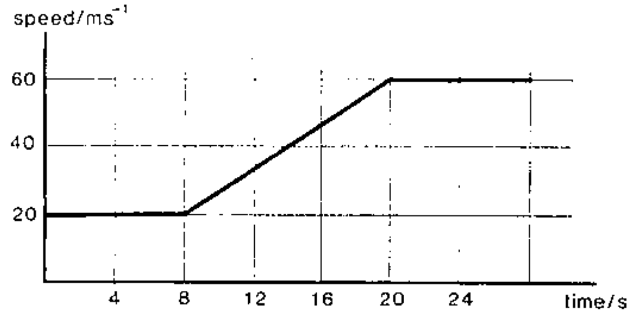
4. A glider, cruising at 20 m/s, goes into a shallow dive and increases its speed. The graph shows its motion starting a few seconds before its dive.

(a) At what time did it start the dive?

(b) What was the time taken during the dive?

(c) What was the acceleration during the dive?

(d) How far did it travel during the dive?



5. During a test run of a hovertrain its speed was recorded as shown in the table below.

Time (s)	0	20	40	60	80	100	120	140
Speed (m/s)	0	10	40	70	100	100	50	0

(a) Draw a graph of the train's motion during the test run.

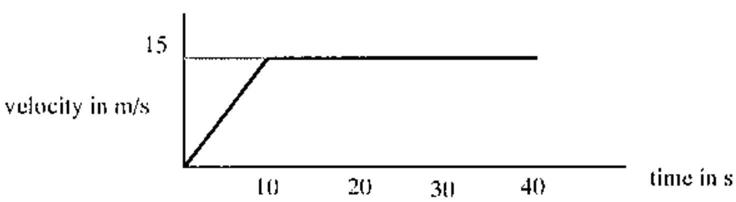
(b) Calculate the two accelerations during the test run.

(c) Calculate the deceleration of the train.

(d) Calculate the total distance travelled during the test run.

(e) Calculate the **average** speed during the run.

6. The graph below shows how the velocity of a car varies over a 40 s period.



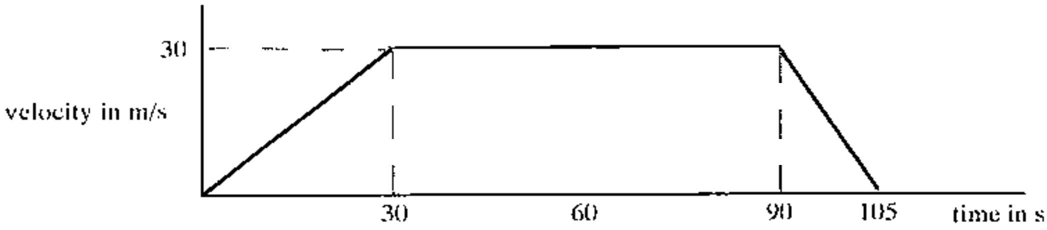
a) Describe the motion of the car during this 40 s period.

b) Calculate the acceleration of the vehicle.

c) How far does the car travel while accelerating?

d) What is the total distance travelled by the car?

7. Use the graph below to answer the following questions.



a) During which time period is the vehicle travelling at a constant velocity?

b) Calculate the values of i) the initial acceleration ii) the final deceleration

c) What is the braking distance of the car?

d) What is the total distance travelled?

e) What is the average velocity of the car?

8. Draw a velocity-time graph to describe the following motion:-A car accelerates from rest to 2 m/s in 8 s, then travels at a constant velocity for 12 s, finally slowing steadily to a halt in 4 s.

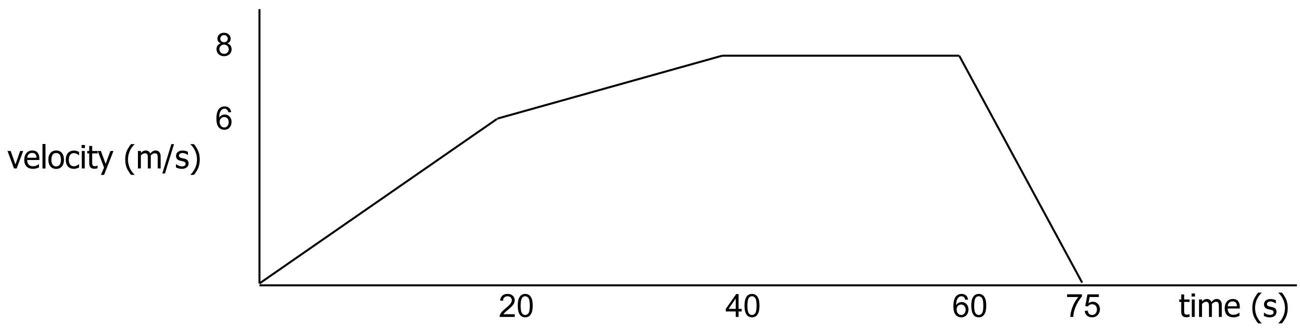
9. For the vehicle in the previous question, what are the values of

a) the maximum velocity

b) the distance travelled

c) the average velocity?

10. The graph below describes the motion of a cyclist.



a) What is the value of the maximum positive acceleration?

b) Show by calculation whether the cyclist travels farther while accelerating, or while cycling at the maximum velocity.

Mass and Weight

1. Define mass.

2. Define weight.

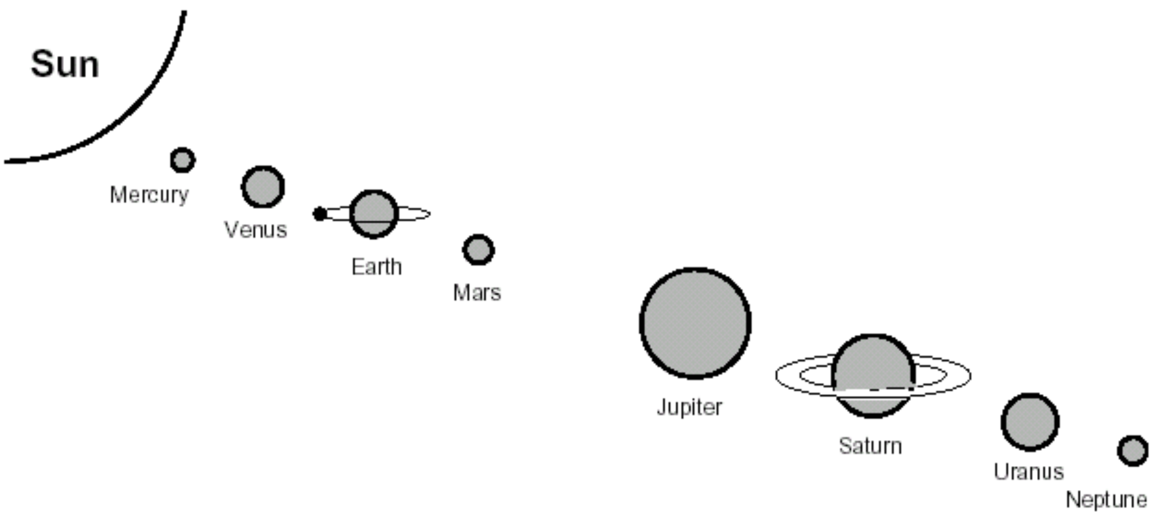
3. a. What is name given to the ratio of $\frac{\text{weight}}{\text{mass}}$?

4. Does mass or weight change depending on how far away you are from a planet and on what planet you are on?

Read the information below on 'g' for other bodies in the Solar System.

Planet	**g (N/kg)**
Mercury	3.7
Venus	8.8
Earth	10
(Moon)	1.6
Mars	3.8
Jupiter	26.4
Saturn	11.5
Uranus	11.7
Neptune	11.8
Pluto	4.2

5. Calculate your mystery friend's weight on each of the planets, assuming your mystery friend's mass is 56 kg.



6. What is the weight of a 10 kg bag of potatoes on Earth?

7. What is the weight of a 250 g bag of sweets on Earth?

8. What is the mass of a girl if her weight on Earth is 450 N?

9. What is the weight of a 10,000 kg spacecraft on
   a)Earth
   b) Mars
   c) Venus?

10. What would a 60 kg man weigh on Jupiter?

11. Which planet's gravity is closest to our own?

12. An astronaut who weighs 700 N on Earth goes to a planet where he weighs 266 N. Calculate his mass and state which planet he was on.

13. What would an astronaut weigh on Earth, if his weight on Venus was 528 N?

Friction

1. Define what friction is.

2. Give two examples where friction slows things down.

3. Give two examples of where friction helps things move.

4. Describe two methods of increasing friction.

5. Describe three methods of decreasing friction.

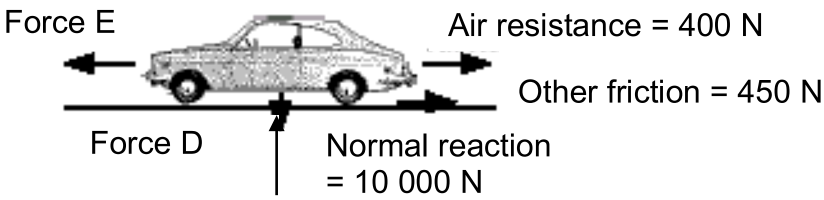
6. Where in a bicycle is friction deliberately
   a) increased
   b) decreased?

7. What is friction commonly called when the one of the surfaces involved is air?

8. What is friction commonly called when the one of the surfaces involved is water?

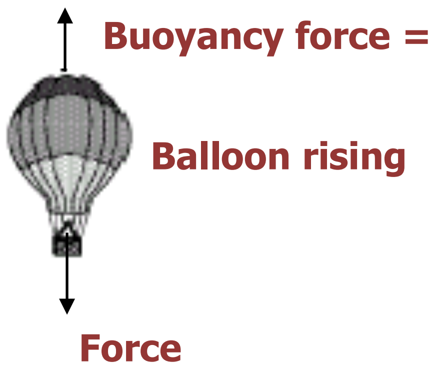
Balanced Forces and Newton's First Law

1. The diagram below shows the forces acting on a car moving at constant velocity.



a) What can you say about the forces acting on this car?
b) How big is the engine force E?
c) What is the weight of the car ?

1. The diagram shows the forces acting on a balloon as it rises.



a) What will be the size of force A?
b) If the balloon was falling at a constant velocity, what would be the size of force A?

2. State Newton's First Law.

4. Explain, using Newton's First Law, why passengers without seat belts in a moving car appear to be "thrown forwards" in the car, when the car stops suddenly.

5. Explain how a parachutist reaches a terminal velocity.

Resultant Forces

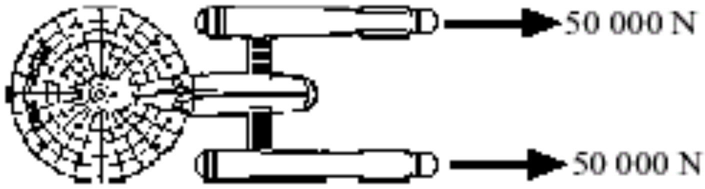
1. What is meant by the resultant force on an object?

2. What are the resultants of the following forces?

a)

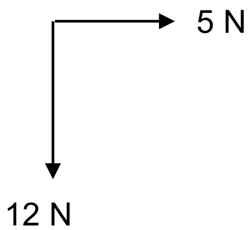
b)

c)

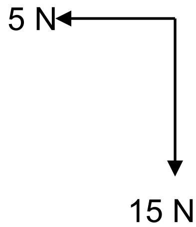


3. By using a scale diagram or otherwise, find the resultant of the following pairs of forces. Remember to draw the vectors "tip to tail".

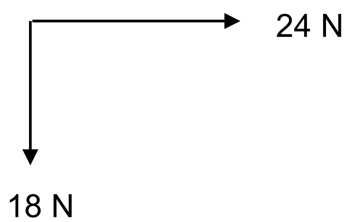
a)



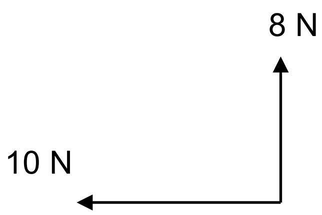
b)



c)



d)



Newton's Second Law

1. What force is needed to accelerate a 5 kg mass at 3 m/s^2?

2. What will be the acceleration of a 12 kg mass acted on by a force of 30 N?

3. What mass would accelerate at 2 m/s^2 when acted on by a 12 N force?

4. What force will accelerate 250 g at 2 m/s^2?

5. What force would be needed to accelerate a 10 tonne lorry at 1.5 m/s^2? (1 tonne = 1000 kg)

6. Give two reasons why a car will have a smaller acceleration in similar conditions when a roof rack is added.

7. Describe an experiment to investigate the effect of varying the unbalanced force acting on a fixed mass.

8. A car of mass 1200 kg experiences friction equal to 500 N when travelling at a certain speed. If the engine force is 1400 N, what will be the car's acceleration?

9. A car of mass 2000 kg has a total engine force of 4500 N. The frictional drag force acting against the car is 1700 N. What is the acceleration of the car?

10. Two girls push a car of mass 1000 kg. Each pushes with a force of 100 N and the force of friction is 120 N. Calculate the acceleration of the car.

11. A boat engine produces a force of 10000 N and the friction and water resistance total 3500 N. If the mass of the boat is 2000 kg, what will be its acceleration?

12. A careless driver tries to start his car with the hand brake still on. The engine exerts a force of 2500 N and the hand brake exerts a force of 1300 N. The car moves off with an acceleration of 1.2 m/s^2. What is the mass of the car?

13. A car of mass 1200 kg can accelerate at 2 m/s^2 with an engine force of 3000 N. What must be the total friction force acting on the car?

14. A helicopter winches an injured climber up from a mountainside. The climber's mass is 65 kg.
    a) What is the weight of the climber?
    b) If he is accelerated upwards at 1.0 m/s^2, what unbalanced force is required?
    c) What total upwards force must be produced by the helicopter?

15. An 800 kg car is accelerated from 0 to 18 m/s in 12 seconds.
    a) What is the resultant force acting on the car?
    b) At the end of the 12 s period the brakes are operated and the car comes to rest in a time of 5 s. What is the average braking force acting on the car?

Answers to numerical problems

Speed, distance and Time

1. 8 m/s
2. –
3. 5.77 m/s
4. a) 10 km/h
   b) 2.7 m/s
5. –
6. 17 000m
7. 2 400m
8. 8000s
9. 57 min (3 409s)
10. 42 min (2 500s)
11. a) 24.3 m/s
    b) 28.3 m/s
12. –
13. 0.4 m/s
14. a) 0.75 m/s
    b) 1.49 m/s

Scalars and Vectors

1. –
2. –
3. a) 2 km E
   b) 3.6 km
4. a) 1.5 m/s
   b) 0.83 m/s E
5. a) 400 m b) 0 c) 8.3 m/s d) 0
6. a) 800 m b) 0 c) 7.02 m/s d) 0
7. a) 30km N b) 50 km c) 30 km/h d) 50 km/h
8. a) 140 km b) 100km on a bearing of 053^0 c) 70 km/h d) 50 km/h on a bearing of 053^0

Acceleration

1. 3 m/s^2
2. 22.2 m/s^2
3. 2 m/s^2
4. 3.5 m/s^2
5. -1 200 m/s^2
6. -2.5 m/s^2
7. –
8. 3.6 m/s^2
9. 3.6 m/s
10. 4 s
11. 3 s
12. 3.4 s
13. a) Micra b) Porsche c) i) 20.7s d) ii) 15.1 s

Velocity-time graphs

1. a) 3 m/s^2 b) 6 m/s^2
2. a) 0.5 s b) 18 m/s c) 4.5 m d) 36 m/s^2
3. a) i) 0.067 m/s^2 ii) 0.2 m/s^2
   b) 30 m
4. a) 8 s b) 12 s c) 3.33 m/s^2 d) 480m
5. a) - b) 0.5 m/s^2 1.5 m/s^2 c) 2.5 m/s^2 d) 7 400 m e) 52.9 m/s
6. a) - b) 1.5 m/s^2 c) 75m d) 525 m
7. a) 30 -> 90 b) -2 m/s^2 c) 225 m d) 2 475 m e) 23.6 m/s
8. -
9. a) 2 m/s b) 36 m c) 1.5 m/s
10. a) 0.3 m/s^2 b) Max vel – 160m Accelerating 200 m

Mass and Weight
1. –
2. –
3. –
4. –
5. –
6. --
7. Mercury – 207 N, Venus – 493 N, Earth 560 N, Mars 213 N, Jupiter 1 480 N, Saturn 644 N, Uranus 655 N, Neptune 661 N.
8. 100 N
9. 2.5 N
10. 45 kg
11. a) 100 000 N
    b) 38 000 N
    c) 88 000 N
12. 1 580 N
13. Venus
14. Mass 70 kg on planet Mars (g=3.8 N/kg)
15. Mass 60 kg, Weight = 600 N

Problems on Friction
No numerical problems

Balanced Forces and Newton's First Law
1. a) They are balanced b) 850 N c) 10 000 N
2. a) 2000 N b) 2000N
3. –
4. –
5. –

Resultant Forces
1. –
2. a) 800 N Left b) 100 N Down c) 100 000 N Right
3. a) 13 N Bearing 157^o b) 15.8 N Bearing 198^o c) 30 N Bearing 127^o d) 12.8 N Bearing 309^o
4.

Newton's Second Law

1. 15 N
2. 2.5 m/s^2
3. 6 kg
4. 0.5 N
5. 15 000 N
6. –
7. –
8. 0.75 m/s^2
9. 1.4 m/s^2
10. 0.08 m/s^2
11. 3.25 m/s^2
12. 1 000 kg
13. 600 N
14. a) 650 N b) 65 N c) 715 N
15. a) 1 200 N b) 2 880 N