# HIGHER PHYSICS

## Our Dynamic Universe

http://www.gsc.org.uk/fantasticforces.aspx

## Part 1 - Dynamics

# HIGHER PHYSICS

## UNIT 1 - OUR DYNAMIC UNIVERSE

## 1) EQUATIONS OF MOTION

Can you talk about:

### (a) Equations of motion for objects with constant acceleration in a straight line.

- Experiments to verify the relationships shown in the equations.

### (b) Motion-time graphs for motion with constant acceleration.

- Displacement-time graphs. Gradient is velocity.
- Velocity-time graphs. Area under graph is displacement. Gradient is acceleration.
- Acceleration-time graphs. Restricted to zero and constant acceleration.
- Graphs for bouncing objects and objects thrown vertically upwards.

### (c) Motion of objects with constant speed or constant acceleration.

- Objects in freefall and the movement of objects on slopes.

# A) EQUATIONS OF MOTIONS FOR OBJECTS WITH CONSTANT ACCELERATION IN A STRAIGHT LINE

The following are some of the **quantities** you will meet in the Higher Physics course:

**DISTANCE, DISPLACEMENT, SPEED, VELOCITY, TIME, FORCE.**

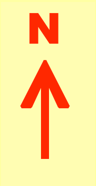
**Quantities** can be divided into 2 groups:

SCALARS

These are specified by stating their magnitude (size) only, with the correct unit.

VECTORS

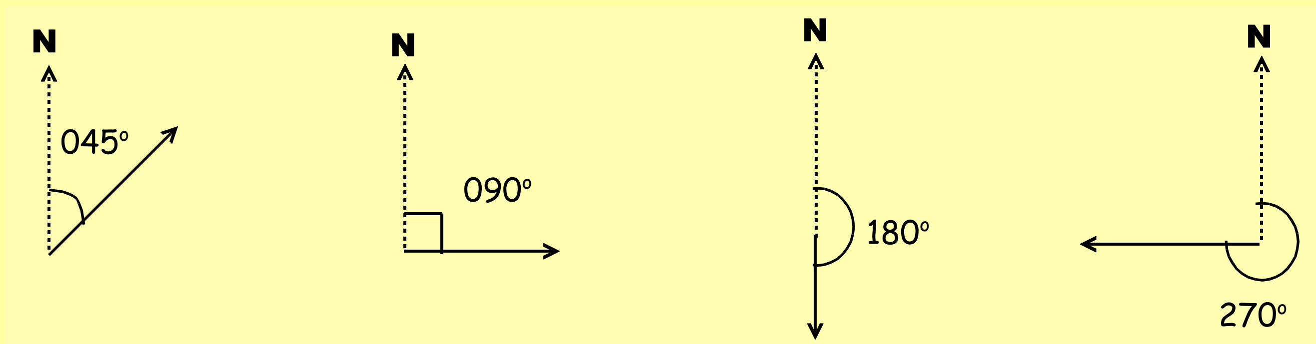
These are specified by stating their magnitude (size), with the correct unit, and a direction (often a compass direction).




COMPASS DIRECTIONS

Compass directions are measured from North which is always taken to be at the top of the page.

The angle specified is always a 3-figure bearing. For example:




Some **scalar** quantities have a corresponding **vector** quantity.

Other **scalar** and **vector** quantities are independent.

| corresponding scalar quantity | corresponding vector quantity |
|---|---|
| distance (e.g., 25 m) | displacement (e.g., 25 m bearing 120°) |
| speed (e.g., 10 $ms^{-1}$) | velocity (e.g., 10 m $s^{-1}$ bearing 090°) |
| time (e.g., 12 s) | NONE |
| NONE | force (e.g., 10 N bearing 045°) |

# DISTANCE and DISPLACEMENT

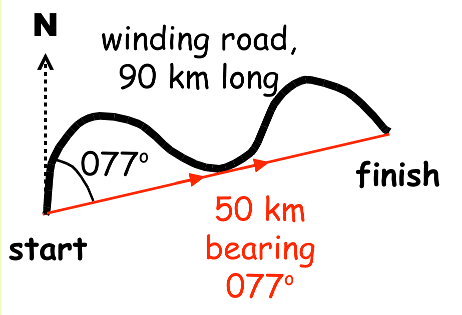
**Distance** (a **scalar** quantity) is **the total length of path travelled**.
[A **unit** must always be stated.]

**Displacement** (a **vector** quantity) is **the length and direction of a straight line drawn from the starting point to the finishing point**.

[A **unit** and **direction** (often a **3-figure bearing from North**) must always be stated, unless the displacement is zero.]

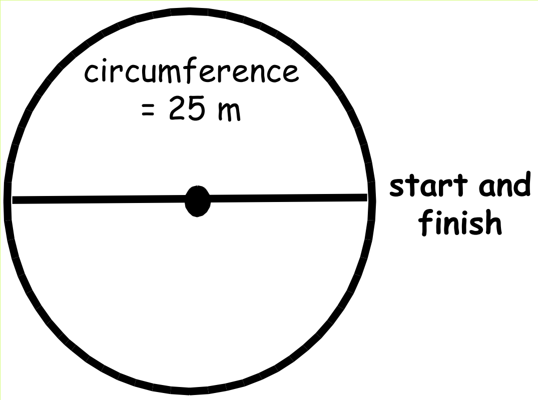
**For example:**

1) Bill drives 90 km along a winding road.




- Distance travelled = 90 km
- Displacement = 50 km bearing 077°

2) Ben jogs once around the centre circle of a football pitch.




- Distance travelled = 25 m
- Displacement = 0 m.
  (He is back where he started, so the length of a straight line drawn from his starting point to his finishing point is 0 m).

# SPEED and VELOCITY

**Speed** (a **scalar** quantity) is **the rate of change of distance**.

$$\text{speed} = \frac{\text{distance}}{\text{time}} \qquad \text{average speed} = \frac{\text{total distance travelled}}{\text{total time taken}}$$

Looks like this in equation sheet: $d = \bar{v}t$

**Velocity** (a **vector** quantity) is **the rate of change of displacement**.

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

Looks like this in equation sheet: $s = \bar{v}t$

**Example**

**Calculate the average speed and the velocity of Bill and Ben in the cases above. (Bill's journey took 2 hours. Ben's journey took 10 seconds).**

**Bill**

**average speed**

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

$\bar{v} = \frac{90}{2}$

$\bar{v} = 45\text{kmh}^{-1}$

**velocity**

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

$\bar{v} = \frac{50}{2}$

$\bar{v} = 25\text{kmh}^{-1}$ (077)

**Ben**

**average speed**

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

$\bar{v} = \frac{25}{10}$

$\bar{v} = 12.5\text{ms}^{-1}$

**velocity**

$s = 0$

Therefore,

$\bar{v} = 0$

# ADDING SCALAR QUANTITIES

Two or more **scalar** quantities can be added arithmetically if they have the same unit, e.g.,

2 cm + 3 cm = 5cm        but        2 cm + 3 minutes CANNOT BE ADDED

# ADDING VECTOR QUANTITIES

Two or more **vector** quantities can be added together to produce a single vector if they have the same unit - but their directions must be taken into account. We do this using the **"tip to tail" rule**.

The single vector obtained is known as the **resultant vector**.

The "TIP TO TAIL" RULE

Each vector must be represented by a straight line of suitable scale.
The straight line must have an arrow head to show its direction.

The vectors must be joined one at a time so that the tip of the previous vector touches the tail of the next vector.

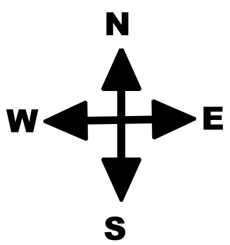
A straight line is drawn from the starting point to the finishing point.
The scaled-up length and direction of this straight line is the resultant vector.
It should have 2 arrow heads to make it easy to recognise.

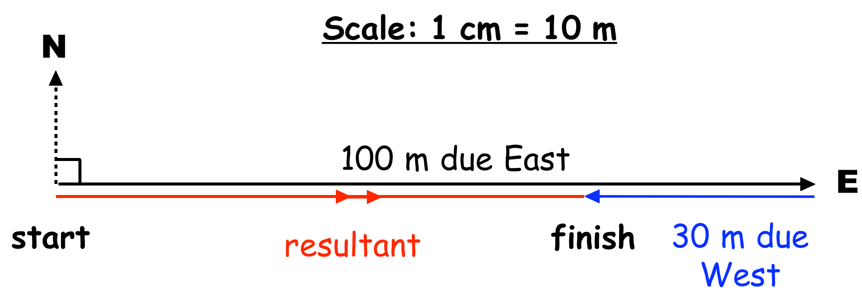
**YOU MUST BE ABLE TO ADD VECTOR QUANTITIES USING BOTH A SCALE DIAGRAM AND MATHEMATICS - Pythogoras theorem, SOHCAHTOA, the Sine Rule and the Cosine Rule.**

**LARGE SCALE DIAGRAMS GIVE MORE ACCURATE RESULTS THAN SMALLER ONES! - ALWAYS USE A SHARP PENCIL!**

Example 1

Amna rides her mountain bike 100 m due East along a straight road, then cycles 30 m due West along the same road.
Determine Amna's **displacement** from her starting point using a **scale diagram**.



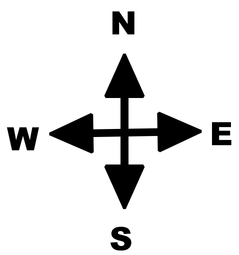

On scale diagram, resultant = 7 cm.
Scaling up, this represents a displacement of 70m bearing 090°.
(Alternatively, we can say displacement = 70m due East).

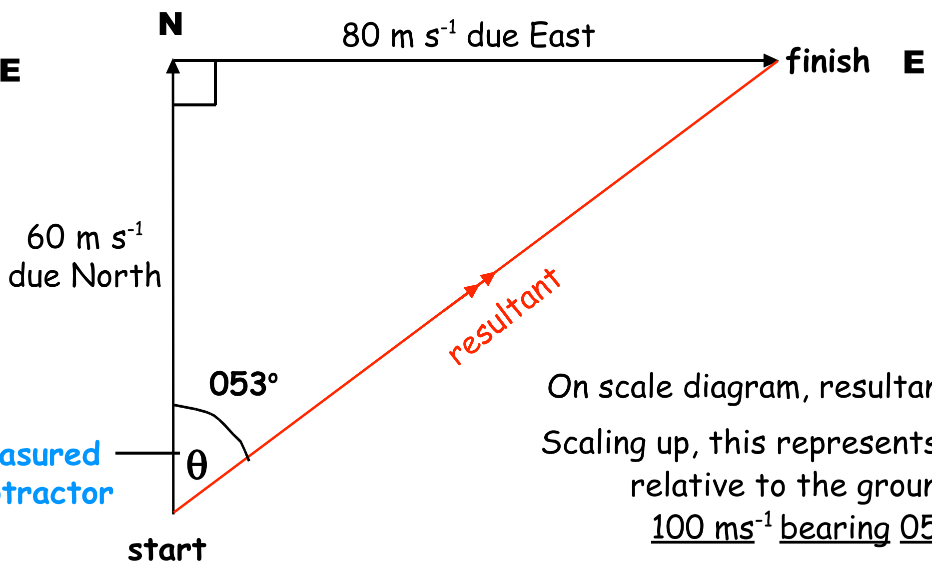
NOTE- In some vector problems, you may be asked to find the **resultant vector** relative to some object, like the ground, which is **stationary**. Don't let this put you off.
Just add the vectors using the "**tip to tail**" rule.
This gives you the resultant vector relative to the stationary object.

Example 2

A helicopter tries to fly due North at 60 $ms^{-1}$. It is affected by a very strong wind blowing due East at 80 $ms^{-1}$. Determine the **resultant velocity** of the helicopter relative to the ground.

Method 1 - by scale diagram    Scale: 1 cm = 10 $ms^{-1}$




On scale diagram, resultant = 10 cm.

Scaling up, this represents a velocity relative to the ground of 100 $ms^{-1}$ bearing 053°.

Method 2 - Using mathematics

A rough sketch of the vector diagram (NOT to scale) should be made if you solve such a problem using mathematics.

First, Using PYTHAGORAS THEOREM

$$\text{resultant}^2 = 60^2 + 80^2 = 3600 + 6400 = 10\,000$$

$$\text{so, resultant} = \sqrt{10\,000} = \underline{100 \text{ m s}^{-1}}$$

Next, Using SOH CAH TOA

$$\tan\theta = \frac{O}{A} = \frac{80}{60} = 1.33$$

$$\text{so, } \theta = \tan^{-1} 1.33 = \underline{53^\circ}$$

Resultant velocity relative to the ground = 100 $ms^{-1}$ bearing 053°.
Note - the mathematical method provides a more accurate answer for the angle.
(You can't read a protractor to 0.1° !!!)

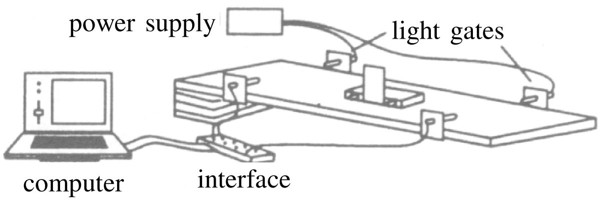
# ACCELERATION

**Acceleration** is **the change of velocity per unit time.** Unit: **$ms^{-2}$ (vector)**.

$$\text{acceleration} = \frac{\text{final velocity - initial velocity}}{\text{time taken for change}} = \frac{v - u}{t}$$

To determine the **acceleration** of a trolley running down a slope, we can use:

a **single card** (**mask**) of known length and **2 light gates** connected to a **computer** (which records times).




**METHOD 1**

Find length of card

Find $t_1$ (time for card fixed on trolley to pass through first (top) light gate).

Find $t_2$ (time for card fixed on trolley to pass through second (bottom) light gate).

Find $t_3$ (time for card fixed on trolley to pass **between** the 2 light gates).

Calculate velocity of card through first (top) light gate ($u$) = $\frac{\text{length of card}}{t_1}$

Calculate velocity of card through second (bottom) light gate ($v$) = $\frac{\text{length of card}}{t_2}$

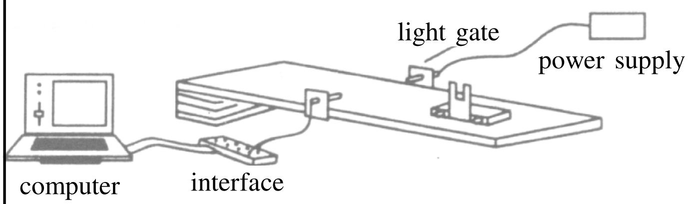
Calculate acceleration using

$$\text{acceleration} = \frac{v - u}{t_3}$$

This method can be adapted to measure **gravitational acceleration**.

A **single mask** can be dropped vertically through **2 light gates**, or a **double mask** can be dropped vertically through **1 light gate**.

a **double card** (**mask**) (2 known lengths) and **1 light gate** connected to a **computer** (which records times).




**METHOD 2**

Find length of right edge of card (first edge to pass through light gate)

Find length of left edge of card (second edge to pass through light gate)

Find $t_1$ (time for first edge of card to pass through light gate).

Find $t_2$ (time for second edge of card to pass through light gate).

Find $t_3$ (time **between** first and second edge of card passing light gate).

Calculate velocity of first edge of card through light gate ($u$) = $\frac{\text{length of edge}}{t_1}$

Calculate velocity of second edge of card through light gate ($v$) = $\frac{\text{length of edge}}{t_2}$

Calculate acceleration using

$$\text{acceleration} = \frac{v - u}{t_3}$$

# THE FOUR EQUATIONS OF MOTION (FOR UNIFORM ACCELERATION IN A STRAIGHT LINE)

**FOUR equations** can be applied to any object moving with uniform (constant) acceleration in a straight line:

$v = u + at$ $\qquad$ $s = \dfrac{(u + v)\,t}{2}$ $\qquad$ $s = ut + 1/2at^2$ $\qquad$ $v^2 = u^2 + 2as$

t = time for motion to take place/ s

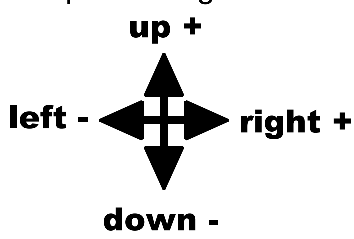
u = initial velocity/ $ms^{-1}$

v = final velocity after time t/ $ms^{-1}$

a = uniform (constant) acceleration during time t/ $ms^{-2}$

s = displacement (in a straight line) during time t/ m

Because **u**, **v**, **a** and **s** are **vectors**, we must specify their direction by placing a **+** or **-** sign in front of the number representing them:




The equation of motion used to solve a problem depends on the quantities given in the problem.

Often, the term straight line is not mentioned in the problem.

If no direction is specified for the accelerating object, we assume it is travelling to the right - This means we use positive vector values in the equations of motion.

**Examples/Problems**

$v = u + at$

A racing car starts from rest and accelerates uniformly in a straight line at 12 $ms^{-2}$ for 5.0 s. Calculate the **final velocity** of the car.

u = 0 $ms^{-1}$ (rest)
a = 12 $ms^{-2}$
t = 5.0 s
v = ?

v = u + at
v = 0 + (12 x5.0)
v = 0 + 60
v = 60 $ms^{-1}$ (in direction of acceleration)

$s = ut + 1/2at^2$

A speedboat travels 400 m in a straight line when it accelerates uniformly from 2.5 $ms^{-1}$ in 10 s. Calculate the acceleration of the speedboat.

s = 400 m
u = 2.5 $ms^{-1}$
t = 10 s
a = ?

s = ut+ 1/2at
400 = (2.5 x 10) + (0.5 x a x$10^2$)
400 = 25 + 50a
50a = 400 - 25 = 375
a = 375/50 = 7.5 m $s^{-2}$ (in direction of original velocity)

$v^2 = u^2 + 2as$

A rocket is travelling through outer space with uniform velocity. It then accelerates at 2.5 $ms^{-2}$ in a straight line in the original direction, reaching 100 $ms^{-1}$ after travelling 1 875 m. Calculate the rocket's **initial velocity**?

| | |
|---|---|
| $a = 2.5\ ms^{-2}$ | $v^2 = u^2 + 2as$ |
| $v = 100\ ms^{-1}$ | $100^2 = u^2 + (2 \times 2.5 \times 1\ 875)$ |
| $s = 1\ 875\ m$ | $10\ 000 = u^2 + 9\ 375$ |
| $u = ?$ | $u^2 = 10\ 000 - 9\ 375 = 625$ |
| | $u = \sqrt{625} = \underline{25\ ms^{-1}}$ (in direction of acceleration) |

# Decelerating Objects and Equations of Motion

When an object **decelerates**, its **velocity decreases**. If the vector quantities in the **equations** of motion are positive, we represent the decreasing velocity by use of a negative sign in front of the acceleration value (and vice versa).

**For example**

$v = u + at$

A car, travelling in a straight line, decelerates uniformly at 2.0 $ms^{-2}$ from 25 $ms^{-1}$ for 3.0 s. Calculate the car's velocity after the 3.0 s.

| | |
|---|---|
| $a = -2.0\ ms^{-2}$ | $v = u + at$ |
| $u = 0\ ms^{-1}$ (rest) | $v = 25 + (-2.0 \times 3.0)$ |
| $t = 5.0\ s$ | $v = 25 + (-6.0)$ |
| $v = ?$ | $v = \underline{19\ ms^{-1}}$ (in direction of original velocity) |

$s = ut + 1/2at^2$

A greyhound is running at 6.0 $ms^{-1}$. It decelerates uniformly in a straight line at 0.5 $ms^{-2}$ for 4.0 s. Calculate the displacement of the greyhound while it was decelerating.

| | |
|---|---|
| $u = 6.0\ ms^{-1}$ | $s = ut + 1/2at$ |
| $a = -0.5\ ms^{-2}$ | $s = (6.0 \times 4.0) + (0.5 \times -0.5 \times 4.0^2)$ |
| $t = 4.0\ s$ | $s = 24 + (-4.0)$ |
| $s = ?$ | $s = \underline{20\ m}$ (in direction of original velocity) |

$v^2 = u^2 + 2as$

A curling stone leaves a player's hand at 5.0 $ms^{-1}$ and decelerates uniformly at 0.75 $ms^{-2}$ in a straight line for 16.5 m until it strikes another stationary stone. Calculate the velocity of the decelerating curling stone at the instant it strikes the stationary one.

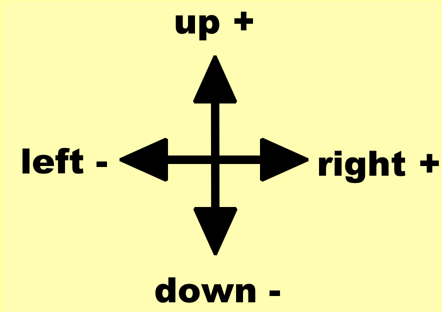
| | |
|---|---|
| $u = 5.0\ ms^{-1}$ | $v^2 = u^2 + 2as$ |
| $a = -0.75\ ms^{-2}$ | $v^2 = 5.0^2 + (2 \times -0.75 \times 16.5)$ |
| $s = 16.5\ m$ | $v^2 = 25 + (-24.75)$ |
| $v = ?$ | $v^2 = 0.25$ |
| | $u = \sqrt{0.25} = \underline{0.5\ ms^{-1}}$ (in direction of original velocity) |

# B) MOTION-TIME GRAPHS FOR MOTION WITH CONSTANT ACCELERATION

**DIRECTION OF VECTOR MOTION**

Velocity, acceleration and displacement are all vector quantities - we must specify a direction for them.

We usually do this by placing a + or - sign in front of the number representing the quantity, according to the direction diagram on the right.




For example, for horizontal motion, +5 $ms^{-1}$ represents a velocity of 5 $ms^{-1}$ to the right and -5 $ms^{-1}$ represents a velocity of 5 $ms^{-1}$ to the left.

For vertical motion, +10 m represents a displacement of 10 m up and -10 m represents a displacement of 10 m down.

(WARNING: The + sign is often missed out! and some graphs/questions you may encounter use the opposite sign convention, e.g., up is -, down is +. BE CAREFUL !!!)

## Comparing motion-time graphs

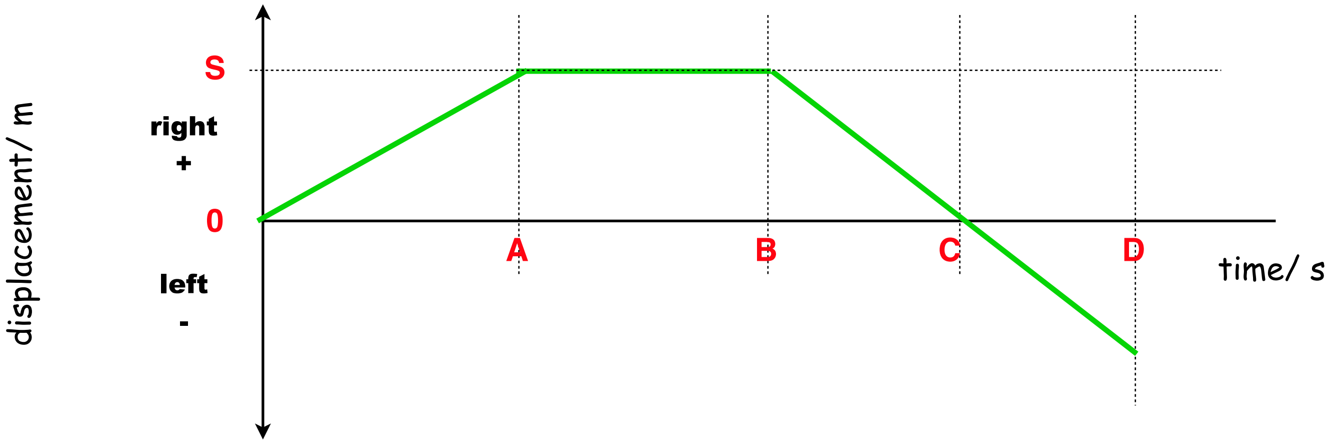
In all areas of science, graphs are used to display information. Graphs are an excellent way of giving information, especially to show relationships between quantities. In this section we will be examining three types of motion-time graphs.

Displacement-time graphs
Velocity-time graphs
Acceleration-time graphs

If you have an example of one of these types of graph then it is possible to draw a corresponding graph for the other two factors.

# Displacement – time graphs

This graph represents how far an object is from its starting point at some known time.
Because displacement is a vector it can have positive and negative values.
[+ve and -ve will be **opposite** **directions** from the starting point.]




OA – the object is moving away from the starting point.

It is moving a **constant** displacement each second.

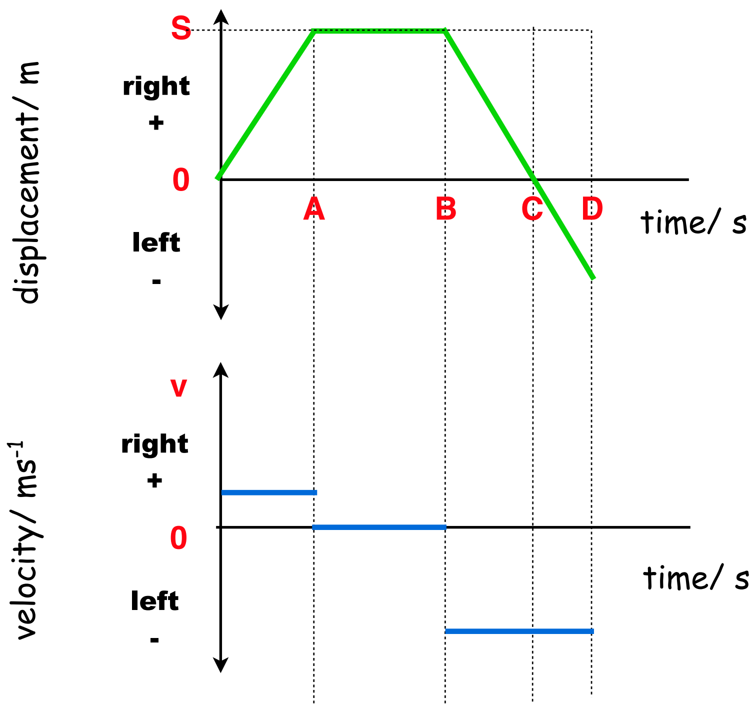
This is shown by the constant gradient.

gradient = $\frac{\text{change in y}}{\text{change in x}}$ = $\frac{\text{displacement}}{\text{time}}$ = **velocity**

We can determine the **velocity** from the **gradient** of a displacement time graph.

AB – the object has a **constant** displacement so is not changing its position, therefore it must be at rest. The gradient in this case is zero, which means the object has a velocity of zero.

BC – the object is now moving back towards the starting point, reaching it at time C.
It then continues to move away from the start, but in the opposite direction.
The gradient of the line is **negative**, indicating the **change in direction** of motion.




The **velocity time** graph is essentially a graph of the gradient of the displacement time graph.

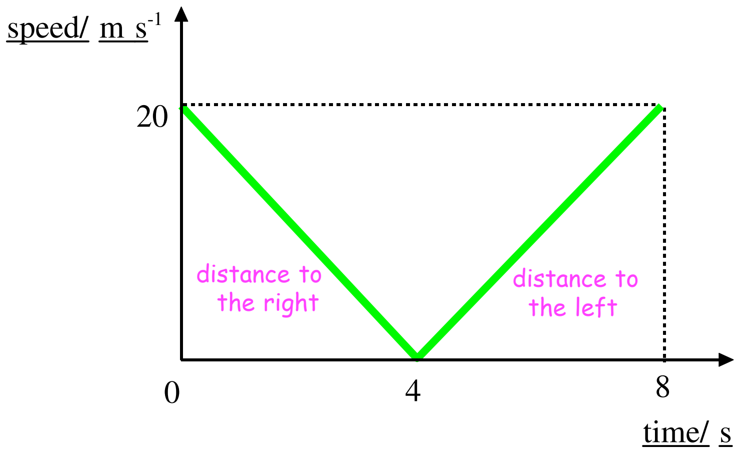
It is important to take care to determine whether the gradient is **positive** or **negative**.

The gradient gives us the information to determine the **direction** an object is moving.

# Comparing speed-time and velocity-time graphs for motion in a straight line

A car, initially travelling at 20 $ms^{-1}$ in a straight line to the **right**, brakes and decelerates uniformly (constantly) at 5.0 $ms^{-2}$, coming to **rest** in 4.0 s. Immediately, it reverses, accelerating uniformly (constantly) at 5.0 $ms^{-2}$ in a straight line to the **left** for 4.0 s, back to where it started.

## speed-time graph of motion

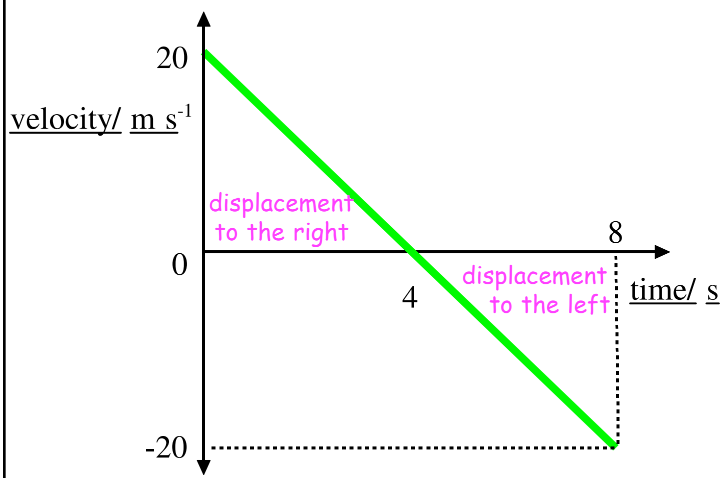



**Speed** is a **scalar** quantity. No account is taken of the direction of travel.

The straight lines indicate uniform deceleration and uniform acceleration.
(**Gradient = acceleration**.)

The **total area** under the graph gives the total distance travelled.

## velocity-time graph of motion




**Velocity** is a **vector** quantity, so change in direction is taken into account. This is shown by the line crossing the time axis at 4.0 s.

In this case, the deceleration and acceleration have the same numerical value, so the gradient of the line (which indicates their value) is uniform.

The **total mathematical area** under the graph gives the **displacement**.

### Determine the total distance travelled:

The **total area** under the graph gives the total distance travelled.

Area = 1/2(20 x 4) + 1/2(20 x 4)

Area = 80

Distance travelled = 80 m

### Show that the displacement is zero:

The **total mathematical area** under the graph gives **the displacement**.

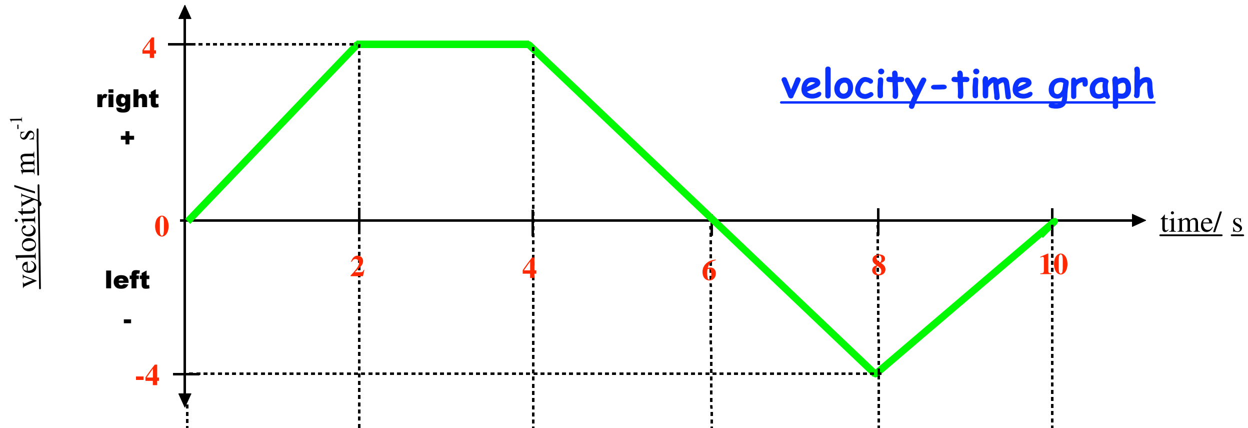
Area = 1/2(20 x 4) + (-)1/2(20 x 4)

Area = 40 + -40

Displacement = 0 m

# Obtaining an acceleration-time graph from a velocity-time graph for motion in a straight line

The velocity-time graph for an object moving in a straight line over horizontal ground is shown. Calculate the acceleration for each part of the graph, then use your values to draw the corresponding acceleration-time graph below:



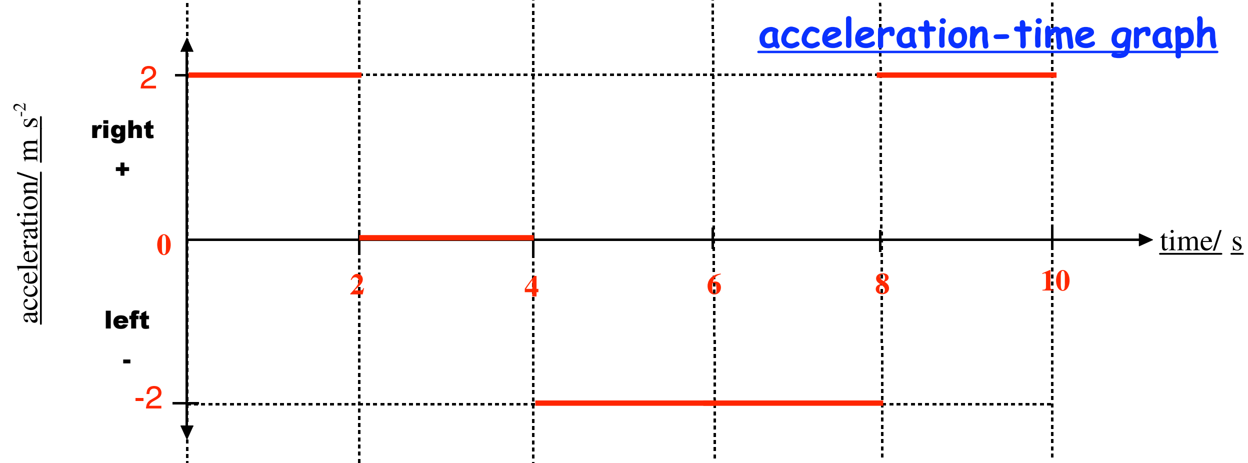

$a = \frac{v - u}{t} = \frac{4 - 0}{2} = 2 ms^{-2}$

$a = \frac{v - u}{t} = \frac{4 - 4}{2} = 0 ms^{-2}$

$a = \frac{v - u}{t} = \frac{0 - 4}{2} = -2 ms^{-2}$

$a = \frac{v - u}{t} = \frac{-4 - 0}{2} = -2 ms^{-2}$

$a = \frac{v - u}{t} = \frac{0 - -4}{2} = 2 ms^{-2}$




Describe fully, the motion of the object - You must include all accelerations, times and directions:

0-2s, accelerates right at 2 $ms^{-2}$
2-4s, constant velocity right at 4 $ms^{-1}$
4-6s, decelerates right at -2 $ms^{-2}$
6-8s, accelerates left at 2 $ms^{-2}$
8-10s, decelerates left to a stop at -2$ms^{-2}$

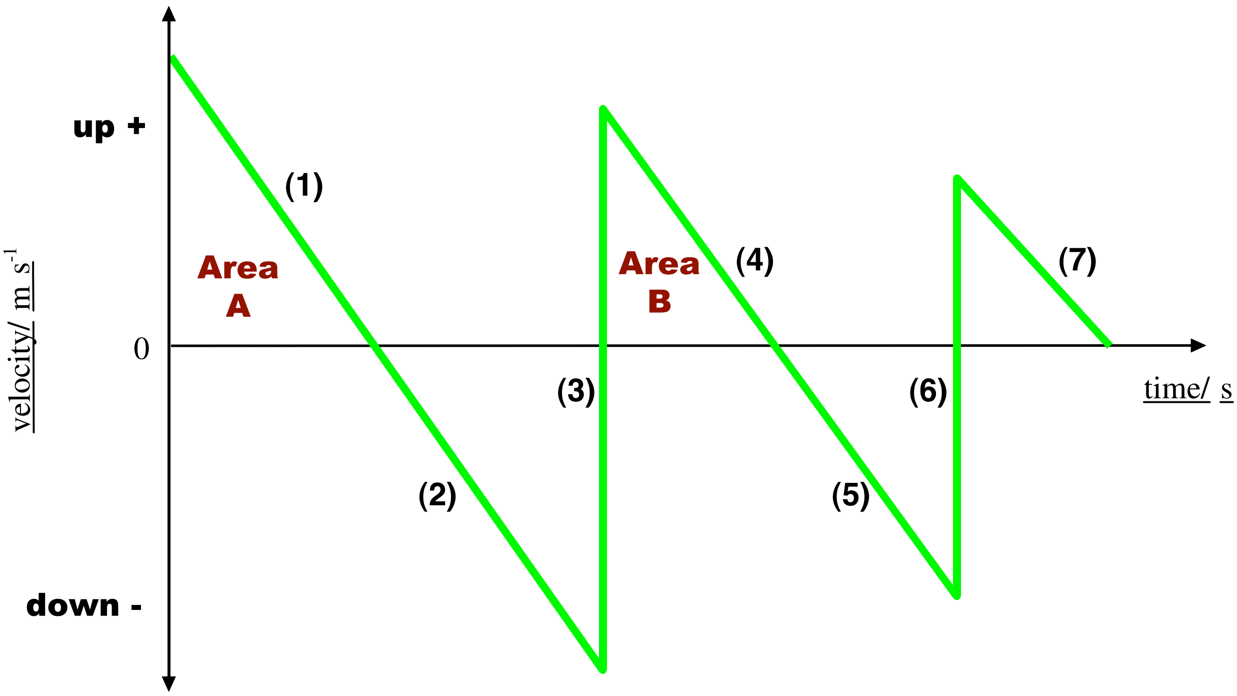
Determine the displacement of the object:

The total mathematical area under the graph gives **the** **displacement**.

0-2s: 1/2(4 x 2) = 4m
2-4s: (2 x 4) = 8m
4-6s: 1/2(4 x 2) = 4m
6-8s: 1/2(-4 x 2) = -4m
8-10s: 1/2(-4 x 2) = -4m
Total displacement = 8m right

# <u>Velocity-time graph for a bouncing ball</u>

**The <u>velocity</u>-<u>time graph</u> for the *<u>vertical</u> (<u>up and down</u>) <u>motion</u>* of a bouncing ball is shown. Initially, the ball was launched *<u>upwards</u>* from ground level.**




What is happening in each section of the graph:

(1) Ball leaves the hand and **decelerates** to top of motion, reaching **<u>zero</u> <u>velocity</u>**.
(2) Ball **accelerates** downward toward the ground
(3) Ball touches ground with **large force** causing it to **<u>change direction</u>** in short time period.
(4) Ball leaves the ground and **decelerates** to top of motion.
(5) - (7) Ball repeats motion.

The graph proves that the **acceleration** of the ball is **constant**, and is the **acceleration due to gravity**, at **<u>$-9.8$ $ms^{-2}$</u>**.

This is evident by the **constant negative gradient** at each section of the graph.

The **areas** represent the **<u>distance</u> <u>travelled</u>** in each section of the motion.

**Area A** is **<u>larger</u>** than **Area B** as on rebound **<u>some energy is lost as heat</u>** and so the **height gained is smaller.**

# C) MOTION OF OBJECTS WITH CONSTANT SPEED OR CONSTANT ACCELERATION.

## Equations of Motion Applied to Objects Dropped or Launched Upwards

**up +**

**down -**

Any object moving **freely** through the air is **accelerated** towards the ground under the influence of **gravity**.

It does not matter if the object is **falling** or **moving upwards**
**Gravity** always provides a **downward acceleration** of **9.8 ms$^{-2}$**.

If we adopt the sign convention shown on the left for the **three equations of motion**, we must use the value of **-9.8 ms$^{-2}$** for the **acceleration** of any object moving **freely** through the air.

$\boxed{a = -9.8 \text{ ms}^{-2}}$

## (1) Dropped Objects

At the instant an object is dropped, it is stationary - It is not moving downwards,
so **initial downward velocity** (**u**) = **0 ms$^{-1}$**.

The object will **accelerate** towards the ground under the influence of **gravity**. **a = -9.8 ms$^{-2}$**.

**Example**

A helicopter is hovering at a constant height. A wheel falls off and hits the ground below 4.0 s later. Calculate:

(a) the downward vertical velocity of the wheel at the instant it hits the ground;

(b) the height of the hovering helicopter.

s = ?
u = 0 ms$^{-1}$
v = ?
a = -9.8 ms$^{-2}$
t = 4.0 s

(a) v = u + at
v = 0 + (-9.8 x 4.0)
v = 0 - 39.2
v = -39 ms$^{-1}$
(i.e., 39 ms$^{-1}$ downwards)

(b) s = ut + 1/2at
s = (0 x 4.0) + (0.5 x -9.8 x 4.0$^2$)
s = 0 + (-78.4)
s = -78 m
(i.e., wheel falls 78 m downwards, so height = 78 m)

**OR**

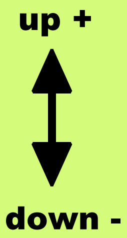
v$^2$ = u$^2$ + 2as
-39.22 = 0$^2$ + (2 x -9.8 x s)
1536.6 = 0 + (-19.6 s)
1536.6 = -19.6 s
s = 1536.6/-19.6 = -78 m
(i.e., wheel falls 78 m downwards, so height = 78 m)

## (2) Objects Launched Upwards

At the instant an object is launched upwards, it is travelling at **maximum velocity**.
**u = maximum upward velocity at launch**.

As soon as the object starts to travel upwards, **gravity** will **accelerate** it towards the ground at **$-9.8\ ms^{-2}$**. (**$a = -9.8\ ms^{-2}$**).

As a result, the **upward velocity** of the object will eventually become **$0\ ms^{-1}$**.
This happens at its **maximum height**. (**$v = 0\ ms^{-1}$ at maximum height**).




**Example**

A spring-powered toy frog is launched vertically upwards from the ground at $4.9\ ms^{-1}$.

(a) What will be the velocity of the toy frog at its maximum height?

(b) Calculate:

(i) the time taken for the toy frog to reach its maximum height;
(ii) the maximum height.

$s = ?$
$u = 4.9\ ms^{-1}$
$v = ?$
$a = -9.8\ ms^{-2}$
$t = ?$

(a) At maximum height, $v = 0\ ms^{-1}$

(b)(i)
$v = u + at$
$0 = 4.9 + (-9.8 \times t)$
$0 = 4.9 - 9.8\ t$
$9.8\ t = 4.9$
$t = 4.9/9.8 = 0.5\ s.$

(b)(ii)
$s = ut + 1/2at$
$s = (4.9 \times 0.5) + (0.5 \times -9.8 \times 0.52)$
$s = 2.45 + (-1.225)$
$s = \underline{1.2\ m}$
(i.e., $\underline{1.2\ m}$ $\underline{\text{upwards}}$,
so height = $\underline{1.2\ m}$)

**OR**

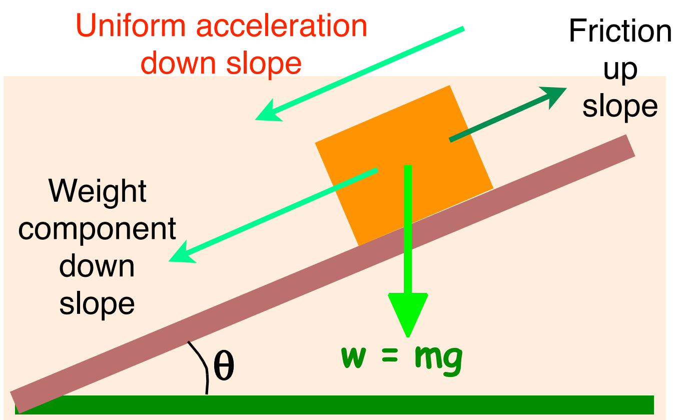
$v^2 = u^2 + 2as$
$0^2 = 4.9^2 + (2 \times -9.8 \times s)$
$0 = 24.01 + (-19.6\ s)$
$19.6\ s = 24.01$
$s = 24.01/19.6 = \underline{1.2\ m}$
(i.e., $\underline{1.2\ m}$ $\underline{\text{upwards}}$,
so height = $\underline{1.2\ m}$)

## (3) Objects on a Slope

As we shall see later, when an object is placed on a slope, the **weight** of the object causes a force down the slope which is constant.

Even if there is a **constant friction force** acting up the slope, the object will have a **uniform acceleration down the slope**.

**The Equations of Motion can also be applied to objects on slopes.**



# HIGHER PHYSICS

## UNIT 1 - OUR DYNAMIC UNIVERSE

## 2) FORCES, ENERGY AND POWER

Can you talk about:

### (a) Balanced and unbalanced forces. The effects of friction. Terminal velocity.

- Forces acting in one dimension only.
- Analysis of motion using Newton's First and Second Laws.
- Friction as a force acting in a direction to oppose motion. No reference to static and dynamic friction.
- Tension as a pulling force exerted by a string or cable on another object.
- Velocity-time graph of falling object when air resistance is taken into account, including changing the surface area of the falling object.
- Analysis of the motion of a rocket may involve a constant force on a changing mass as fuel is used up.

### (b) Resolving a force into two perpendicular components.

- Forces acting at an angle to the direction of movement.
- The weight of an object on a slope can be resolved into a component acting down the slope and a component acting normal to the slope.
- Systems of balanced and unbalanced forces with forces acting in two dimensions.

### (c) Work done, potential energy, kinetic energy and power.

- Work done as transfer of energy.
- Conservation of energy.

# A) BALANCED AND UNBALANCED FORCES, THE EFFECTS OF FRICTION AND TERMINAL VELOCITY

## Balanced Forces

The forces acting on this object cancel each other out - The **resultant force** is **0 N**.

**resultant force = 0 N**


## Unbalanced Forces

The forces acting on this object **do not** cancel each other out - The **resultant force** is **4 N to the right**.
The forces are **unbalanced**.

**resultant force = 4 N to the right**


**NEWTON'S FIRST LAW OF MOTION**

**If an object is at rest or moving with a constant velocity in a straight line, the forces acting on it are balanced.**

**If an object is accelerating, the forces acting on it are unbalanced.**
**(The object accelerates in the direction of the unbalanced force.)**

**NEWTON'S SECOND LAW OF MOTION**

**The acceleration (a) of an object is directly proportional to the unbalanced force ($F_{un}$) in newtons acting on it and inversely proportional to its mass (m) in kilograms.**

Combining $a \propto F_{UN}$ and $a \propto \dfrac{1}{m}$ gives $a = \text{constant} \times \dfrac{F_{un}}{m}$

## Defining the Newton

Combining $a \propto F_{un}$ and $a \propto \dfrac{1}{m}$ gives $a = \text{constant} \times \dfrac{F_{un}}{m}$

When the **unbalanced force** ($F_{un}$) is measured in newtons and the **mass** (m) is measured in kilograms, the value of the constant is **1**.

So, $a = 1 \times \dfrac{F_{un}}{m}$ or $a = \dfrac{F_{un}}{m}$

Rearranging gives $F_{un} = ma$

**This shows that 1 newton is the value of the unbalanced force which will accelerate a mass of 1 kg at 1 $ms^{-2}$.**

# SOLVING $F_{un} = ma$ PROBLEMS

The following technique should be applied to $F_{un} = ma$ problems involving either **single objects** or **objects connected together** (like a train with carriages.)

**Draw a free body diagram showing the magnitude (size) and direction of all the forces acting on the object/objects.**
**Use the free body diagram to determine the magnitude (size) and direction of the unbalanced force ($F_{un}$) and draw this on the diagram.**

**Apply $F_{un} = ma$.**

If the objects are **connected together** and the problem asks about the **whole system**, use the **total mass** of the system in the equation $F_{un} = ma$.

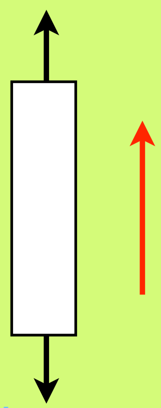
If the problem asks about only **part of the system** (like one carriage of a long train), only show the **single object** on your free body diagram. Use this **unbalanced force** and the **mass of the single object** (not the mass of the whole system) in the equation $F_{un} = ma$.

**Example 1**

A space rocket of mass $3 \times 10^6$ kg is launched from the earth's surface when its engine produces an upward thrust of $3 \times 10^7$ N. Calculate the rocket's acceleration at launch.

**Free body diagram**
**(Represent the rocket by a box.)**

thrust = $(3 \times 10^7)$ N



$F_{un} = (6 \times 10^5)$ N

weight $= mg$
$= (3 \times 10^6)\text{ kg} \times 9.8\text{ N kg}^{-1}$
$= (2.94 \times 10^7)$ N

$F_{un}$ = thrust - weight
$F_{un} = (3 \times 10^7)\text{ N} - (2.94 \times 10^7)\text{ N}$
$= (6 \times 10^5)$ N (upwards)

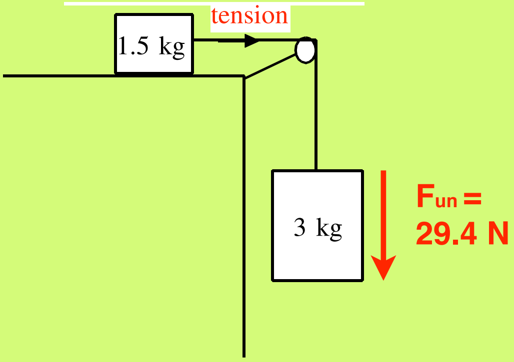
$$a = \frac{F_{un}}{m} = \frac{(6 \times 10^5)\text{ N}}{(3 \times 10^6)\text{ kg}} = 0.2\text{ ms}^{-2}\text{ (upwards)}$$

**Example 2**

2 wooden blocks are tied together by piece of weightless string. One block (of mass 1.5 kg) sits on a horizontal table. There is no force of friction between the block and table. The other block (of mass 3 kg) is passed over a frictionless pulley. This block falls to the floor, dragging the 1.5 kg block across the table.

Calculate: (a) the acceleration of both wooden blocks;
(b) the tension (pulling force) in the string.

**Free body diagram**
**(Represent the blocks by boxes.)**




weight of 3 kg block = mg
= 3 kg x 9.8 N kg$^{-1}$
= 29.4 N (downwards)

(a) The weight of the 3 kg block is the unbalanced force which produces the acceleration.

$$a = \frac{F_{un}}{m_{total}}$$
$$= \frac{29.4\text{ N}}{1.5\text{ kg} + 3\text{ kg}}$$
$$= \frac{29.4\text{ N}}{4.5\text{ kg}}$$
$$= 6.5\text{ ms}^{-2}\text{ (down and right)}$$

(b) The tension in the string is the pulling force on the 1.5 kg block.

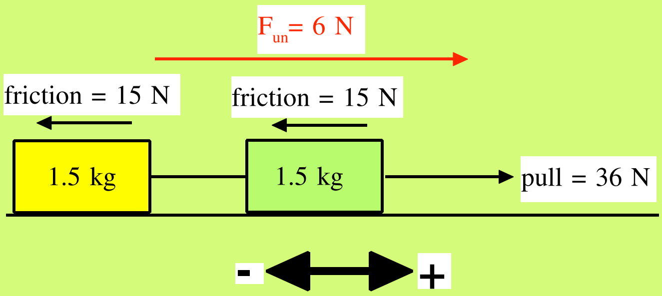
tension $= m_{1.5\text{ kg}} \times a$
= 1.5 kg x 6.5 ms$^{-2}$
= 9.8 N

## Example 3

Adam pulls 2 metal blocks (both of mass 1.5 kg), joined by string of zero mass, along a horizontal bench top with a constant force of 36 N. The force of friction acting on each block is 15 N.

Calculate: (a) the acceleration of the metal blocks;
(b) the tension (force) in the string between the 2 metal blocks.

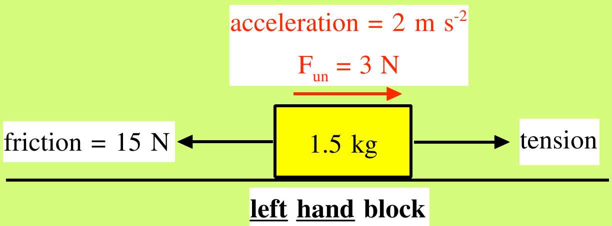
(a) **Free body diagram**
**(Represent the blocks by boxes.)**




$F_{un}$ = pull - friction
$F_{un}$ = 36 N - (2 x 15) N
= 36 N - 30 N
= 6 N (to the right)

$$a = \frac{F_{un}}{m_{total}}$$
$$= \frac{6\text{ N}}{1.5\text{ kg} + 1.5\text{ kg}}$$
$$= \frac{6\text{ N}}{3\text{ kg}}$$
$$= 2\text{ ms}^{-2}\text{ (to the right)}$$

(b) **Free body diagram**
**(Represent the <u>left hand block</u> by a box.)**




Unbalanced force acting on left block ($F_{un}$)
$= m_{1.5\text{ kg}}\, a$
= 1.5 kg x 2 ms$^{-2}$
= 3 N (to the right)

$F_{un}$ = tension - friction
3 N = tension - 15 N
tension = 3 N - (-15) N
= 3 N + 15 N
= 18 N

The tension force produces the acceleration and overcomes the force of friction.

## Example 4

The following examples relate to Hannah, mass 60 kg, who is standing on a set of scales in a lift.

Two forces act:

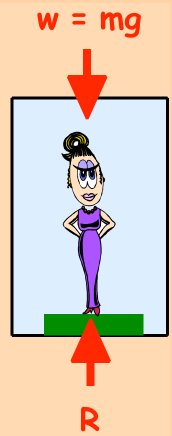
Weight downwards (W)

Value does not change.

Reaction upwards (R)

Value changes as motion of lift changes.

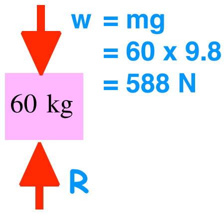
(R is the reading on the scales.)




### 1) Lift cable breaks

Determine the reading on the scales (R) if the lift cable breaks, causing the lift, scales and Hannah to accelerate downwards at 9.8 ms$^{-2}$.

**Free body diagram**




**Both Hannah and the scales accelerate downwards at the same rate**

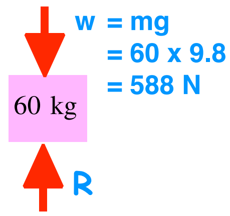
**There is no reaction force upwards**

$\therefore$ **R = 0 N**

### 2) Lift stationary

Determine the reading on the scales (R) if the lift is stationary.

**Free body diagram**




**Lift is stationary**

$\Rightarrow$ **balanced forces**

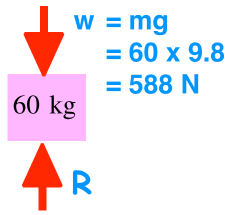
$\Rightarrow$ **R = W**

$\Rightarrow$ **R = 588 N**

### 3) Lift travelling at constant velocity

Determine the reading on the scales (R) if the lift is travelling at constant velocity.

**Free body diagram**




**Constant velocity**

$\Rightarrow$ **balanced forces**

$\Rightarrow$ **R = W**

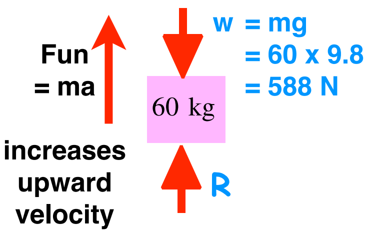
$\Rightarrow$ **R = 588 N**

### 4) Lift accelerating upwards

Calculate the reading on the scales (R) if the lift is accelerating upwards at 2.5 ms$^{-2}$.

**Free body diagram**

**Unbalanced force ($F_{un}$= ma) and R act in same direction:**



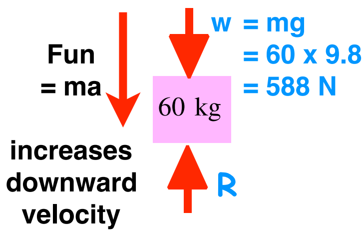

**ma = R - W**
**150 x 2.5 = R - 588**
**150 = R - 588**
**R = 150 + 588**
**R = 738 N**

### 5) Lift accelerating downwards

Calculate the reading on the scales (R) if the lift is accelerating downwards at 1.5 ms$^{-2}$.

**Free body diagram**

**Unbalanced force ($F_{un}$= ma) and W act in same direction:**



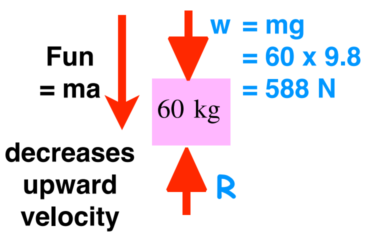

**ma = W - R**
**60 x 1.5 = 588 - R**
**90 = 588 - R**
**R = 588 - 90**
**R = 498 N**

### 6) Lift decelerating upwards

Calculate the reading on the scales (R) if the lift is decelerating upwards at 1.5 ms$^{-2}$.

**Free body diagram**

**Unbalanced force ($F_{un}$= ma) and W act in same direction:**



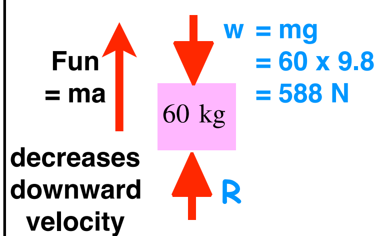

**ma = W - R**
**60 x 1.5 = 588 - R**
**90 = 588 - R**
**R = 588 - 90**
**R = 498 N**

### 7) Lift decelerating downwards

Calculate the reading on the scales (R) if the lift is decelerating downwards at 2.5 ms$^{-2}$.

**Free body diagram**

**Unbalanced force ($F_{un}$= ma) and R act in same direction:**




**ma = R - W**
**150 x 1.5 = R - 588**
**150 = R - 588**
**R = 150 + 588**
**R = 738 N**

# Velocity-time graphs and air resistance

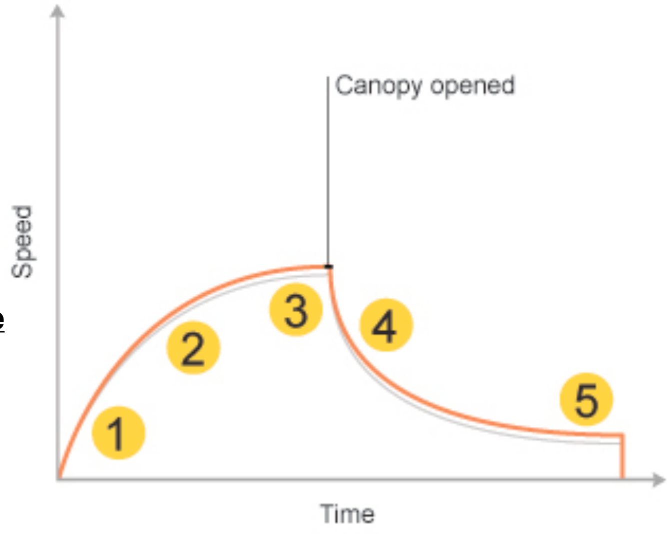
In section **one**, we looked at **velocity-time graphs** for **constant acceleration**, but often situations are more complex, for example when jumping out of a plane. *Some really crazy people do this for fun.*

**Before the parachute opens**

1.When the skydiver jumps out of the plane he **accelerates** due to the force of gravity pulling him down.
2.As he speeds up the upwards air resistance force increases. He carries on accelerating as long as the air resistance is less than his weight.
3.Eventually, he reaches his **terminal speed** when the air resistance and weight become equal. They're said to be balanced.

**After the parachute opens**

4.When the canopy opens it has a **large surface area** which **increases** the **air resistance**. This unbalances the forces and causes the parachutist to slow down.
5.As the parachutist **slows down**, his **air resistance gets less** until eventually it equals the downward force of gravity on him (his weight). Once again the **two forces balance** and he falls at terminal speed. This time it's a much slower terminal speed than before.



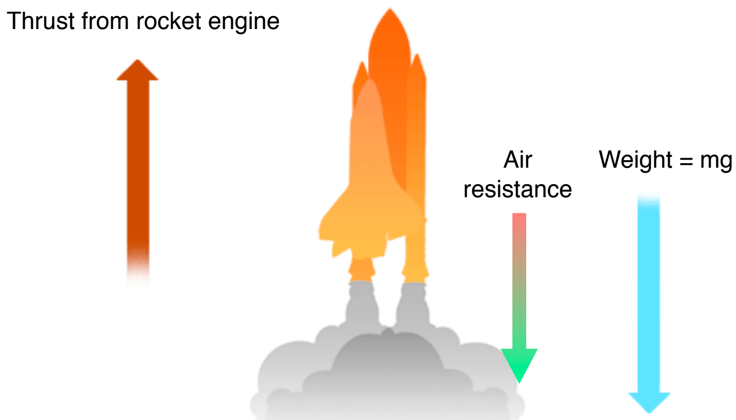

http://www.bbc.co.uk/schools/gcsebitesize/science/add_ocr_gateway/forces/fallingrev2.shtml

# To infinity and beyond...

**Changing speed with time**

As a rocket **rises** through the atmosphere, despite a **constant upward thrust** due to the rocket engines, the acceleration ***is not constant***.

**Three** things contribute to an **increase** in the rocket's acceleration:




http://www.bbc.co.uk/scotland/learning/bitesize/standard/physics/transport/forces_at_work_rev1.shtml

1. Gravitational field strength "g" decreases with distance from the Earth's surface,

   ➪ **Weight force decreases**

2. The rocket fuel is being used up as the rocket rises, decreasing the overall mass of the rocket.

   ➪ **Weight force decreases**

3. The atmosphere becomes thinner as the rocket rises.

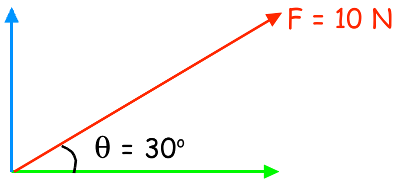
   ➪ **Air resistance decreases**

# B) RESOLVING A FORCE INTO TWO PERPENDICULAR COMPONENTS

Any **vector** can be replaced by **2 vectors** of the correct magnitude (size) acting at right-angles (90°) to each other.

For example:

$F \sin \theta$
$= 10 \times \sin 30°$
$= 10 \times 0.500$
$= \underline{5.0 \text{ N}}$




$F \cos \theta$
$= 10 \times \cos 30°$
$= 10 \times 0.866$
$= \underline{8.7 \text{ N}}$

The **10 N** vector can be replaced by the 2 vectors: **5.0 N** acting **vertically** and **8.7 N** acting **horizontally**. (These 2 vectors are at right-angles to each other). The **5.0 N** and **8.7 N** vectors are known as **components** of the **10 N** vector.

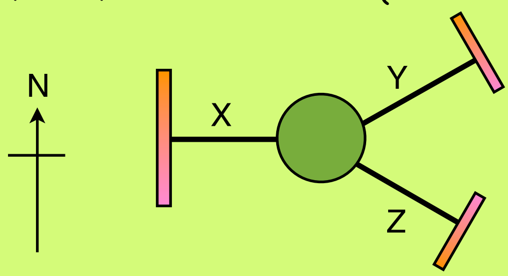
The **5.0 N** and **8.7 N** forces **acting together** have exactly the same effect as the **10 N** force **acting on its own. Acting together**, the **5.0 N** and **8.7 N** forces would move an object **in exactly the same direction as the 10 N force would, at exactly the same velocity.**

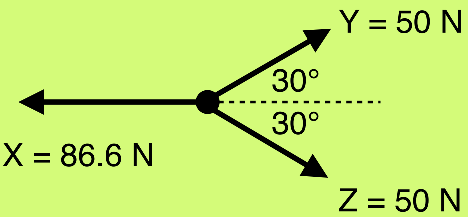
## Systems of balanced and unbalanced forces with forces acting in two dimensions

When **two or more forces** are acting on an object, in two dimensions, the skills of resolving forces and investigating whether forces are balanced or unbalanced are essential.

**Example**

An object of 28 kg is held stationary by the forces acting in ropes X, Y and Z. The sizes of the forces are shown. (Friction can be ignored).




(a) What is the resultant of the 50 N forces which act in ropes Y and Z?

The resultant force of Y and Z is 86.6 N East, since the object is stationary and so forces Y and Z must balance force X.

Alternatively:

Horizontal component of Y is F = 50 cos 30° = 43.3 N.

Horizontal component of Z is F = 50 cos 30° = 43.3 N.

Total horizontal component = 86.6 N

(b) Rope X snaps. Calculate the initial acceleration of the mass.

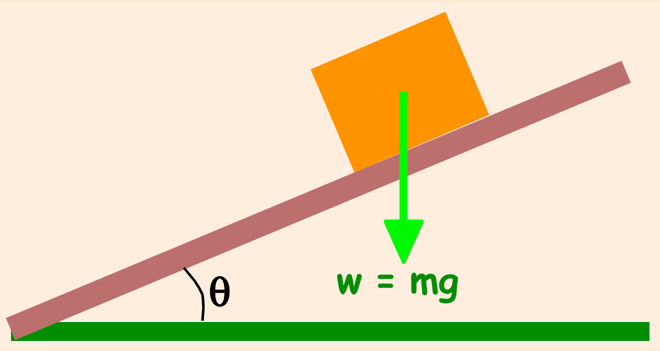
$$a = \frac{F}{m}$$

$$a = \frac{86.6}{28}$$

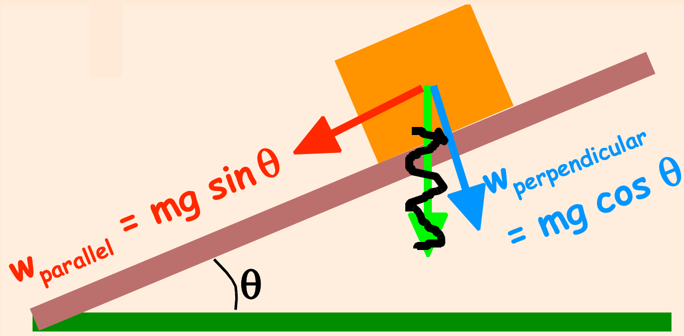
$$a = 3.09 \text{ ms}^{-2}$$

# Objects on a Slope

When an object is placed on a slope, the **weight** of the object acts **downwards** towards the centre of the earth.



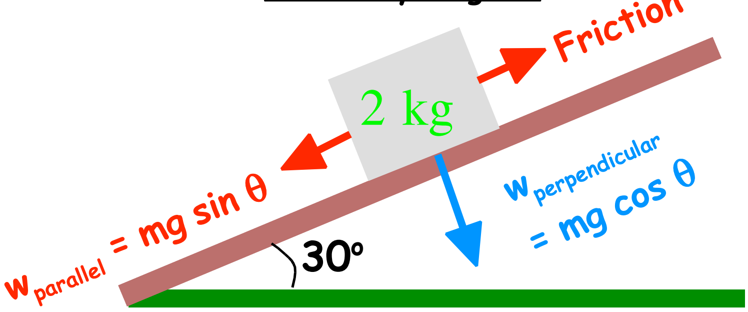

The **weight** of the object can be resolved into **right-angle components** acting **down** (**parallel to**) the slope and **perpendicular to** the slope.




**Example 5**

A 2 kg metal block is placed on a wooden slope which is at an angle of 30° to the horizontal.
The block accelerates down the slope.
A constant friction force of 1.2 N acts up the slope.

**Free body diagram**




Determine:

(a) (i) the component of weight acting down (parallel to) the slope;

(ii) the component of weight acting perpendicular to the slope.

(b) the unbalanced force acting on the metal block down (parallel to) the slope.

(c) the acceleration of the metal block down the slope.

(a) (i) $W_{parallel} = mg \sin \theta$

$= 2\text{ kg} \times 9.8\text{ N kg}^{-1} \times \sin 30°$

$= \underline{9.8\text{ N}}$

(ii) $W_{perpendicular} = mg \cos \theta$

$= 2\text{ kg} \times 9.8\text{ N kg}^{-1} \times \cos 30°$

$= \underline{17\text{ N}}$

(b) $F_{un} = W_{parallel} - \text{Friction}$

$= 9.8\text{ N} - 1.2\text{ N}$

$= \underline{8.6\text{ N}}$ (down the slope)

(c) $a = \dfrac{F_{un}}{m} = \dfrac{8.6\text{ N}}{2\text{ kg}} = \underline{4.3\text{ ms}^{-2}}$ (<u>down the slope</u>)

# C) WORK DONE, POTENTIAL ENERGY, KINETIC ENERGY AND POWER

For each of these "Intermediate 2" formulae, the names of the symbols are given and their standard units.

| Energy | Potential energy | Kinetic energy | Work done |
|---|---|---|---|
| $E = Pt$ | $E_p = mgh$ | $E_k = 1/2mv^2$ | $E_W = Fs$ |
| E: Energy (J) | $E_p$: Potential Energy (J) | $E_k$: Kinetic Energy (J) | $E_W$: Work done (J) |
| P: Power (W) | m: mass (kg) | m: mass (kg) | F: Force (N) |
| t: time (s) | g: gravitational field strength (N/kg) | v: velocity ($ms^{-1}$) | s: displacement (m) |
| | h: height (m) | | |

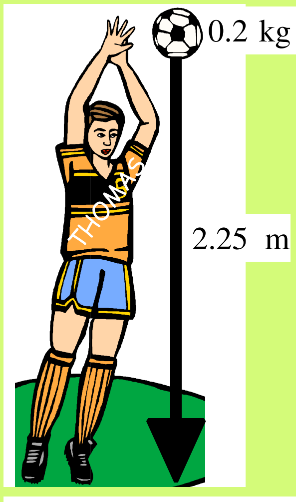
**LAW OF "CONSERVATION OF ENERGY"**

**Energy cannot be created or destroyed, but can be changed from one form to another (or other forms).**

**Example**

**(a) Thomas drops a football of mass 0.2 kg from a height of 2.25 m. Calculate the velocity of the ball at the instant before it hits the ground.**

**(b) Does the mass of the ball affect the velocity?**




(a) Ignore air resistance

Before the ball is dropped, it possesses only gravitational potential energy. At the instant before the ball hits the ground, all the gravitational potential energy has been converted to kinetic energy.

Ep lost = Ek gained

$mgh = 1/2mv^2$

$gh = 1/2v^2$ ('m' appears on both sides of equation, so can be cancelled out).

$9.8 \times 2.25 = 0.5\ v^2$

$22.1 = 0.5\ v^2$

$v^2 = 22.1/0.5 = 44.2$

$v = 44.2 = 6.6\ ms^{-1}$

b) Mass does not appear in equation used for calculation, so has no effect on the velocity of the ball

# HIGHER PHYSICS

## UNIT 1 - OUR DYNAMIC UNIVERSE

## 3) COLLISIONS AND EXPLOSIONS

Can you talk about:

### (a) Elastic and inelastic collisions

- Conservation of momentum in one dimension and in which the objects may move in opposite directions.
- Kinetic energy in elastic and inelastic collisions.

### (b) Explosions and Newton's Third Law.

- Conservation of momentum in explosions in one dimension only.

### (c) Impulse.

- Force-time graphs during contact of colliding objects.
- Impulse can be found from the area under a force-time graph.

# A) ELASTIC AND INELASTIC COLLISIONS

The **momentum** of an object is the product of its **mass** and **velocity**: Unit: **kg $ms^{-1}$** (**Vector**).

**momentum = mass x velocity**

**Example**

Calculate the momentum of a 70 kg ice skater when she is:

(a) moving to the right at 5 $ms^{-1}$; (b) moving to the left at 6 $ms^{-1}$.

**DIRECTION IS VITAL !**

- ⟷ +

(a) momentum = mv

= 70 kg x 5 $ms^{-1}$

= 350 kg $ms^{-1}$

i.e., 350 kg $ms^{-1}$ to the right

(b) momentum = mv

= 70 kg x -6 $ms^{-1}$

= -420 kg $ms^{-1}$

i.e., 420 kg $ms^{-1}$ to the left

# The Law of Conservation of Linear Momentum

The **law of conservation of linear momentum** applies to collisions between 2 objects in a straight line and to an object that explodes into 2 parts that travel in opposite directions along the same straight line.

**The Law of Conservation of Linear Momentum**

**In the absence of external forces, the total momentum just before a collision/explosion is equal to the total momentum just after the collision/explosion.**

There are 2 types of collision - **elastic** and **inelastic**.
We also consider **explosions**.

## I. Elastic Collisions

In an **elastic collision**:

- the 2 colliding objects **bounce apart** after the collision.
- **momentum is conserved**. (The total momentum just before the collision = the total momentum just after the collision.)
- **kinetic energy is conserved**. (The total kinetic energy just before the collision = the total kinetic energy just after the collision.)

## II. Inelastic Collisions

In an **inelastic collision**:

- the 2 colliding objects **stick together** due to the collision.
- **momentum is conserved**. (The total momentum just before the collision = the total momentum just after the collision.)
- **kinetic energy decreases**. (The total kinetic energy just after the collision is less than the total kinetic energy just before the collision.) Some **kinetic energy** is changed into **sound**, **heat** and **energy of deformation** (which changes the shape of the objects) during the collision.

## Example Momentum Problem

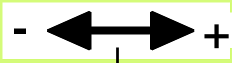
A 2 kg trolley moving to the **right** at **10 ms$^{-1}$** collides with a **10 kg** trolley which is also moving to the **right** at **1 ms$^{-1}$**.

Immediately after the collision, the **2 kg** trolley rebounds to the **left** at **5 ms$^{-1}$**.

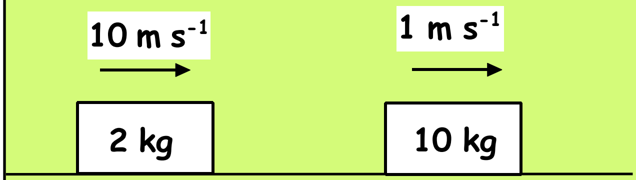
(a) Calculate the **velocity** of the **10 kg** trolley immediately **after** the collision.

(b) Show that the collision is **elastic**.

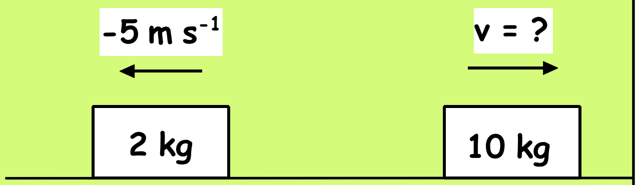
**DIRECTION IS VITAL !**




**Before Collision**




**After Collision**




Total momentum = (2 kg x 10 ms$^{-1}$) + (10 kg x 1 ms$^{-1}$)
= 20 + 10
= 30 kg ms$^{-1}$

Total momentum = (2 kg x -5 ms$^{-1}$)+ (10kg x v)
= -10 + 10v kg ms$^{-1}$

Total momentum just before collision = Total momentum just after collision
30 = (-10 + 10v)
10 v = 30 - (-10)
10v = 40
v = 40/10 = 4 ms$^{-1}$ (ie., 4 ms$^{-1}$ to the right)

Total kinetic energy before collision
= (1/2 x 2 x 10$^2$) + (1/2 x 10 x 1$^2$)
= 100 + 5
= 105 J

Total kinetic energy after collision
= (1/2 x 2 x 5$^2$) + (1/2 x 10 x 4$^2$)
= 25 + 80
= 105 J

Total kinetic energy just before collision = Total kinetic energy just after collision
SO, COLLISION IS ELASTIC.

**Note**

**You should set out all your momentum problems like this - This makes it easier for you (and anybody marking your work) to see exactly what you are doing.**

- **Always include a sketch to show the masses of the colliding objects and their velocities just before and just after the collision.**
- **Take plenty space on your page - Some people take a new page for every problem.**
- **Take care with your calculations and be careful with directions. Remember:**

**DIRECTION IS VITAL !** - ⟷ +

# B) EXPLOSIONS

In an **explosion**:

- **There is only 1 stationary object at the start**. This object **explodes** (**splits up**) into **2 parts** which **travel in opposite directions in a straight line**.
- **Momentum is conserved**. (The total momentum just before the explosion = the total momentum just after the explosion.)
- **Kinetic energy increases**. At the start, the object is stationary, so has **zero kinetic energy**. It has **potential** (**stored**) **energy**. When the object explodes, this **potential energy** is changed into **kinetic energy** - the 2 parts move in opposite directions.

**Example Momentum Problem**

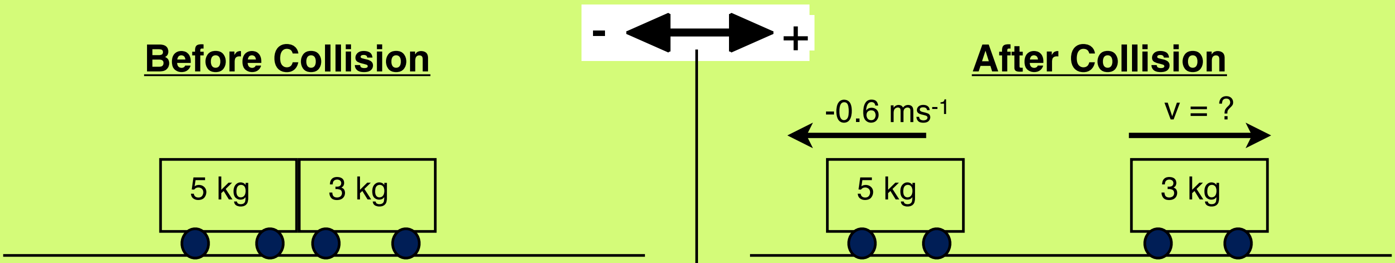
Two trolleys, initially at rest and touching on a smooth, level surface, explode apart when a spring loaded pole is released on one trolley.

Immediately after the explosion, the **5 kg** trolley rebounds to the **left** at **0.6 $ms^{-1}$**.

(a) Calculate the **velocity** of the **3 kg** trolley immediately **after** the collision.

(b) Show that in the collision **kinetic energy increases**.

**DIRECTION IS VITAL !**




Total momentum $= 0 + 0$
$= 0$ kg $ms^{-1}$

Total momentum $= (5 \text{ kg} \times -0.6 \text{ m s}^{-1}) + (3\text{kg} \times v)$
$= -3 + 3v$ kg $ms^{-1}$

Total momentum just before collision = Total momentum just after collision

$$0 = (-3 + 3v)$$
$$-3\,v = -3$$
$$v = -3/-3 = \underline{1 \text{ ms}^{-1} \text{ (i.e., } 1 \text{ ms}^{-1} \text{ to the right)}}$$

Total kinetic energy
$= 0 + 0$
$= 0$ J

Total kinetic energy
$= (1/2 \times 5 \times 0.6^2) + (1/2 \times 3 \times 1^2)$
$= 0.9 + 1.5$
$= 2.4$ J

Total kinetic energy just before collision < Total kinetic energy just after collision

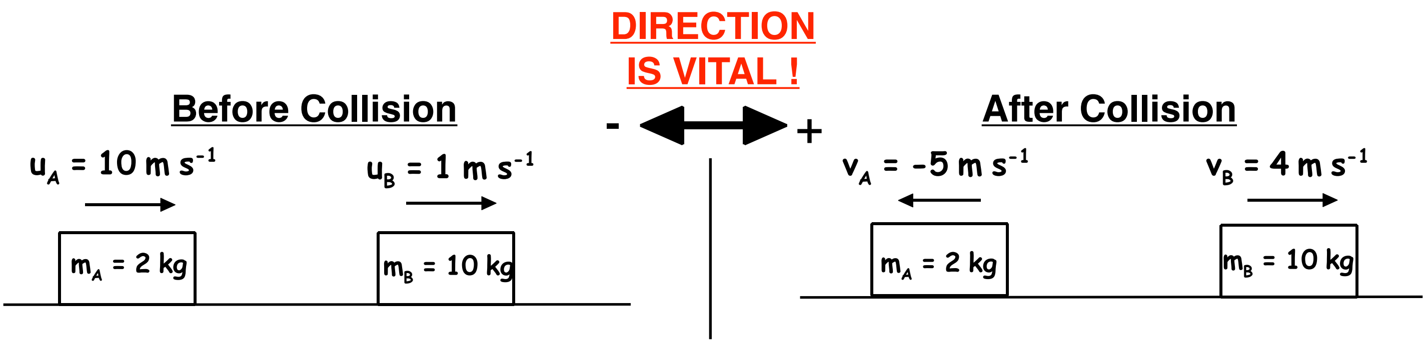
SO, <u>KINETIC ENERGY IS GAINED IN EXPLOSION</u>

# MOMENTUM and NEWTON'S THIRD LAW

**NEWTON'S THIRD LAW**

**If object A exerts a force on object B, then object B exerts a force on object A which is equal in magnitude (size) but in the opposite direction.**

**We can infer "Newton's Third Law" using the "Law of Conservation of Linear Momentum."**




Change in momentum of **A** = $m_A(v_A - u_A) = 2 \times (-5 - 10) = -30$ kg ms$^{-1}$

Change in momentum of **B** = $m_B(v_B - u_B) = 10 \times (4 - 1) = 30$ kg ms$^{-1}$

The change in momentum of A is **equal** in magnitude (size) but **opposite** in direction to the change in momentum of B.

Assume **A** and **B** are in contact for time **t** = 0.1 seconds:

$$\text{Force acting on } A = m_A a = \frac{m_A(v_A - u_A)}{t} = \frac{-30}{0.1} = \underline{-300 \text{ N}}$$

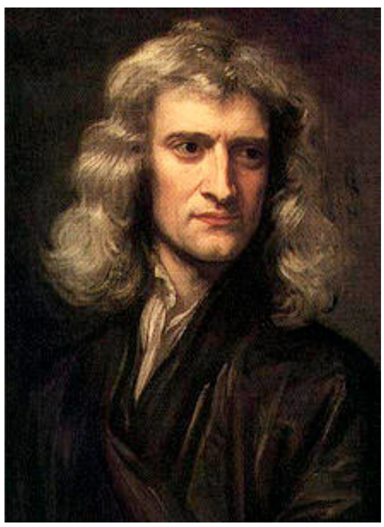
$$\text{Force acting on } B = m_B a = \frac{m_B(v_B - u_B)}{t} = \frac{30}{0.1} = \underline{300 \text{ N}}$$

The forces acting on A and B are **equal** in magnitude (size) but **opposite** in direction.

**Sir Isaac Newton**

Sir Isaac Newton *(25 December 1642 – 20 March 1727)* an English physicist, mathematician, astronomer, natural philosopher, alchemist, and theologian, who has been considered by many to be ***the greatest and most influential scientist who ever lived.***

His monograph ***Philosophiæ Naturalis Principia Mathematica***, published in 1687, lays the foundations for most of classical mechanics. In this work, Newton described **universal gravitation** and **the three laws of motion**, which dominated the scientific view of the physical universe for the next two centuries.



http://en.wikipedia.org/wiki/Isaac_Newton

# C) IMPULSE and CHANGE IN MOMENTUM

When a **force** acts on an object, the **force** is said to give the object an **impulse**.

The **impulse** of a force is equal to the **force** (**F**) multiplied by the **time** (**t**) over which the force acts:

**impulse of force = Ft** (Unit: N s  Vector.)

If a **force** acts on an object of **mass m** travelling with **velocity u**, giving it a new velocity **v**, the **velocity** of the object changes by (**v-u**), so the **momentum** of the object changes by **m(v-u)**.

The **impulse** of a **force** (**Ft**) changes the **momentum** of an object by **m(v-u)**, so:

**impulse = change in momentum**

**$Ft = m(v-u)$**

**Example 1**

Calculate the impulse a force of 5 N exerts on an object which it pushes for 3 seconds.

impulse = Ft
= 5 N x 3 s
= 15 Ns

**Example 2**

A ball of mass 0.2 kg is thrown against a brick wall. The ball is travelling horizontally to the right at 3.0 $ms^{-1}$ when it strikes the wall. It rebounds horizontally to the left at 2.5 $ms^{-1}$.

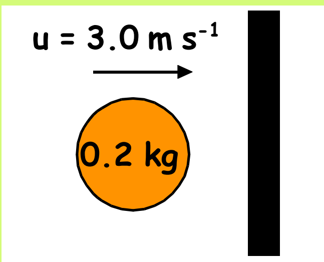
(a) Calculate the ball's change in velocity.

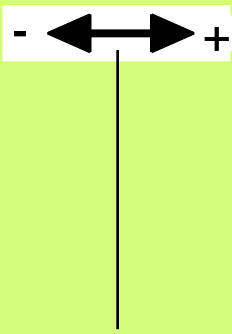
(b) Calculate the ball's change in momentum.

(c) What is the impulse the wall exerts on the ball?

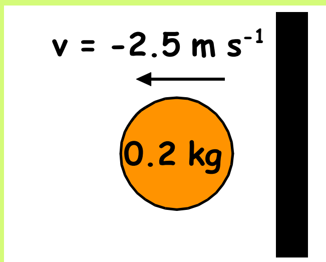
**DIRECTION IS VITAL !**

**Before Collision With Wall**




**After Collision With Wall**




(a) Change in velocity = v - u
= (-2.5) - 3.0
= -5.5 $ms^{-1}$ (i.e., 5.5 $ms^{-1}$ to the left)

(b) Change in momentum = m(v - u)
= 0.2 x [(-2.5) - 3.0]
= 0.2 x -5.5
= -1.1 kg $ms^{-1}$ (i.e., 1.1 kg $ms^{-1}$ to the left)

(c) Impulse = change in momentum
= -1.1 N s (i.e., 1.1 N s to the left)

**Example 3**

A golf ball of mass 0.1 kg, initially at rest, was hit by a golf club, giving it an initial horizontal velocity of 50 $ms^{-1}$. The club and ball were in contact for 0.002 seconds.

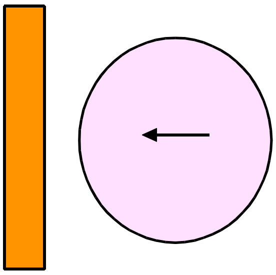
Calculate the average force that the club exerted on the ball.

Ft = m (v - u)
F x 0.002 = 0.1 x (50 - 0)
0.002 F = 5
F = 5/0.002 = 2 500 N

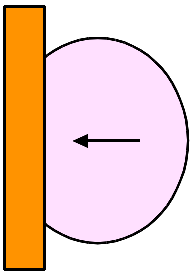
# The Average Force Exerted During An Impact

You will notice that on the previous page, the term ***average force*** has been used in connection with impulse. This is because the magnitude (size) of the force that acts during an impact changes during the impact - so we are only able to determine an average value for the force.

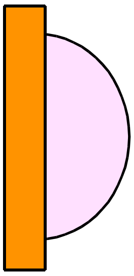
For example, imagine a ball striking a wall. The force the wall exerts on the ball is zero before the impact, rises to a maximum as the ball strikes the wall and is deformed (squashed), then decreases to zero as the ball rebounds from the wall, regaining its shape.



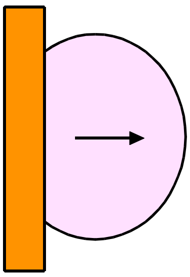
**I. Ball moves towards wall. Force wall exerts on ball is zero.**



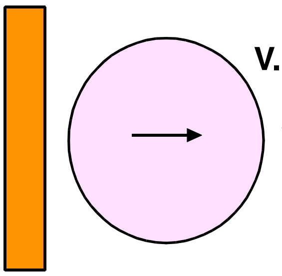
**II. Ball strikes wall. Wall exerts force on ball, deforming ball. The deforming force increases, so ball deforms (squashes) more.**



**III. Force exerted by wall on ball reaches its maximum value. Ball is deformed (squashed) to its maximum.**



**IV. Ball rebounds from wall and starts to regain its shape. Force wall exerts on ball decreases.**



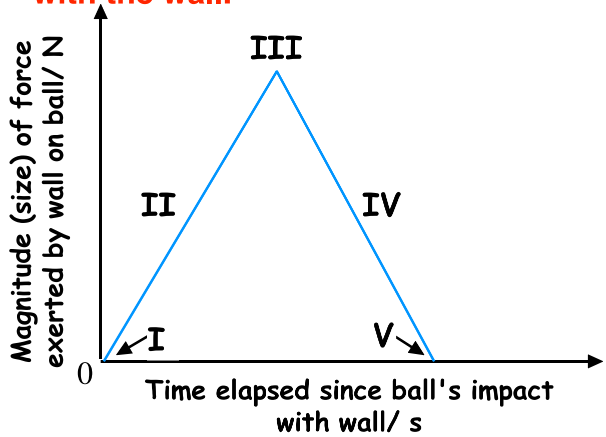
**V. Ball has completely rebounded from wall. Force exerted by wall on ball is zero.**

This can be represented on a force-time graph.

The area under the force-time graph represents:

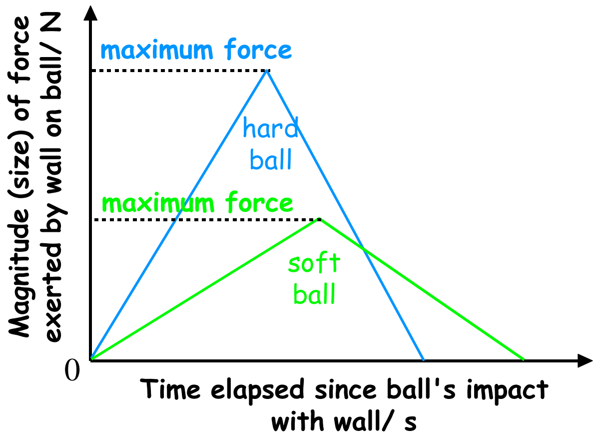
(a) The **impulse** of the force exerted by the wall on the ball during its time of contact.

**(b)** The **change in momentum** experienced by **the ball during its time of contact with the wall.**

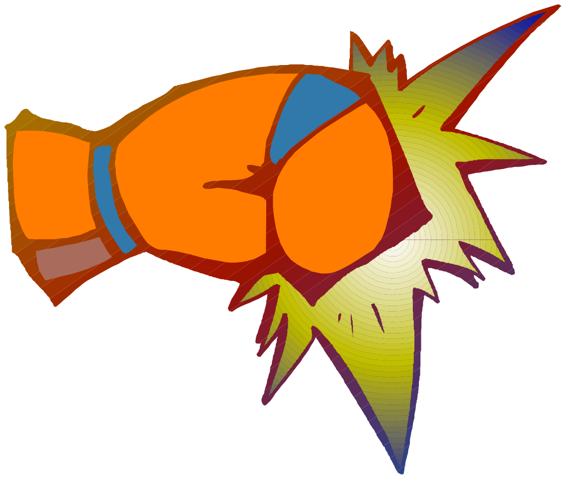



If the ball is **hard** (**rigid**), like a golf ball, the **time of contact** between the ball and wall will be **small** and the **maximum force** exerted by the wall on the ball will be **large** (see graph below).

If the ball is **softer**, like a tennis ball, the **time of contact** between the ball and wall will be **longer** and the **maximum force** exerted by the wall on the ball will be **smaller** (see graph below).



| | | | |
|---|---|---|---|
| **impulse = Ft** | Hard object | Shorter time of contact during impact | Larger maximum force |
| | Soft object | Longer time of contact during impact | Smaller maximum force |



Boxers wear soft (padded) boxing gloves to reduce the damage their punches do to their opponents.

A punch with a **hard**, **bare fist** will be in contact with the opponent's body for a **very short time** - so the **maximum force** exerted by the fist on the opponent will be **large** - so the damage caused will be **large**.

A punch with a **soft**, **padded glove** will be in contact with the opponent's body for a **longer time** - so the **maximum force** exerted by the glove on the opponent will be **smaller** - so the damage caused to the opponent will be **less**.

Helmets worn by American football players and motor cyclists contain soft foam padding **which is in contact with the head**.

With **no helmet on**, a blow to the head during a collision will last for a **very short time** - so the **maximum force** exerted on the head will be **large** - so the damage caused to the head will be **large**.

With **a helmet on**, a blow to the head during a collision will last for a **longer time** (due to the soft foam padding) - so the **maximum force** exerted on the head will be **smaller** - so the damage caused to the head will be **less**.

**Example**

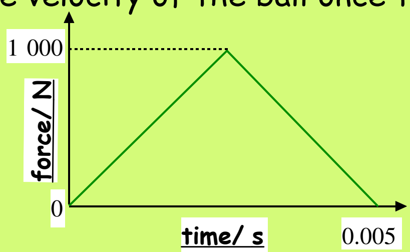
A ball of mass 0.2 kg is initially at rest. It is acted upon by a changing force, as shown on the graph below.

Determine:

(a)the impulse the force gives to the ball;

(b)the change in momentum of the ball;

(c)the velocity of the ball once the force has acted on it.




(a) Impulse = Area under force-time graph
= 1/2 x base x height
= 1/2 x 0.005 x 1 000
= 2.5 N s

(b) Change in momentum = Impulse
= Area under force-time graph
= 2.5 kg $ms^{-1}$

(c) Change in momentum = m (v - u)
2.5 = 0.2 (v - 0)
2.5 = 0.2v
v = 2.5/0.2
v = 12.5 $ms^{-1}$

## UNIT 1 - OUR DYNAMIC UNIVERSE

# 4) GRAVITATION

Can you talk about:

## (a) Projectiles and Satellites

- Resolving the motion of a projectile with an initial velocity into horizontal and vertical components and their use in calculations.
- Comparison of projectiles with objects in free fall.
- Newton's thought experiment and an explanation of why satellites remain in orbit.

## (b) Gravity and mass.

- Gravitational Field Strength of planets, natural satellites and stellar objects.
- Calculating the force exerted on objects placed in a gravity field.
- Newton's Universal Law of Gravitation.

# A) PROJECTILES AND SATELLITES

Any object that is thrown, launched or falls through the air is known as a **projectile**.
The path travelled by the **projectile** is known as its **trajectory**.

In our study of **projectile motion**, we assume that **air resistance** has no effect.
In reality, **air resistance** makes the values we obtain from our calculations slightly greater than those obtained from real-life situations - but our calculated values are reasonably accurate.

When dealing with **projectile motion** for an object projected **horizontally**,
we treat the motion as independent **horizontal** and **vertical** components:

## Horizontal motion

- **Always uniform (constant) velocity equal to the horizontal projection velocity**, i.e., if a projectile is fired **horizontally** at 5 $ms^{-1}$ to the right, its **horizontal component of velocity** will remain at 5 $ms^{-1}$ to the right, until it hits the ground.
- The **larger** the **horizontal component of** velocity, the **further** the **range** (horizontal distance travelled) before hitting the ground.
- Because there is **no acceleration** in the **horizontal** direction, the **three equations of motion do not apply**. You can only apply the equation:

$$\text{horizontal displacement } (s_h) = \text{horizontal velocity } (v_h) \times \text{time } (t)$$


## Vertical motion

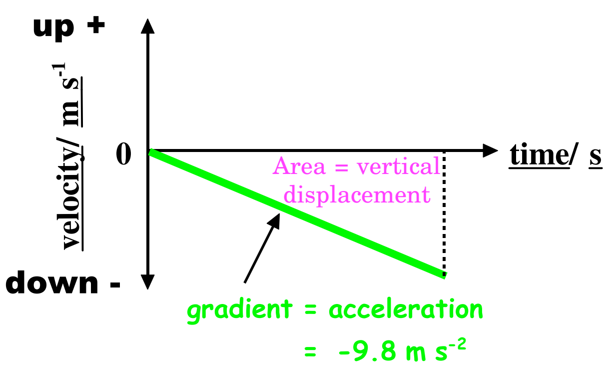
up +

down -

- At the instant the projectile is launched **horizontally**, it is not moving downwards, so **initial downward velocity** (**u**) = **0 $ms^{-1}$**.
- The projectile **accelerates** towards the ground under the influence of **gravity**. Using the sign convention shown on the left, **a = -9.8 $ms^{-2}$**.
- The higher the starting point above the ground, the greater the **final vertical velocity** (**v**) just before hitting the ground. (**v** is **downward**, so should be given a **negative** value).

The **three equations of motion** apply:

$$v = u + at, \quad s = ut + 1/2at^2, \quad v^2 = u^2 + 2as$$



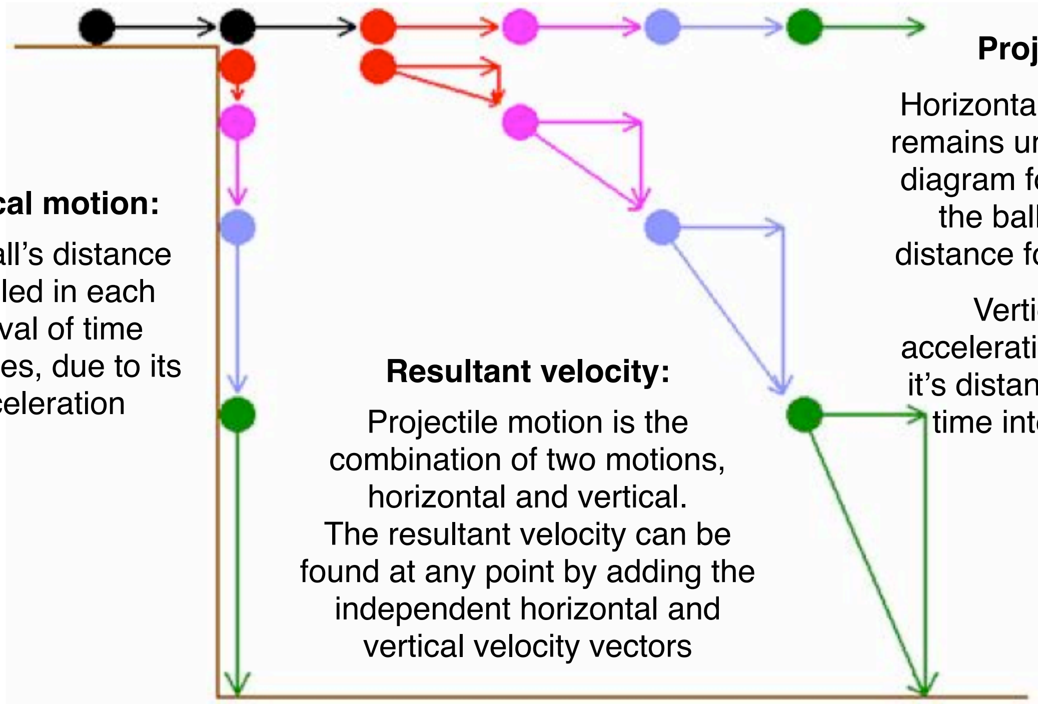
# Projectiles vs objects in freefall

It is helpful to compare the path of a projectile with that of an object **dropped vertically** downward.

The diagram shows the position of a ball released from one position at **equal intervals of time**.

**Horizontal motion:**

Ball travels the same distance for each time interval



**Vertical motion:**

The ball's distance travelled in each interval of time increases, due to its acceleration

**Resultant velocity:**

Projectile motion is the combination of two motions, horizontal and vertical.
The resultant velocity can be found at any point by adding the independent horizontal and vertical velocity vectors

**Projectile motion:**

Horizontally, the ball's velocity remains unchanged, so like the diagram for horizontal motion, the ball travels the same distance for each time interval.

Vertically, the ball is accelerating due to gravity, so it's distance travelled in each time interval is increasing

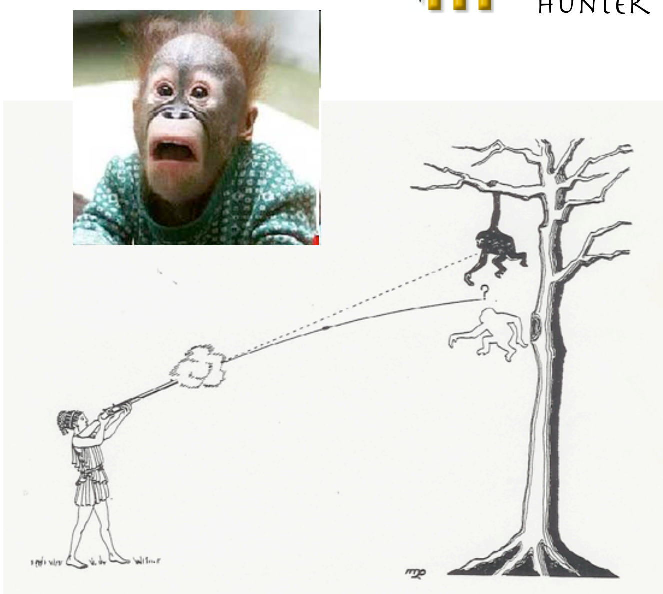
MONKEY AND HUNTER

## Monkey and Hunter Demonstration

The Monkey and the Hunter is a classic Physics demonstration to show that a projectile fired horizontally and an objected dropped vertically fall at the same rate.

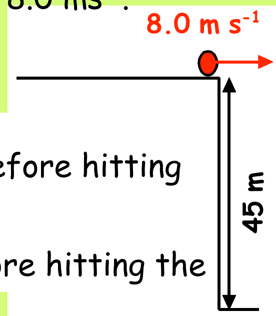
The monkey, seeing the hunter through the scope of his rifle, decides to outwit the hunter by letting go of his branch at the instant the hunter pulls his trigger, assuming that the bullet will fly over his head.

The question is, did the monkey attend Higher Physics classes, and was he right?



**Example**

A projectile is fired horizontally from the top of a 45 m high wall at 8.0 $ms^{-1}$.




(a) What time does the projectile take to hit the ground?

(b) What is the projectile's range (horizontal distance travelled)?

(c) What is the projectile's horizontal component of velocity just before hitting the ground?

(d) What is the projectile's vertical component of velocity just before hitting the ground?

(e) What is the projectile's resultant velocity just before hitting the ground?

(a) For vertical motion, $s = -45$ m, $u = 0$ $ms^{-1}$, $a = -9.8$ $ms^{-2}$

$s = ut + 1/2at^2$

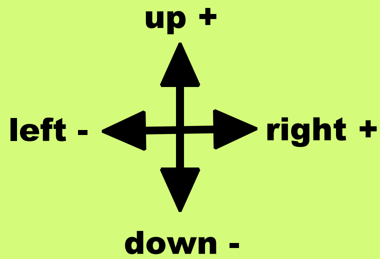
$-45 = (0 \times t) + (0.5 \times -9.8 \times t^2)$

$-45 = 0 + (-4.9t^2)$

$-45 = -4.9t^2$

$t^2 = -45/-4.9 = 9.2$

$t = 9.2 = \underline{3.0\ s}$




(b) For horizontal motion, $v_h = 8.0$ $ms^{-1}$, $t = 3.0$ s

$s_h = v_h \times t$

$= 8.0 \times 3.0$

$= \underline{24\ m\ right}$

(c) Horizontal component of velocity remains constant, so $v_h = 8.0$ $ms^{-1}$ right

(d) For vertical motion, $u = 0$ $ms^{-1}$, $a = -9.8$ $ms^{-2}$, $t = 3.0$ s

$v = u + at$

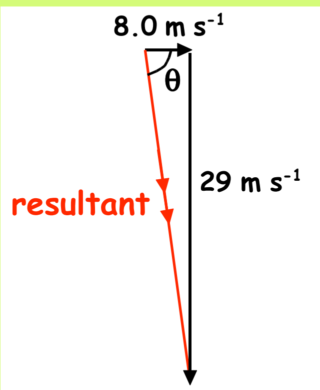
$= 0 + (-9.8 \times 3.0)$

$= 0 - 29.4$

$= \underline{-29\ ms^{-1}}$

(i.e., 29 $ms^{-1}$ downwards)

(e) Resultant velocity of the projectile just before it hits the ground is a combination of the horizontal and vertical components of velocity at that instant:




$resultant^2 = 8.0^2 + 29^2$

$= 64 + 841$

$= 905$

so, resultant $= \sqrt{905}$

$= \underline{30\ ms^{-1}}$

$\tan = \frac{O}{A} = \frac{29}{8.0} = 3.6$

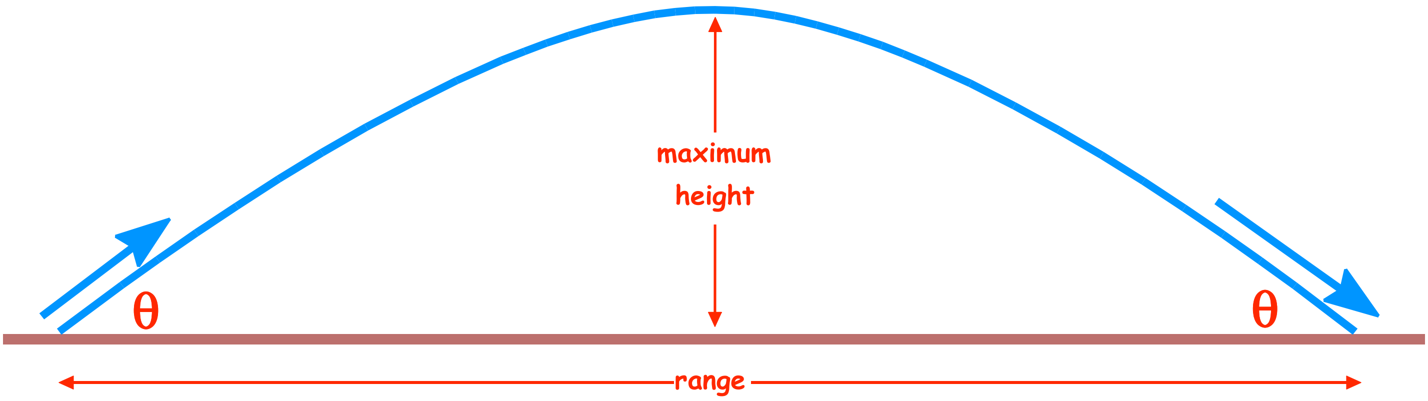
so, $\theta = \tan^{-1} 3.6$

$= \underline{74°}$

Resultant velocity of projectile just before hitting ground is <u>30 $ms^{-1}$ at 74° below the horizontal</u>.

# Projectiles Fired at an Angle to the Ground

Any object projected into the air (other than vertically upwards) will have a **symmetrical** **parabolic trajectory**, like that shown below. **Air resistance** is **neglected**.




1) The **horizontal distance travelled** by the projectile is known as its **range**.
2) The projectile reaches its **maximum height** when it has travelled a **horizontal distance** equal to half its range.
3) The **time** taken for the projectile to reach its **maximum height** is therefore **half the time taken** to complete its flight.
4) The size of the **launch angle** (θ) is the same as the size of the **landing angle**, although the launch and landing directions are different.

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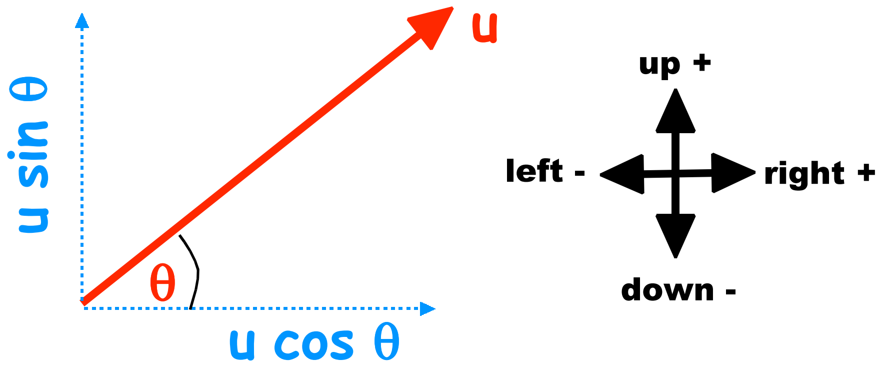
When tackling problems on such projectile motion, it is first necessary to resolve the **launch velocity** (**u**) into its **horizontal** and **vertical** components:

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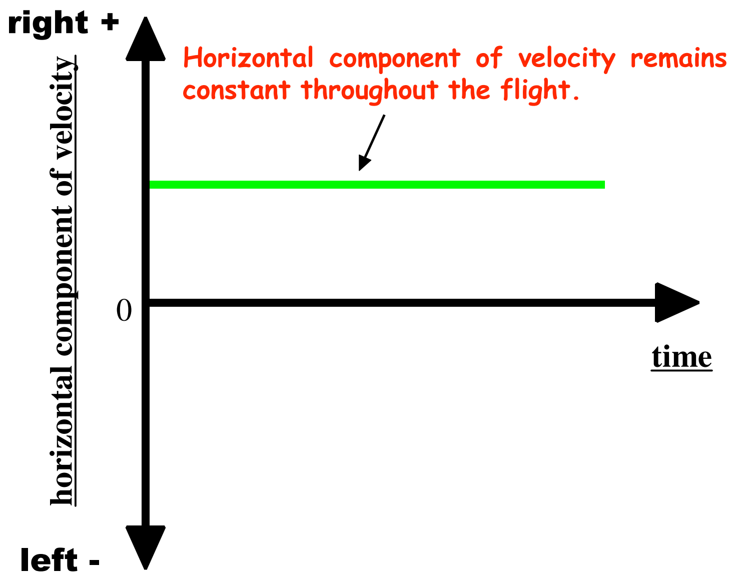
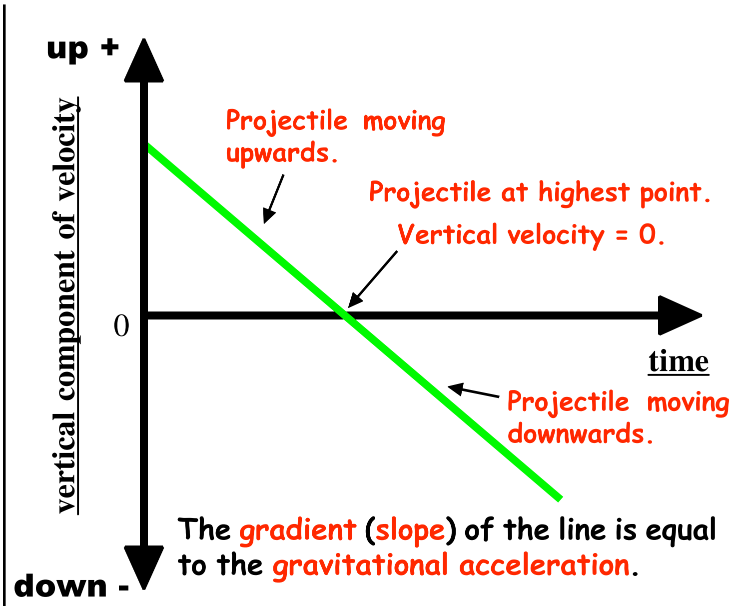


**Example**

A long-range artillery shell is fired from level ground with a velocity of 500 $ms^{-1}$ at an angle of 30° to the horizontal.

Determine:

(a) the greatest height the shell reaches;

(b) the time taken to reach that height;

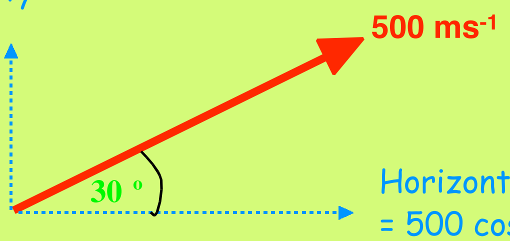
(c) the total time the shell is in the air;

(d) the horizontal distance the shell travels (i.e., its range).

---

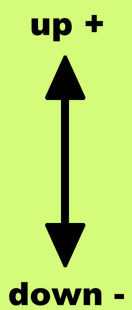
First, resolve the velocity into its horizontal and vertical components:

Vertical component of velocity
= 500 sin 30°
= 500 x 0.5
= 250 $ms^{-1}$.




Horizontal component of velocity
= 500 cos 30°
= 500 x 0.866
= 433 $ms^{-1}$.

(a)




gravitational acceleration = -9.8 $ms^{-2}$

v at highest point = 0

$v^2 = u^2 + 2as$

$0^2 = 250^2 + (2 \times -9.8 \times s)$

$0 = 62\,500 - 19.6\,s$

$19.6\,s = 62\,500$

$s = 62\,500/19.6 =$ **3 200 m**

(b) $v = u + at$

$0 = 250 + (-9.8 \times t)$

$0 = 250 - 9.8\,t$

$9.8\,t = 250$

$t = 250/9.8 =$ **26 s**

(c) Total time shell is in air = 2 x 26 s = **52 s**

(d) $s_h = v_h t$

$= 433 \times 52$

= **23 000 m right**

# Newton's Thought Experiment

As well as giving us the three laws, Isaac Newton also came up with an ingenious thought experiment for satellite motion that predated the first artificial satellite by almost 300 years.

Essentially Newton suggested that if a cannon fired a cannonball **it would fall towards the Earth**. If it was fired at ever higher speeds then at ***some speed*** it would fall towards the Earth but never land since the **curvature of the Earth would be the same as the flight path** of the cannonball.

This would then be a satellite. The object remains in orbit because **it is being pulled to the Earth by gravity**, **NOT** because it has ***escaped gravity***.

If **gravity** was suddenly **switched off**, the object would **continue in a straight line**. This is how satellites remain in orbit.

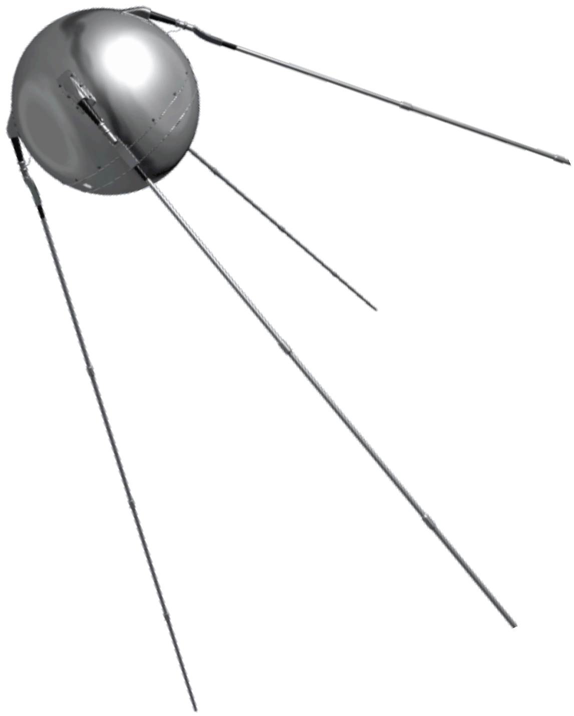
http://tap.iop.org/fields/gravity/403/img_full_46835.gif

**Newton's Thought Experiment** became a reality when the first artificial satellite (**Sputnik**) was launched in 1957.

The world's first artificial satellite was about the size of a beach ball (**58 cm** in diameter), weighed only **83.6 kg**, and took about **98 minutes** to orbit the Earth on its elliptical path.

The launch ushered in new political, military, technological, and scientific developments. While the Sputnik launch was a single event, it marked the start of the space age and the **US vs USSR space race**.

On January 31, 1958, the tide changed, when the United States successfully launched **Explorer I**. This satellite carried a small scientific payload that eventually discovered the **magnetic radiation belts** around the Earth, named after principal investigator **James Van Allen**.



http://viajespolares.blogia.com/upload/20071004171329-sputnik-visual.gif

# B) GRAVITY AND MASS

## Formation of the solar system

**Gravity** is responsible for the formation of the solar system.

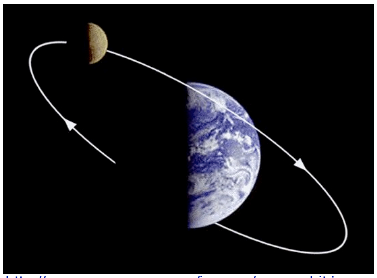
At some point, generally believed to be between 4 and 5 billion years ago, a huge cloud of molecules collapsed together due to their own gravitational attraction. Most of these molecules collapsed into a gravitational centre forming the Sun. However a small amount of mass formed a disk that circled the newly formed star. The gravitational attraction between the particles that made up this disk then resulted in the formation of the planets we can observe today.

This process is known as the **aggregation** of **matter**.

http://activity.ntsec.gov.tw/space/EN/Content/xf1001.jpg

## Gravity and orbits

As we know the Earth follows a curved path around the Sun.

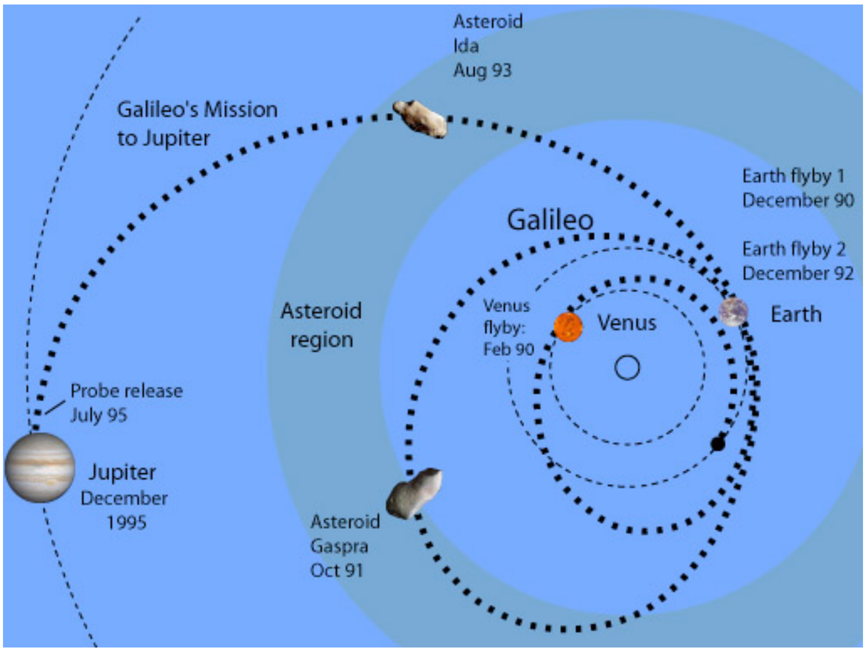


http://www.cozypages.com/images/moonorbit.jpg

This means that, according to **first law of motion**, there must be an **unbalanced force** acting on the Earth. This force is provided by the **gravitational pull of the Sun**. The same is true for the orbit of the Moon. The Earth's gravity is exerting a force on the Moon.

## Gravity assist

Gravity has also been used to assist exploration in the solar system. During the 1990s NASA sent a probe called Galileo to investigate the planet Jupiter. The found that it would be very difficult to give the probe enough energy to reach Jupiter directly so they devised an ingenious method of boosting the probe's speed during its flight.




This was done by flying the probe past Venus and using the **planet's gravitational field** to ***sling shot*** it with increased speed. The process was then repeated using the Earth's gravitational field (twice) before the probe had enough speed to reach Jupiter.

http://hyperphysics.phy-astr.gsu.edu/hbase/solar/picsol/galjour.jpg

## Gravitational field strength

What is a **field** in Physics?

It is simply an area or volume of space.

A FIELD is a **place** where a **force** is exerted on a **particle** or **mass**, at a **distance** from the **cause**

### Types of fields

**Gravitational field:** A place where there is a force on a mass.

**Electric field:** A place where there is a force on a charge.

**Magnetic field:** A place where there is a force on a moving charge.

In Higher Physics we learn about each type of field.

**Gravitational field strength (g)** at any point is defined as the **gravitational force** acting on a unit mass placed at that point.

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

**where**
- **g** is the gravitational field strength in **$Nkg^{-1}$**
- **F** is the force in **N**
- **m** is the mass in **kg**

We refer to the gravitational force as the WEIGHT, W.

Gravitational field strength, *g* is a VECTOR quantity, having the same direction as the force or weight.

$$g = \frac{W}{m} \quad \textbf{OR} \quad W = mg$$

For masses near a planet, the direction of *g* is towards the centre of the planet.

### When does a = g?

If a mass is allowed to fall freely, (ignoring air resistance), the unbalanced force is the W, and it accelerates downward with a constant acceleration, *a*.

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

Acceleration due to gravity in free fall is EQUAL to gravitational field strength.

If we can measure the acceleration of a falling object, we can determine *g.*


### Example

During the Apollo 15 moon landing, the astronauts dropped a hammer on the moon.


Distance hammer fell: 1.10 m

time taken to fall: 1.15 s

**Calculate the gravitational field strength on the moon?**

$s = ut + 1/2at^2$

$1.10 = 0 + 1/2 \times a \times 1.15^2$

$a = 1.66\ ms^{-2}$

$\therefore g = 1.66\ N\ kg^{-1}$

(Dropped from rest so u = 0)

Note:

The value of *g* can be very different for different celestial objects e.g.

**Sun**: 270 $N\ kg^{-1}$ **Jupiter** 25 $N\ kg^{-1}$ **Pluto** 0.7 $N\ kg^{-1}$

# Newton's Law of Universal Gravitation

**Newton's law of universal gravitation** proposed that **each body** with mass will exert a force on **each other body** with mass.

The theory states that the force of gravitational attraction is dependent on **the masses** of both objects and is inversely proportional to the **square of the distance** that separates them.

$$F = \frac{Gm_1m_2}{r^2}$$

**where**
$F$ is the force in **N**
$m_1$ and $m_2$ are the two masses in **kg**
$r$ is the distance between them in **m**
$G$ is the gravitational constant in **N m² kg⁻²**


http://0.tqn.com/d/chemistry/1/0/U/3/1/Cavendish_Henry.jpg

**Note:**

The value of G is one of the most difficult constants to measure accurately. Cavendish determined it in the late 1700s, and Boys (1855-1944) improved on its accuracy. The value we use in Higher Physics is

$$G = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$$


http://en.wikipedia.org/wiki/File:CVBoys.jpg

## Examples

The formula allows us to calculate the force of gravity between point masses or spherical objects (or any object that we assume to be spherical!)

### Everyday objects

Calculate the gravitational force between a folder of mass 0.3 kg and a pen of mass 0.05 kg on a desk, 0.25 m apart.

$$F = \frac{Gm_1m_2}{r^2}$$

$$F = \frac{6.67 \times 10^{-11} \times 0.3 \times 0.05}{0.25^2}$$

$$F = \underline{1.60 \times 10^{-11}\ \text{N}}$$

### Subatomic objects

Calculate the gravitational force between a proton and a neutron in the nucleus of an atom.

$$F = \frac{Gm_1m_2}{r^2}$$

*Note the force of gravity is clearly insignificant except when dealing with very large mass!*

$$F = \frac{6.67 \times 10^{-11} \times 1.67 \times 10^{-27} \times 1.67 \times 10^{-27}}{(0.84 \times 10^{-15})^2}$$

$$F = \underline{2.64 \times 10^{-34}\ \text{N}}$$

### Gravitational force and Weight

Calculate the gravitational force between the same pen of mass 0.05 kg and the earth.

**Assume the pen is on the surface of Earth, so $r$ = radius of Earth and $m_1$ = mass of Earth**

$$F = \frac{Gm_1m_2}{r^2}$$

$$F = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 0.05}{(6.38 \times 10^6)^2}$$

$$F = \underline{0.489\ \text{N}}$$

The gravitational force between the pen and the Earth is equal to the weight of the pen.

$W = mg$

$W = 0.05 \times 9.8$

$\underline{W = 0.49\ \text{N}}$

# TUTORIAL QUESTIONS

## Section 1: Equation of motion

### Vector problems

1. Complete a table with the headings "vectors" and "scalars" with 4 physical quantities in each column.

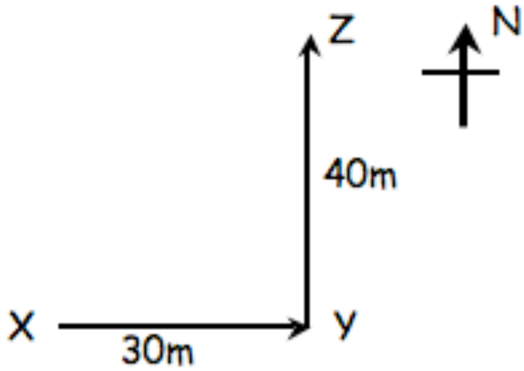
2. Write a simple description, in your own words, to distinguish between vector and scalar quantities.

3. What was the velocity of the runner in lane 1 in the women's 400m final at the London Olympics?

4. What is your average velocity from 3a.m. Monday to 3a.m. Tuesday? Give a reason for your answer.

5. A car travels 50 km due north and then returns 30 km due south. The whole journey takes 2 hours. Calculate:
(a) the total distance travelled by the car
(b) the average speed of the car
(c) the resultant displacement of the car
(d) the average velocity of the car.

6. A girl delivers newspapers to three houses, X, Y and Z, as shown in the diagram.
She starts at X and walks directly from X to Y and then to Z.




(a) Calculate the total distance the girl walks.
(b) Calculate the girl's final displacement from X.
(c) The girl walks at a steady speed of 1 m $s^{-1}$.
(i) Calculate the time she takes to get from X to Z.
(ii) Calculate her resultant velocity.

### Equations of Motion (suvat)

1. An object is travelling at a speed of 8·0 $ms^{-1}$. It then accelerates uniformly at 4·0 $ms^{-2}$ for 10 s. How far does the object travel in this 10 s?

2. A car is travelling at a speed of 15·0 $ms^{-1}$. It accelerates uniformly at 6·0 $ms^{-2}$ and travels a distance of 200 m while accelerating.
Calculate the velocity of the car at the end of the 200 m.

3. A ball is thrown vertically upwards to a height of 40 m above its starting point. Calculate the speed at which it was thrown.

4. A car is travelling at a speed of 30·0 $ms^{-1}$. It then slows down at 1·80 $ms^{-2}$ until it comes to rest. It travels a distance of 250 m while slowing down. What time does it take to travel the 250 m?

5. A stone is thrown with an initial speed 5·0 $ms^{-1}$ vertically down a well. The stone strikes the water 60 m below where it was thrown. Calculate the time taken for the stone to reach the surface of the water. (The effects of friction can be ignored).

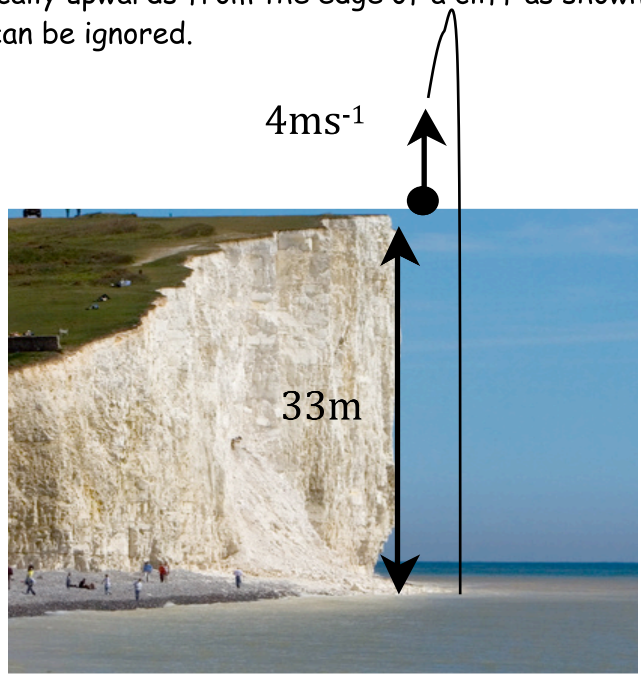
6. A tennis ball launcher is 0·60 m long. A tennis ball leaves the launcher at a speed of 30 $ms^{-1}$.
(a) Calculate the average acceleration of the tennis ball in the launcher.
(b) Calculate the time the ball accelerates in the launcher.

7. In an experiment to find 'g' a steel ball falls from rest through a distance of 0·40 m. The time taken to fall this distance is 0·29 s.
What is the value of 'g' calculated from the data of this experiment?

8. A trolley accelerates uniformly down a slope. Two light gates connected to a motion computer are spaced 0·50 m apart on the slope. The speeds recorded as the trolley passes the light gates are 0·20 $ms^{-1}$ and 0·50 $ms^{-1}$.
(a) Calculate the acceleration of the trolley.
(b) What time does the trolley take to travel the 0·5 m between the light gates?

9. A helicopter is rising vertically at a speed of 10·0 $ms^{-1}$ when a wheel falls off. The wheel hits the ground 8·00 s later.
Calculate the height of the helicopter above the ground when the wheel came off.
The effects of friction can be ignored.

10. A ball is thrown vertically upwards from the edge of a cliff as shown in the diagram.
The effects of friction can be ignored.




(a) (i) What is the height of the ball above sea level 2·0 s after being thrown?
(ii) What is the velocity of the ball 2·0 s after being thrown?

(b) What is the total distance travelled by the ball from launch to landing in the sea?

## Free Falling Objects

1. Draw a diagram to show the forces acting on a 3kg mass at the **instant** it is released.

2. What will the initial acceleration of the object be?

3. What happens to the magnitude of the air resistance acting on the object as it falls? Explain your answer.

4. Describe what happens to the acceleration of the object as it falls, you must justify your answer.

5. Give an example of a situation when the air resistance is greater than the weight of a falling object.

6. Why can the air resistance not exceed the weight of the object for any length of time? What would happen if this situation did occur?

7. Sketch a velocity time graph for the motion of an object that experiences air resistance; assume it is falling from a very large height.

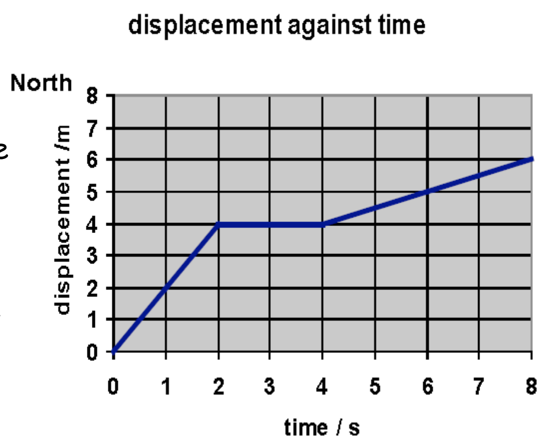
## Displacement –Time Graphs

1. Draw a displacement time graph to represent the following information:
Billy walks 50m East, at a constant rate, in a time of 40s. He then turns and walks 30m West in 30s. He stops for 20s before continuing West for another 50m in a time of 20s.

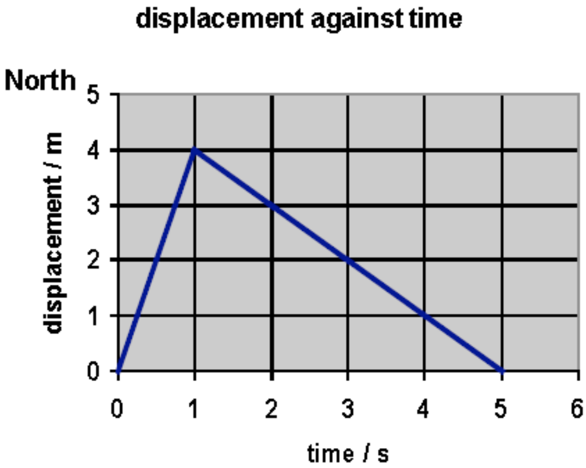
2. Draw Billy's corresponding velocity time graph.

3. The graph shows how the displacement of an object varies with time.

(a) Calculate the velocity of the object between 0 and 1 s.
(b) What is the velocity of the object between 2 and 4 s from the start?
(c) Draw the corresponding distance against time graph for the movement of this object.
(d) Calculate the average speed of the object for the 8 seconds shown on the graph.
(e) Draw the corresponding velocity against time graph for the movement of this object.

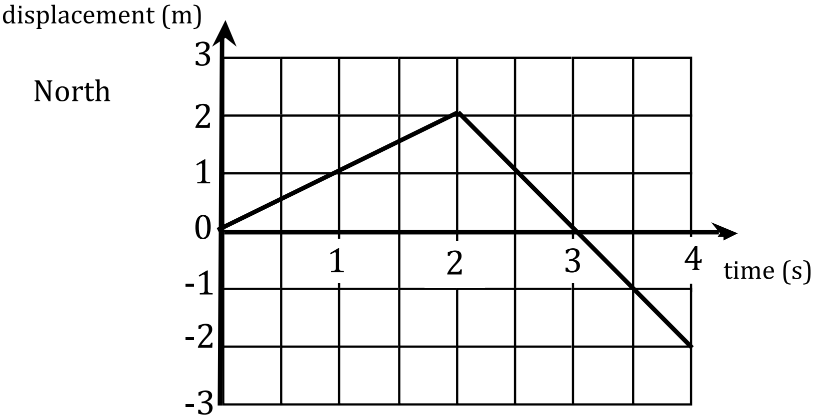


4. The graph shows how the displacement of an object varies with time.



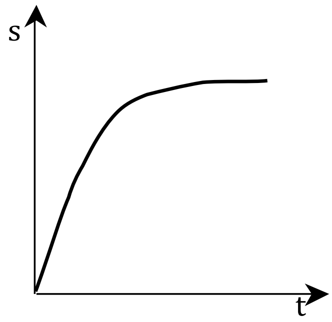

(a) Calculate the velocity of the object during the first second from the start.
(b) Calculate the velocity of the object between 1 and 5 s from the start.
(c) Draw the corresponding distance against time graph for this object.
(d) Calculate the average speed of the object for the 5 seconds.
(e) Draw the corresponding velocity against time graph for this object.
(f) What are the displacement and the velocity of the object 0·5 seconds after the start?
(g) What are the displacement and the velocity of the object 3 seconds after the start?

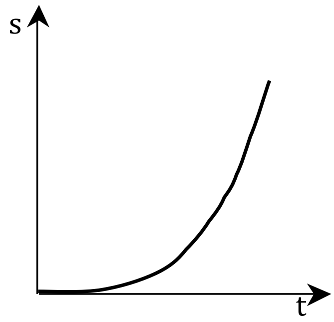
5. The graph shows the displacement against time graph for the movement of an object.




(a) Calculate the velocity of the object between 0 and 2 s.
(b) Calculate the velocity of the object between 2 and 4 s from the start.
(c) Draw the corresponding distance against time graph for this object.
(d) Calculate the average speed of the object for the 4 seconds.
(e) Draw the corresponding velocity against time graph for this object.
(f) What are the displacement and the velocity of the object 0·5 s after the start?
(g) What are the displacement and the velocity of the object 3 seconds after the start?

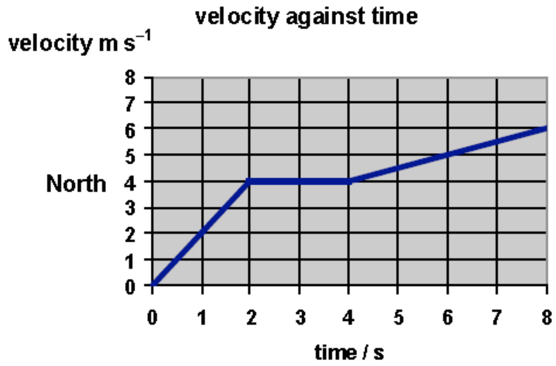
6. Sketch velocity time graphs for the displacement time graphs below. No numerical values are required. [Hint: think of the gradient!]



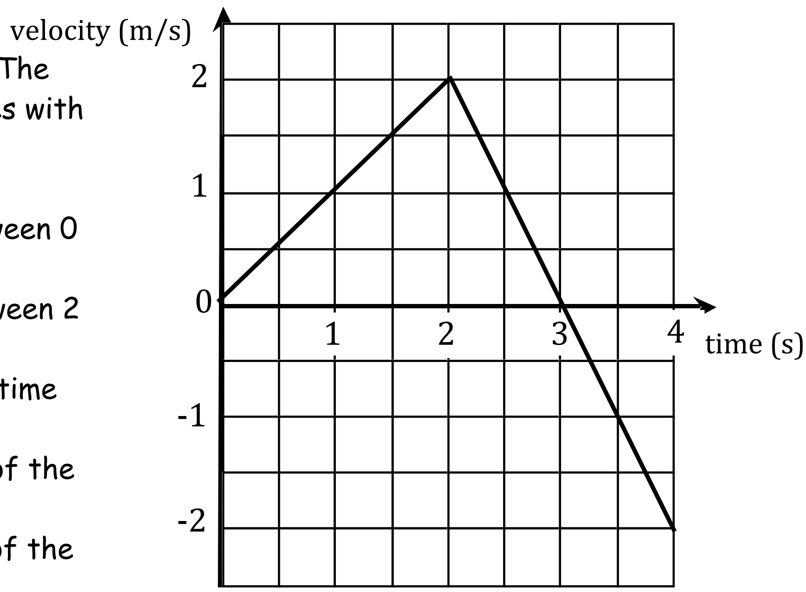

**<u>Velocity – Time Graphs</u>**

1. An object starts from a displacement of 0 m. The graph shows how the velocity of the object varies with time from the start.



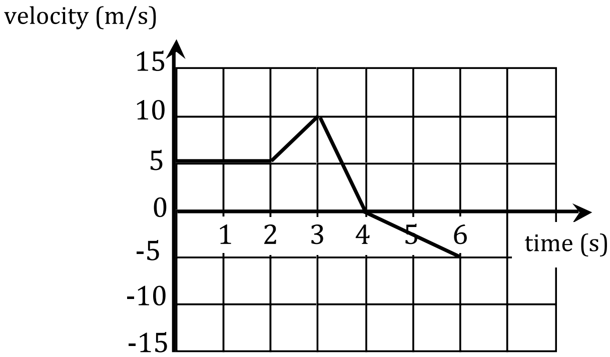

(a) Calculate the acceleration of the object between 0 and 1 s.
(b) What is the acceleration of the object between 2 and 4 s from the start?
(c) Calculate the displacement of the object 2 seconds after the start.
(d) What is the displacement of the object 8 seconds after the start?
(e) Sketch the corresponding displacement against time graph for the movement of this object.

2. An object starts from a displacement of 0 m. The graph shows how the velocity of the object varies with time from the start.




(a) Calculate the acceleration of the object between 0 and 2 s.
(b) Calculate the acceleration of the object between 2 and 4 s from the start.
(c) Draw the corresponding acceleration against time graph for this object.
(d) What are the displacement and the velocity of the object 3 seconds after the start?
(e) What are the displacement and the velocity of the object 4 seconds after the start?
(f) Sketch the corresponding displacement against time graph for the movement of this object.

3. The velocity-time graph for an object is shown below.



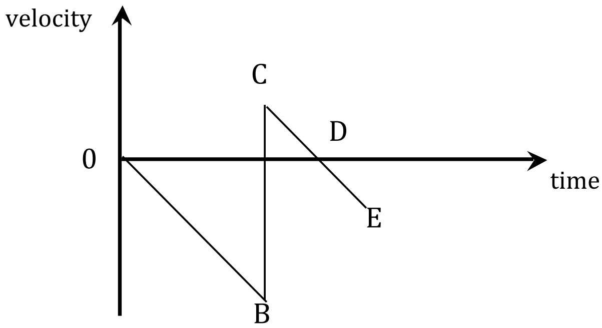

A positive value indicates a velocity due north and a negative value indicates a velocity due south. The displacement of the object is 0 at the start of timing.

(a) Calculate the displacement of the object:

(i) 3 s after timing starts
(ii) 4 s after timing starts
(iii) 6 s after timing starts.

(b) Draw the corresponding acceleration–time graph.

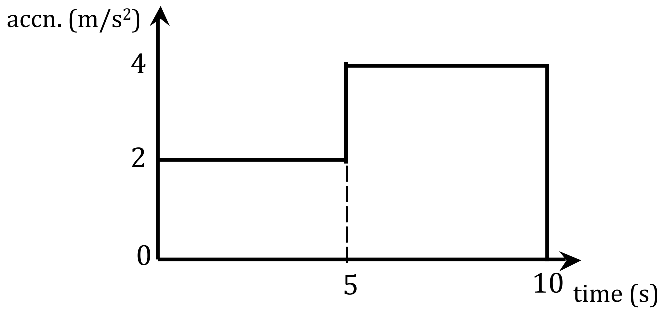
4. The graph shows the velocity of a ball that is dropped and bounces on a floor.




(a) Which direction is represented by a positive velocity?
(b) In which direction is the ball travelling during section OB of the graph?
(c) Describe the velocity of the ball as represented by section CD of the graph.
(d) Describe the velocity of the ball as represented by section DE of the graph.
(e) What happened to the ball at the time represented by point B on the graph?
(f) What happened to the ball at the time represented by point C on the graph?
(g) How does the speed of the ball immediately before rebound from the floor compare with the speed immediately after rebound?
(h) Sketch a graph of acceleration against time for the movement of the ball.

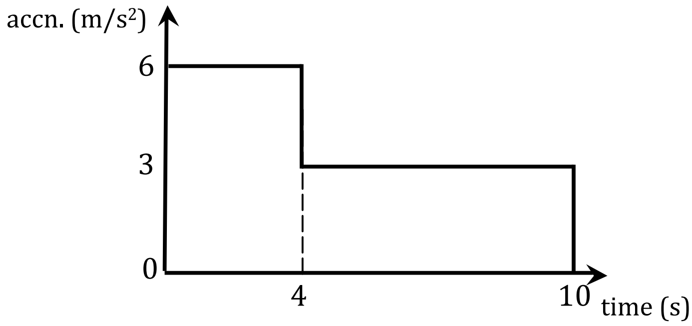
## Acceleration – Time Graphs

1. The graph shows how the acceleration a, of an object, starting from rest, varies with time.




Draw a graph to show how the velocity of the object varies with time for the 10 seconds of the motion.

2. The graph shows how the acceleration of an object changes with time. The object begins at rest.




(a) Calculate the speed of the object after 4 seconds.
(b) Calculate the speed of the object after 7 seconds.
(c) Draw a velocity time graph for the 10s of motion.

## Thinking Questions

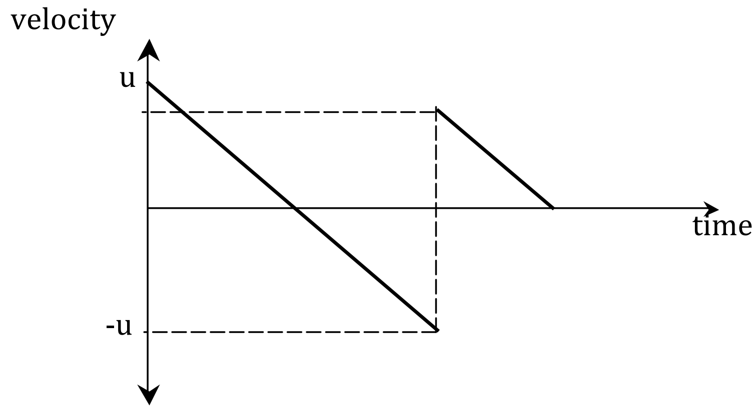
1. Describe a situation where a runner has a displacement of 100 m due north, a velocity of 3 m $s^{-1}$ due north and an acceleration of 2 $ms^{-2}$ due south. Your description should include a diagram. [TQ]

2. Is it possible for an object to be accelerating but have a constant speed? You must justify your answer. [TQ]

3. Is it possible for an object to move with a constant speed for
5 s and have a displacement of 0 m? You must justify your answer. [TQ]

4. Is it possible for an object to move with a constant velocity for 5 s and have a displacement of 0 m? You must justify your answer. [TQ]

5. The following questions relate to the graph shown below. this velocity time graph represents the motion of a ball dropped from rest onto a surface.




(a). Why will the acceleration of the ball be the same when it is moving upwards as when it is moving downwards?

(b). What will the acceleration be if this experiment was conducted on Earth?

(c). Why will the velocity of the ball immediately after rebounding be less than the initial velocity of the ball?

(d). Sketch a graph showing the velocity time graph if the time of contact during rebound was not zero.

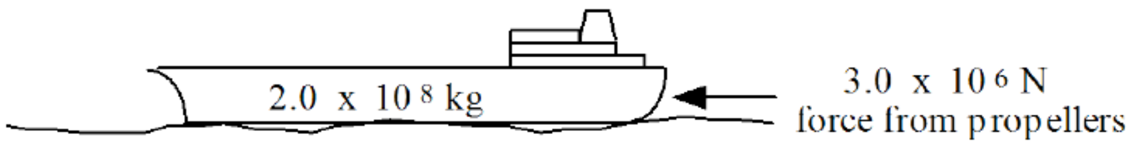
(e). Sketch a graph showing the velocity time graph if the air resistance was not zero.

**Forces questions revisited**

1. State Newton's 1st Law of Motion.

2. A lift of mass 500 kg travels upwards at a constant speed.
Calculate the tension in the cable that pulls the lift upwards.

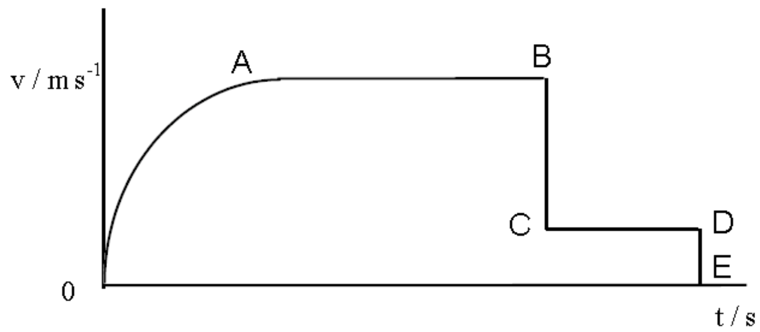
3. (a) A fully loaded oil tanker has a mass of $2{\cdot}0 \times 10^8$ kg.
As the speed of the tanker increases from 0 to a steady maximum speed of 8.0 m $s^{-1}$ the force from the propellers remains constant at $3.0 \times 10^6$ N.




(i) Calculate the acceleration of the tanker just as it starts from rest.
(ii) What is the size of the force of friction acting on the tanker when it is moving at a steady speed of 8.0 $ms^{-1}$?

(b) When its engines are stopped, the tanker takes 50 minutes to come to rest from a speed of 8.0 m $s^{-1}$. Calculate its average deceleration.

4. The graph shows how the speed of a parachutist varies with time after having jumped from an aeroplane.




With reference to the origin of the graph and the letters A, B, C, D and E explain the variation of speed with time for each stage of the parachutist's fall.

5. Two girls push a car of mass 2000 kg. Each applies a force of 50 N and the force of friction is 60 N. Calculate the acceleration of the car.

6. A boy on a skateboard rides up a slope. The total mass of the boy and the skateboard is 90 kg. He decelerates uniformly from 12 $ms^{-1}$ to 2 $ms^{-1}$ in 6 seconds. Calculate the resultant force acting on him.

7. A box of mass 30 kg is pulled along a rough surface by a constant force of 140 N. The acceleration of the box is 4·0 $ms^{-2}$ .

(a) Calculate the magnitude of the unbalanced force causing the acceleration.

(b) Calculate the force of friction between the box and the surface.

8. A car of mass 800 kg is accelerated from rest to 18 $ms^{-1}$ in 12 seconds.

(a) What is the size of the resultant force acting on the car?

(b) How far does the car travel in these 12 seconds?

(c) At the end of the 12 seconds period the brakes are operated and the car comes to rest in a distance of 50 m.
What is the size of the average frictional force acting on the car?

## Higher Forces

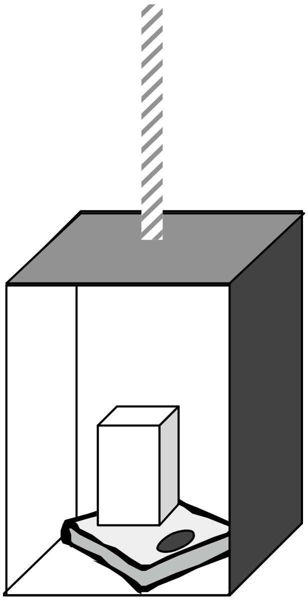
9. (a) A rocket of mass $4{\cdot}0 \times 10^4$ kg is launched vertically upwards from the surface of the Earth. Its engines produce a constant thrust of $7{\cdot}0 \times 10^5$ N.
(i) Draw a diagram showing all the forces acting on the rocket just after take-off.
(ii) Calculate the initial acceleration of the rocket.

(b) As the rocket rises the thrust remains constant but the acceleration of the rocket increases. Give three reasons for this increase in acceleration.

(c) Explain in terms of Newton's laws of motion why a rocket can travel from the Earth to the Moon and for most of the journey not burn up any fuel.

10. A rocket takes off from the surface of the Earth and accelerates to 90 $ms^{-1}$ in a time of 4·0 s. The resultant force acting on it is 40 kN upwards.
(a) Calculate the mass of the rocket.

(b) The average force of friction is 5000 N. Calculate the thrust of the rocket engines.



11. A helicopter of mass 2000 kg rises upwards with an acceleration of 4·00 $ms^{-2}$. The force of friction caused by air resistance is 1000N. Calculate the upwards force produced by the rotors of the helicopter.

12. A crate of mass 200 kg is placed on a balance, calibrated in newtons, in a lift.
(a) What is the reading on the balance when the lift is stationary?

(b) The lift now accelerates upwards at 1·50 $ms^{-2}$. What is the new reading on the balance?

(c) The lift then travels upwards at a constant speed of 5·00 $ms^{-1}$. What is the new reading on the balance?

(d) For the last stage of the journey the lift decelerates at 1·50 $ms^{-2}$ while going up. Calculate the reading on the balance.

13. A small lift in a hotel is fully loaded and has a total mass of 250 kg. For safety reasons the tension in the pulling cable must never be greater than 3500 N.
(a) What is the tension in the cable when the lift is:

(i) at rest

(ii) moving up at a constant speed of 1 $ms^{-1}$

(iii) moving up with a constant acceleration of 2 $ms^{-2}$

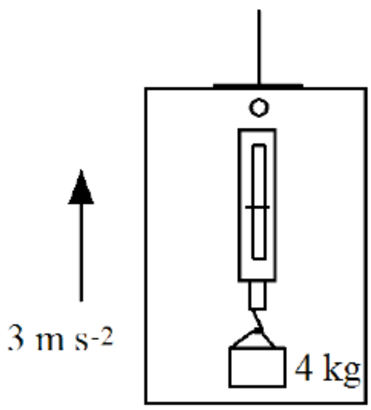
(iv) moving down with a constant acceleration of 2 $ms^{-2}$.

(b) Calculate the maximum permitted upward acceleration of the fully loaded lift.

(c) Describe a situation where the lift could have an upward acceleration greater than the value in (b) without breaching safety regulations.

14. A package of mass 4·00 kg is hung from a spring (Newton) balance attached to the ceiling of a lift.

The lift is accelerating upwards at 3·00 $ms^{-2}$. What is the reading on the spring balance?

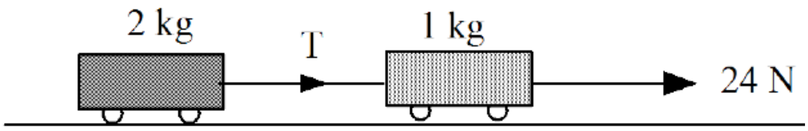


15. The graph shows how the **downward** speed of a lift varies with time.


(a) Draw the corresponding acceleration against time graph.

(b) A 4.0 kg mass is suspended from a spring balance inside the lift. Determine the reading on the balance at each stage of the motion.

16. Two trolleys joined by a string are pulled along a frictionless flat surface as shown.




(a) Calculate the acceleration of the trolleys.

(b) Calculate the tension, T, in the string joining the trolleys.

17. A car of mass 1200 kg tows a caravan of mass 1000 kg. The frictional forces on the car and caravan are 200 N and 500 N, respectively. The car accelerates at 2.0 $ms^{-2}$.

(a) Calculate the force exerted by the engine of the car.

(b) What force does the tow bar exert on the caravan?

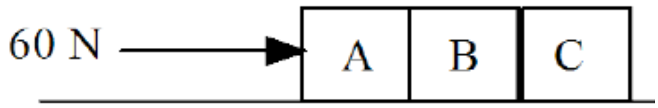
(c) The car then travels at a constant speed of 10 $ms^{-1}$.
Assuming the frictional forces to be unchanged, calculate:
(i) the new engine force
(ii) the force exerted by the tow bar on the caravan.

(d) The car brakes and decelerates at 5·0 $ms^{-2}$.
Calculate the force exerted by the brakes (assume the other frictional forces remain constant).

18. A log of mass 400 kg is stationary. A tractor of mass 1200 kg pulls the log with a tow rope. The tension in the tow rope is 2000 N and the frictional force on the log is 800 N. How far will the log move in 4 s?

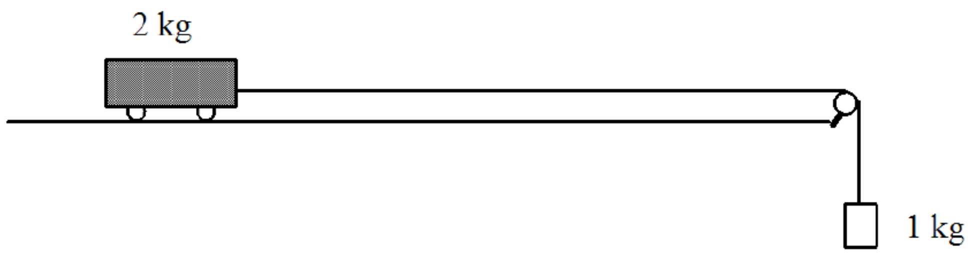
19. A force of 60 N is used to push three blocks as shown.
Each block has a mass of 8·0 kg and the force of friction on each block is 4·0 N.

(a) Calculate:
(i) the acceleration of the blocks
(ii) the force that block A exerts on block B
(iii) the force block B exerts on block C.




(b) The pushing force is then reduced until the blocks move at constant speed.
(i) Calculate the value of this pushing force.
(ii) Does the force that block A exerts on block B now equal the force that block B exerts on block C? Explain.

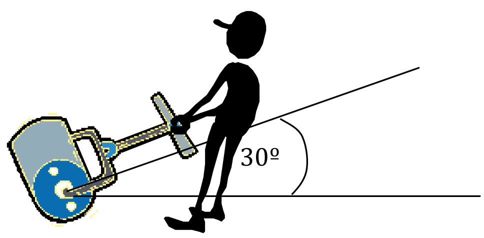
20. A 2·0 kg trolley is connected by string to a 1·0 kg mass as shown. The bench and pulley are frictionless.




(a) Calculate the acceleration of the trolley.
(b) Calculate the tension in the string.

<u>Resolution of Forces</u>

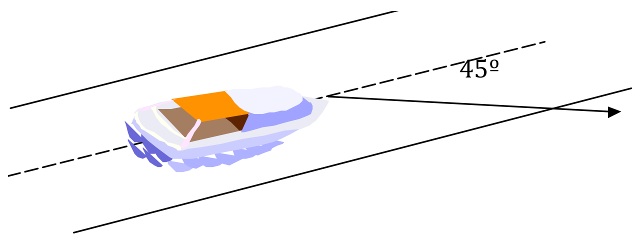
1. A man pulls a garden roller with a force of 50 N.




(a) Find the effective horizontal force applied to the roller.

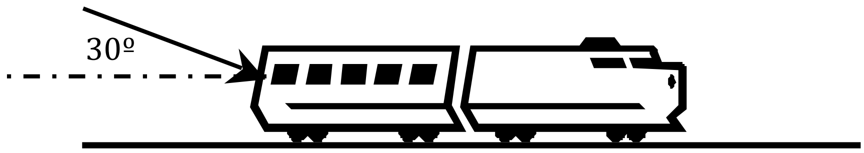
(b) Describe and explain how the man can increase this effective horizontal force without changing the size of the force applied.

2. A barge is dragged along a canal as shown below.




What is the size of the component of the force parallel to the canal?

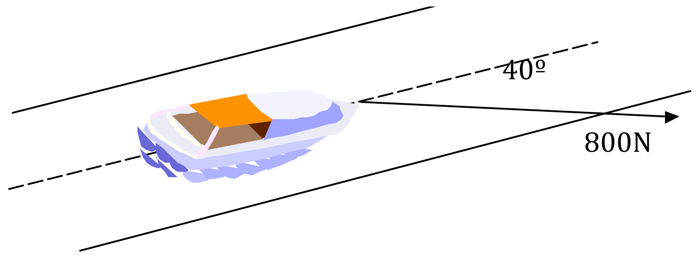
3. A toy train of mass 0·20 kg is given a push of 10 N along the rails at an angle of 30° above the horizontal.




Calculate:
(a) the magnitude of the component of force along the rails

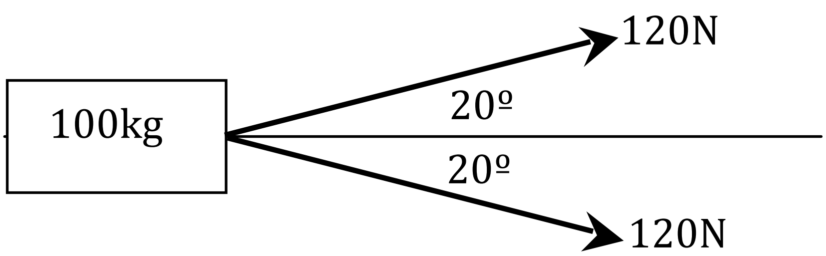
(b) the acceleration of the train.

4. A barge of mass 1000 kg is pulled by a rope along a canal as shown.




The rope applies a force of 800 N at an angle of 40° to the direction of the canal. The force of friction between the barge and the water is 100 N. Calculate the acceleration of the barge.

5. A crate of mass 100 kg is pulled along a rough surface by two ropes at the angles shown.

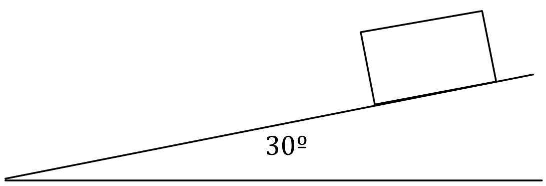



(a) The crate is moving at a constant speed of 1·0 $ms^{-1}$. What is the size of the force of friction?

(b) The forces are now each increased to 140 N at the same angle. Assuming the friction force remains constant, calculate the acceleration of the crate.

6. A 2·0 kg block of wood is placed on a slope as shown.

The block remains stationary. What are the size and direction of the frictional force on the block?



7. A runway is 2·0 m long and raised 0·30 m at one end. A trolley of mass 0·50 kg is placed on the runway. The trolley moves down the runway with constant speed.
Calculate the magnitude of the force of friction acting on the trolley.
[Hint: draw a sketch of the set up]

8. A car of mass 900 kg is parked on a hill. The slope of the hill is 15° to the horizontal. The brakes on the car fail. The car runs down the hill for a distance of 50 m until it crashes into a hedge. The average force of friction on the car as it runs down the hill is 300 N.

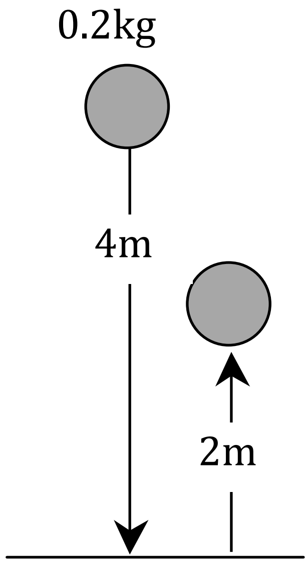
(a) Calculate the component of the weight acting down the slope.
(b) Find the acceleration of the car.
(c) Calculate the speed of the car just before it hits the hedge.

9. A trolley of mass 2·0 kg is placed on a slope which makes an angle of 60° to the horizontal.

(a) A student pushes the trolley and then releases it so that it moves up the slope. The force of friction on the trolley is 1·0 N.
(i) Why does the trolley continue to move up the slope after it is released?
(ii) Sketch a diagram to show the forces acting on the trolley after the pushing force is removed.
(iii) Calculate the unbalanced force on the trolley as it moves up the slope, after the pushing force is removed.
(iv) Calculate acceleration of the trolley as it moves up the slope.

(b) The trolley eventually comes to rest then starts to move down the slope.
(i) Sketch a diagram to show the forces acting on the trolley as it moves down the slope.
(ii) Calculate the unbalanced force on the trolley as it moves down the slope.
(iii) Calculate the acceleration of the trolley down the slope.

**Work, Potential and Kinetic Energy[recap]**




1. A small ball of mass 0·20 kg is dropped from a height of 4·0 m above the ground. The ball rebounds to a height of 2·0 m.

(a) Calculate total loss in energy of the ball.

(b) Calculate the speed of the ball just before it hits the ground.

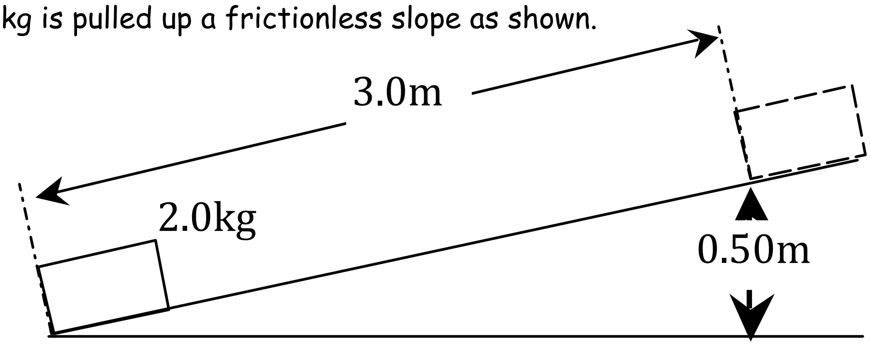
(c) Calculate the speed of the ball just after it leaves the ground.

2. A box of mass 70 kg is pulled along a horizontal surface by a horizontal force of 90 N. The box is pulled a distance of 12 m. There is a frictional force of 80 N between the box and the surface.

(a) Calculate the total work done by the pulling force.

(b) Calculate the amount of kinetic energy gained by the box.

3. A box of mass 2·0 kg is pulled up a frictionless slope as shown.




(a) Calculate the gravitational potential energy gained by the box when it is pulled up the slope.

(b) The block is now released.
(i) Use conservation of energy to find the speed of the box at the bottom of the slope.
(ii) Use another method to confirm your answer to (i).

4. A winch driven by a motor is used to lift a crate of mass 50 kg through a vertical height of 20 m.
(a) Calculate the size of the minimum force required to lift the crate.

(b) Calculate the minimum amount of work done by the winch while lifting the crate.

(c) The power of the winch is 2·5 kW. Calculate the minimum time taken to lift the crate to the required height.

5. A train has a constant speed of 10 $ms^{-1}$ over a distance of 2·0 km.
The driving force of the train engine is $3 \cdot 0 \times 10^4$ N.
What is the power developed by the train engine?

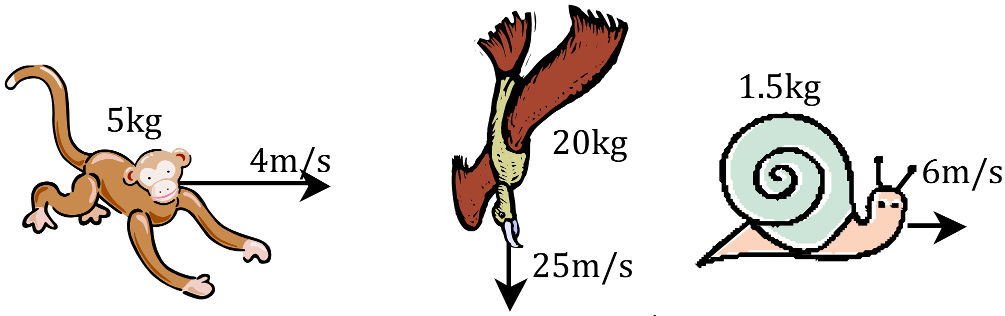
6. An arrow of mass 22 g has a speed of 30 $ms^{-1}$ as it strikes a target. The tip of the arrow goes $3 \cdot 0 \times 10^{-2}$ m into the target.

(a) Calculate the average force of the target on the arrow.

(b) What is the time taken for the arrow to come to rest after striking the target, assuming the target exerts a constant force on the arrow?

<u>Collisions and Explosions</u>

1. What is the momentum of the animal in each of the following situations?



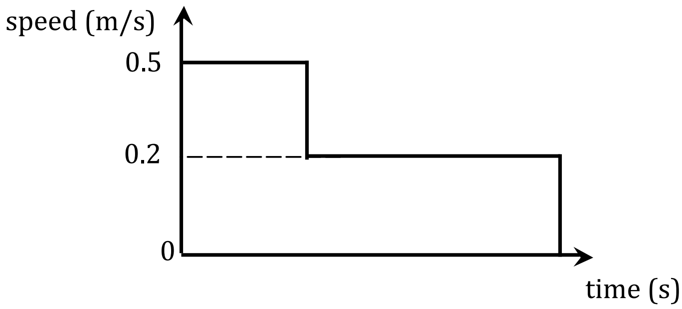

2. A trolley of mass 2·0 kg is travelling with a speed of 1·5 $ms^{-1}$. The trolley collides and sticks to a stationary trolley of mass 2·0 kg.
(a) Calculate the velocity of the trolleys immediately after the collision.

(b) Show that the collision is inelastic.

3. A target of mass 4·0 kg hangs from a tree by a long string. An arrow of mass 100 g is fired at the target and embeds itself in the target. The speed of the arrow is 100 $ms^{-1}$ just before it strikes the target.

4. A trolley of mass 2·0 kg is moving at a constant speed when it collides and sticks to a second stationary trolley.
The graph shows how the speed of the **2·0 kg** trolley varies with time.

Determine the mass of the second trolley.

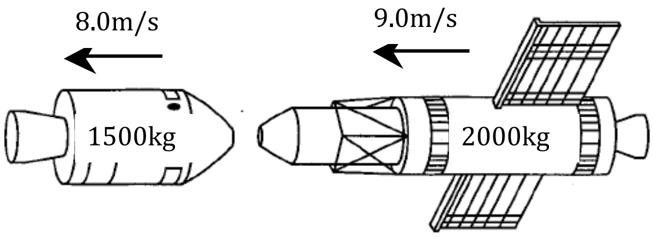


5. In a game of bowls a bowl of mass 1·0 kg is travelling at a speed of 2·0ms$^{-1}$ when it hits a stationary jack 'straight on'. The jack has a mass of 300 g. The bowl continues to move straight on with a speed of 1·2 ms$^{-1}$ after the collision.

(a) What is the speed of the jack immediately after the collision?

(b) How much kinetic energy is lost during the collision?

6. Two space vehicles make a docking manoeuvre (joining together) in space. One vehicle has a mass of 2000 kg and is travelling at 9·0 ms$^{-1}$. The second vehicle has a mass of 1500 kg and is moving at 8·0 ms$^{-1}$ in the same direction as the first.



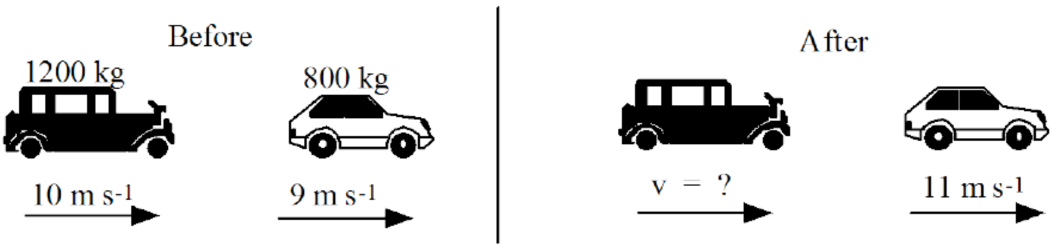

Determine their common velocity after docking.

7. Two cars are travelling along a race track. The car in front has a mass of 1400 kg and is moving at 20 ms$^{-1}$. The car behind has a mass of 1000 kg and is moving at 30ms$^{-1}$. The cars collide and as a result of the collision the car in front has a speed of 25 ms$^{-1}$.

(a) Determine the speed of the rear car after the collision.

(b) Show clearly whether this collision is elastic or inelastic.

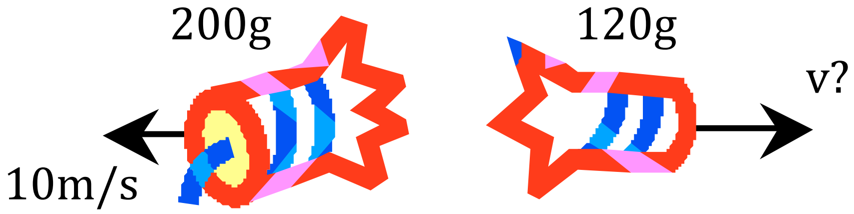
8. One vehicle approaches another from behind as shown.




The vehicle at the rear is moving faster than the one in front and they collide. This causes the vehicle in front to be 'nudged' forward with an increased speed. Determine the speed of the rear vehicle immediately after the collision.

9. A trolley of mass 0·8 kg is travelling at 1·5 $ms^{-1}$. It collides head-on with another vehicle of mass 1·2 kg travelling at 2·0 $ms^{-1}$ in the opposite direction. The vehicles lock together on impact. Determine the speed and direction of the vehicles after the collision.

10. A firework is launched vertically and when it reaches its maximum height it explodes into two pieces.




One of the pieces has a mass of 200 g and moves off with a speed of 10 $ms^{-1}$. The other piece has a mass of 120 g. What is the velocity of the second piece of the firework?

11. Two trolleys initially at rest and in contact move apart when a plunger on one trolley is released. One trolley with a mass of 2 kg moves off with a speed of 4 $ms^{-1}$. The other moves off with a speed of 2 $ms^{-1}$, in the opposite direction. Calculate the mass of this trolley.

12. A man of mass 80 kg and woman of mass 50 kg are skating on ice. At one point they stand next to each other and the woman pushes the man. As a result of the push the man moves off at a speed of 0·5 $ms^{-1}$. What is the velocity of the woman as a result of the push?

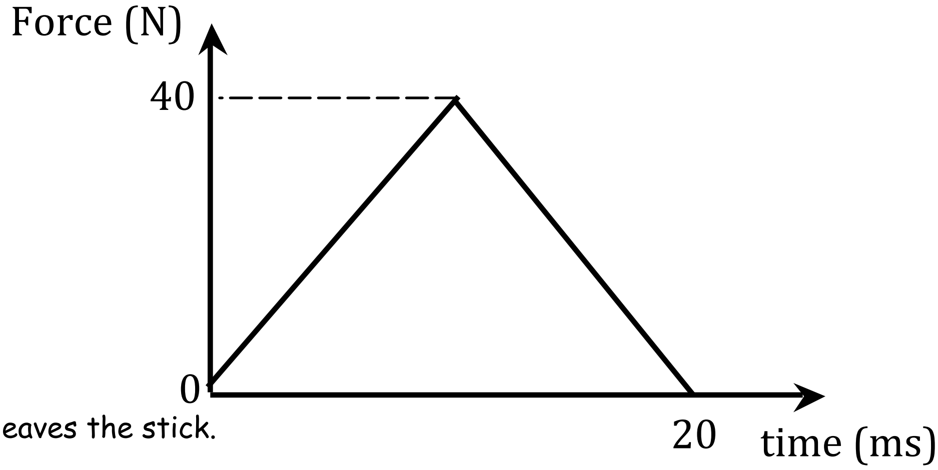
13. Two trolleys initially at rest and in contact fly apart when a plunger on one of them is released. One trolley has a mass of 2·0 kg and moves off at a speed of 2·0 $ms^{-1}$· The second trolley has a mass of 3·0 kg. Calculate the velocity of this trolley.

14. A cue exerts an average force of 7·00 N on a stationary snooker ball of mass 200 g. The impact of the cue on the ball lasts for 45·0 ms.
What is the speed of the ball as it leaves the cue?

15 A football of mass 500 g is stationary. When a girl kicks the ball her foot is in contact with the ball for a time of 50 ms. As a result of the kick the ball moves off at a speed of 10 $ms^{-1}$. Calculate the average force exerted by her foot on the ball.

16. A stationary golf ball of mass 100 g is struck by a club. The ball moves off at a speed of 30 $ms^{-1}$. The average force of the club on the ball is 100 N. Calculate the time of contact between the club and the ball.

17. The graph shows how the force exerted by a hockey stick on a stationary hockey ball varies with time.




The mass of the ball is 150 g.
Determine the speed of the ball as it leaves the stick.

18. A ball of mass 100 g falls from a height of 0·20 m onto concrete. The ball rebounds to a height of 0·18 m. The duration of the impact is 25 ms. Calculate:
(a) the change in momentum of the ball caused by the 'bounce'
(b) the impulse on the ball during the bounce
(c) the average unbalanced force exerted on the ball by the concrete
(d) the average unbalanced force of the concrete on the ball.
(e) What is in the total average upwards force on the ball during impact?

19. A rubber ball of mass 40·0 g is dropped from a height of 0·800 m onto the pavement. The ball rebounds to a height of 0·450 m. The average force of contact between the pavement and the ball is 2·80 N.

(a) Calculate the velocity of the ball just before it hits the ground and the velocity just after hitting the ground.

(b) Calculate the time of contact between the ball and pavement.

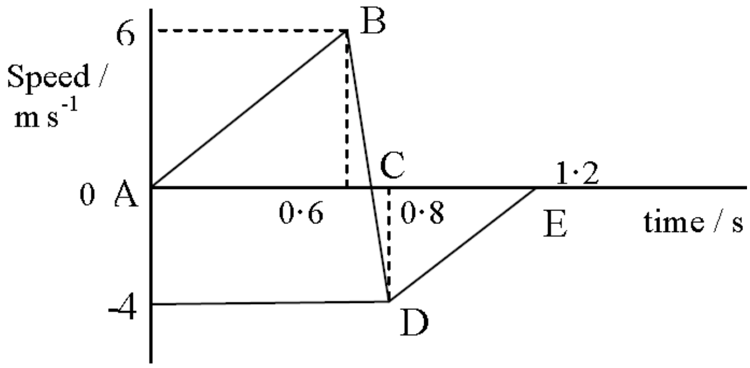
20. A ball of mass 400 g travels falls from rest and hits the ground. The velocity-time graph represents the motion of the ball for the first 1·2 s after it starts to fall.

(a) Describe the motion of the ball during sections AB, BC, CD and DE on the graph.

(b) What is the time of contact of the ball with the ground?

(c) Calculate the average unbalanced force of the ground on the ball.

(d) How much energy is lost due to contact with the ground?



21. Water with a speed of 50 $ms^{-1}$ is ejected horizontally from a fire hose at a rate of 25 $kgs^{-1}$. The water hits a wall horizontally and does not rebound from the wall. Calculate the average force exerted on the wall by the water.

22. A rocket ejects gas at a rate of 50 $kgs^{-1}$, ejecting it with a constant speed of 1800 $ms^{-1}$. Calculate magnitude of the force exerted by the ejected gas on the rocket.

23. Describe in detail an experiment that you would do to determine the average force between a football boot and a football as the ball is being kicked. Draw a diagram of the apparatus and include all the measurements taken and details of the calculations carried out.

24. A 2·0 kg trolley travelling at 6·0 $ms^{-1}$ collides with a stationary 1·0 kg trolley. The trolleys remain connected after the collision.
(a) Calculate:
(i) the velocity of the trolleys just after the collision
(ii) the momentum gained by the 1·0 kg trolley
(iii) the momentum lost by the 2·0 kg trolley.

(b) The collision lasts for 0·50 s. Calculate the magnitude of the average force acting on each trolley.

25. In a problem two objects, having known masses and velocities, collide and stick together. Why does the problem ask for the velocity immediately after collision to be calculated? [TQ]

26. A Newton's cradle apparatus is used to demonstrate conservation of momentum. Four steel spheres, each of mass 0.1 kg, are suspended so that they are in a straight line. Sphere 1 is pulled to the side and released, as shown in diagram I.

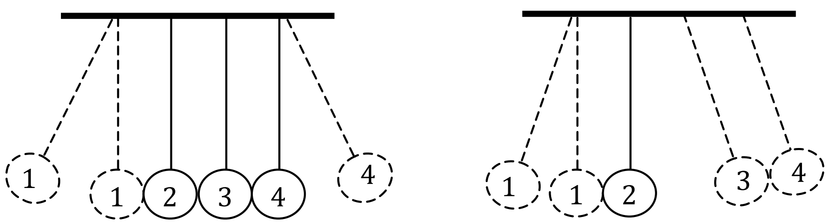



Diagram I Diagram II

When sphere 1 strikes sphere 2 (as shown by the dotted lines) then sphere 4 moves off the line and reaches the position shown by the dotted lines.

The student estimates that sphere 1 has a speed of 2$ms^{-1}$ when it strikes sphere 2. She also estimates that sphere 4 leaves the line with an initial speed of 2 $ms^{-1}$. Hence conservation of momentum has been demonstrated.

A second student suggests that when the demonstration is repeated there is a possibility that spheres 3 and 4, each with a speed of 0·5 $ms^{-1}$, could move off the line as shown in diagram II.

Use your knowledge of physics to show this is not possible. [TQ]

**Projectiles**

1. A plane is travelling with a horizontal velocity of 350 $ms^{-1}$ at a height of 300 m. A box is dropped from the plane. The effects of friction can be ignored.

(a) Calculate the time taken for the box to reach the ground.

(b) Calculate the horizontal distance between the point where the box is dropped and the point where it hits the ground.

(c) What is the position of the plane relative to the box when the box hits the ground?

2. A projectile is fired horizontally with a speed of 12·0 $ms^{-1}$ from the edge of a cliff. The projectile hits the sea at a point 60·0 m from the base of the cliff.

(a) Calculate the time of flight of the projectile.

(b) What is the height of the starting point of the projectile above sea level?
State any assumptions you have made.

3. A ball is thrown horizontally with a speed of 15 $ms^{-1}$ from the top of a vertical cliff. It reaches the horizontal ground at a distance of 45 m from the foot of the cliff.

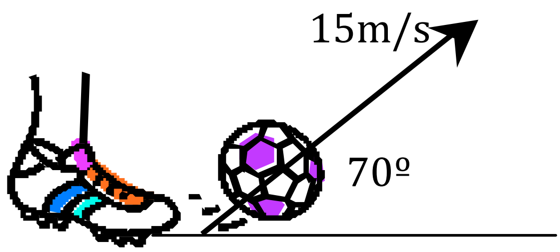
(a)

(i) Draw a graph of vertical speed against time for the ball for the time from when it is thrown until it hits the ground.
(ii) Draw a graph of horizontal speed against time for the ball.

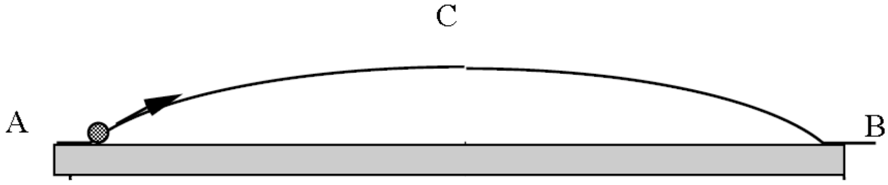
(b) Calculate the velocity of the ball 2 s after it is thrown.
(Magnitude **and** direction are required.)

4. A football is kicked up at an angle of 70° above the horizontal at 15 $ms^{-1}$.

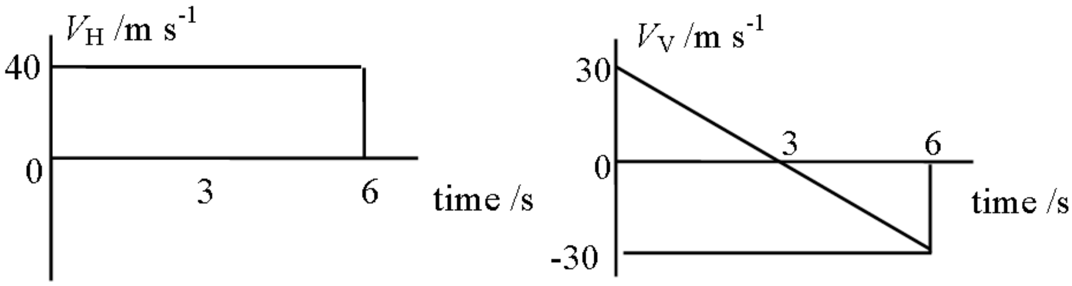
Calculate:
(a) the horizontal component of the velocity
(b) the vertical component of the velocity.



5. A projectile is fired across level ground and takes 6 s to travel from A to B. The highest point reached is C. Air resistance is negligible.




Velocity-time graphs for the flight are shown below. $V_H$ is the horizontal velocity and $V_V$ is the vertical velocity.




(a) Describe:

(i) the horizontal motion of the projectile

(ii) the vertical motion of the projectile.

(b) Use a vector diagram to find the speed and angle at which the projectile was fired from point A.

(c) Find the speed at position C. Explain why this is the smallest speed of the projectile. [TQ]

(d) Calculate the height above the ground of point C.

(e) Find the horizontal range of the projectile.

6. A ball of mass 5·0 kg is projected with a velocity of 40 ms$^{-1}$ at an angle of 30° to the horizontal.

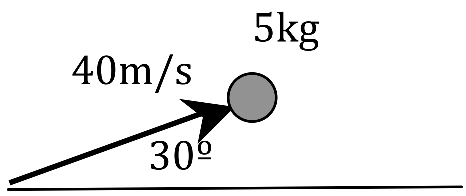
Calculate:

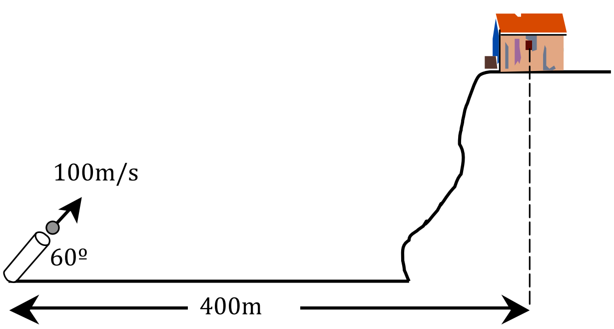
(a) the vertical component of the initial velocity of the ball

(b) the maximum vertical height reached by the ball

(c) the time of flight for the whole trajectory

(d) the horizontal range of the ball.



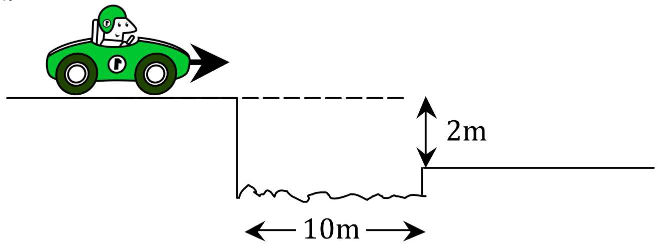




7. A launcher is used to fire a ball with a velocity of 100 ms$^{-1}$ at an angle of 60° to the ground. The ball strikes a target on a hill as shown.

(a) Calculate the time taken for the ball to reach the target.

(b) What is the height of the target above the launcher?

8. A stunt driver attempts to jump across a canal of width 10 m.
The vertical drop to the other side is 2 m as shown.




(a) Calculate the minimum horizontal speed required so that the car reaches the other side.

(b) Explain why your answer to (a) is the minimum horizontal speed required. [TQ]

(c) State any assumptions you have made. [TQ]

9. A ball is thrown horizontally from a cliff. The effect of friction can be ignored.

(a) Is there any time when the velocity of the ball is parallel to its acceleration? Justify your answer. [TQ]

(b) Is there any time when the velocity of the ball is perpendicular to its acceleration? Justify your answer. [TQ]

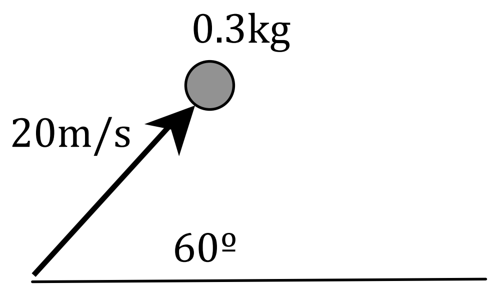
10. A ball is thrown at an angle of 45° to the horizontal. The effect of friction can be ignored.

(a) Is there any time when the velocity of the ball is parallel to its acceleration? Justify your answer. [TQ]

(b) Is there any time when the velocity of the ball is perpendicular to its acceleration? Justify your answer. [TQ]

11. A small ball of mass 0·3 kg is projected at an angle of 60° to the horizontal. The initial speed of the ball is 20 $ms^{-1}$.

Show that the maximum possible gain in potential energy of the ball is 45 J.




12. A ball is thrown horizontally with a speed of 20 $ms^{-1}$ from a cliff. The effects of air resistance can be ignored. How long after being thrown will the velocity of the ball be at an angle of 45° to the horizontal?

## Gravity and Mass

In the following questions, when required, use the following data:
Gravitational constant = $6{\cdot}67 \times 10^{-11}$ N m$^{2}$ kg$^{-2}$

1. State the inverse square law of gravitation.

2. Show that the force of attraction between two large ships, each of mass $5{\cdot}00 \times 10^{7}$ kg and separated by a distance of 20 m, is 417 N.

3. Calculate the gravitational force between two cars parked 0·50 m apart. The mass of each car is 1000 kg.

4. In a hydrogen atom an electron orbits a proton with a radius of $5{\cdot}30 \times 10^{-11}$ m. The mass of an electron is $9{\cdot}11 \times 10^{-31}$ kg and the mass of a proton is $1{\cdot}67 \times 10^{-27}$ kg. Calculate the gravitational force of attraction between the proton and the electron in a hydrogen atom.

5. The distance between the Earth and the Sun is $1{\cdot}50 \times 10^{11}$ m. The mass of the Earth is $5{\cdot}98 \times 10^{24}$ kg and the mass of the Sun is $1{\cdot}99 \times 10^{30}$ kg. Calculate the gravitational force between the Earth and the Sun.

6. Two protons exert a gravitational force of $1{\cdot}16 \times 10^{-35}$ N on each other. The mass of a proton is $1{\cdot}67 \times 10^{-27}$ kg. Calculate the distance separating the protons.

# TUTORIAL SOLUTIONS

**Vector Problems**

3. $0 ms^{-1}$, runner starts and finishes on start line so displacement for the race is zero.
4. $0 ms^{-1}$ still in same place in bed!
5. (a) 80 km (b) 40 km $h^{-1}$ (c) 20 km north (d) 10 km $h^{-1}$ north
6. (a) 70 m (b) 50 m bearing 037 (c) (i) 70 s (ii) 0·71 m $s^{-1}$ bearing 037

**Equations of Motion (suvat)**

1. 280 m
2. 51·2 $ms^{-1}$
3. 28 $ms^{-1}$
4. 16·7 s
5. 3·0 s
6. (a) 750 $ms^{-2}$ (b) 0·04 s
7. 9·5 $ms^{-2}$
8. (a) 0·21 $ms^{-2}$ (b) 1·4 s
9. 234 m
10. (a) (i) 21·4 m (ii) 15·6 $ms^{-1}$ downwards (b) 34·6 m

**Free Falling Objects**

2. 9.8$ms^{-2}$ downwards
3. increases, air resistance increases with velocity
4. decreases, unbalanced force reduces as air resistance increases.
5. parachutist, just after the parachute is opened.
6. The object could stop moving before it hit the ground. It could even start to go upwards.

**Displacement –Time Graphs**

3. (a) 2 $ms^{-1}$ due north (b) 0 $ms^{-1}$ (d) 0·75 $ms^{-1}$

4. (a) 4 $ms^{-1}$ due north (b) 1·0 $ms^{-1}$ due south (d) 1·6 $ms^{-1}$

(f) displacement 2 m due north, velocity 4 m $s^{-1}$ due north

(g) displacement 2 m due north, velocity 1 m $s^{-1}$ due south¶

5. (a) 1 m $s^{-1}$ due north (b) 2 m $s^{-1}$ due south (d) 1 m $s^{-1}$

(f) displacement 0·5 m due north, velocity 1 m $s^{-1}$ due north

(g) displacement 0, velocity 2 m $s^{-1}$ due south

4. (a) 2 m $s^{-2}$ due north (b) 0 m $s^{-2}$ (c) 4 m due north (d) 32 m due north¶

5. (a) 1 m $s^{-2}$ due north (b) 2 m $s^{-2}$ due south

(d) displacement 3 m due north, velocity 0 m $s^{-1}$

(e) displacement 2 m due north, velocity 2 m $s^{-1}$ due south

**Velocity – Time Graphs**

1. (a) 2 m $s^{-2}$ due north (b) 0 m $s^{-2}$ (c) 4 m due north (d) 32 m due north

2. (a) 1 m $s^{-2}$ due north (b) 2 m $s^{-2}$ due south
(d) displacement 3 m due north, velocity 0 m $s^{-1}$
(e) displacement 2 m due south, velocity 2 m $s^{-1}$ due south

3. (a)(i) 17·5 m due north (ii) 22·5 m due north (iii) 17·5 m due north

4. (a) upwards (b) downwards (c) velocity is decreasing upwards
(d) velocity is increasing downwards (e) it hits the ground
(f) it starts to travel upwards (g) speed before is greater

**Acceleration – Time Graphs**

2. (a) 24m$s^{-1}$ (b) 33m$s^{-1}$

**Forces questions revisited**

1. An object will remain at rest or move with constant velocity unless an unbalanced force acts upon it.
2. 4900 N
3. (a) (i) $1{\cdot}5 \times 10^{-2}$ m$s^{-2}$ (ii) $3{\cdot}0 \times 10^{6}$ N (b) $-2{\cdot}7 \times 10^{-3}$ m$s^{-2}$
5. 0·02 m$s^{-2}$
6. 150 N
7. (a) 120 N (b) 20 N
8. (a) 1200 N (b) 108 m (c) 2592 N
9. (a) (ii) 7·7 m $s^{-2}$

10. (a) $1{\cdot}78 \times 10^{3}$ kg (b) $45 \times 10^{3}$ N
11. $2{\cdot}86 \times 10^{4}$ N
12. (a) $1{\cdot}96 \times 10^{3}$ N (b) $2.26 \times 10^{3}$ N (c) $1.96 \times 10^{3}$ N (d) $1.66 \times 10^{3}$ N
13. (a) (i) $2{\cdot}45 \times 10^{3}$ N (ii) $2{\cdot}45 \times 10^{3}$ N (iii) $2{\cdot}95 \times 10^{3}$ N (iv) $1{\cdot}95 \times 10^{3}$ N
(b) 4·2 m $s^{-2}$
14. 51·2 N
15. (b) 0·4 s reading 37·2 N 4 s to 10 s reading 39·2 N 10 s to 12 s reading 43·2 N
16. (a) 8 m $s^{-2}$ (b) 16 N
17. (a) $5{\cdot}1 \times 10^{3}$ N (b) $2{\cdot}5 \times 10^{3}$ N (c) (i) 700 N (ii) 500 N (d) $1{\cdot}03 \times 10^{4}$ N
18. 24 m
19. (a) (i) 2 m $s^{-2}$ (ii) 40 N (iii) 20 N (b) (i) 12 N

20. (a) 3·27 m$s^{-2}$ (b) 6·54 N

**Resolution of Forces**

1. (a) 43·3 N
2. 353·6 N
3. (a) 8·7 N (b) 43·5 m $s^{-2}$
4. 0·513 m $s^{-2}$
5. (a) 226 N (b) 0·371 m $s^{-2}$
6. 9·8 N up the slope
7. 0·735 N
8. (a) 2283 N (b) 2·2 m $s^{-2}$ (c) 14·8 m $s^{-1}$
9. (a) (iii) 18 N down the slope (iv) 9 m $s^{-2}$ down the slope
(b) (ii) 16 N down the slope (iii) 8 m $s^{-2}$ down the slope

**Work, Potential and Kinetic Energy[recap]**

1. (a) 3·92 J (b) 8·9 m $s^{-1}$ (c) 6·3 m $s^{-1}$
2. (a) 1080 J (b) 120 J
3. (a) 9·8 J (b) (i) 3·1 m $s^{-1}$ (ii) suvat
4. (a) 490 N (b) $9·8 \times 10^{3}$ J (c) 3·9 s
5. $3·0 \times 10^{5}$ W
6. (a) 330 N (b) $2·0 \times 10^{-3}$ s

**Collisions and Explosions**

1. (a) 20 kg $ms^{-1}$ to the right (b) 500 kg $ms^{-1}$ downwards (c) 9 kg $ms^{-1}$ to the right
2. (a) 0·75 $ms^{-1}$ in the direction in which the first trolley was moving
3. 2·4 $ms^{-1}$
4. 3·0 kg
5. (a) 2·7 $ms^{-1}$ (b) 0·19 J
6. 8·6 $ms^{-1}$ in the original direction of travel
7. (a) 23 $ms^{-1}$
8. 8·7 $ms^{-1}$
9. 0·6 $ms^{-1}$ in the original direction of travel of the 1·2 kg trolley
10. 16·7 $ms^{-1}$ in the opposite direction to the first piece
11. 4 kg
12. 0·8 $ms^{-1}$ in the opposite direction to the velocity of the man
13. 1·3 $ms^{-1}$ in the opposite direction to the velocity of the first trolley
14. 1·58 $ms^{-1}$ 15. 100 N
16. $3·0 \times 10^{-2}$ s 17. 2·67 m $s^{-1}$

18 (a) + 0·39 kg m $s^{-1}$ if you have chosen upwards directions to be positive
(b) + 0·39 N s if you have chosen upwards directions to be positive
(c) 15·6 N downwards (d) 15·6 N upwards (e) 16·6 N upwards

19. (a) v before = 3·96 $ms^{-1}$ downwards; v after = 2·97 $ms^{-1}$ upwards

(b) $9{\cdot}9 \times 10^{-2}$ s

20.(b) 0·2 s (c) 20 N upwards (or –20 N for the sign convention used in the graph)

(d) 4·0 J

21. $1{\cdot}25 \times 10^{3}$ N towards the wall

22. $9{\cdot}0 \times 10^{4}$ N

24. (a) (i) 4·0 $m\ s^{-1}$ in the direction the 2·0 kg trolley was travelling

(ii) 4·0 $kg\ m\ s^{-1}$ in the direction the 2·0 kg trolley was travelling

(iii) 4·0 $kg\ m\ s^{-1}$ in the opposite direction the 2·0 kg trolley was travelling

(b) 8·0 N

**Projectiles**

1. (a) 7·8 s (b) 2730 m (c) directly above box
2. (a) 5·0 s (b) 123 m
3. (b) 24·7 $m\ s^{-1}$ at an angle of 52.6° below the horizontal
4. (a) $v_H$ = 5·1 $m\ s^{-1}$, $v_V$= 14·1 $m\ s^{-1}$
5. (b) 50 $m\ s^{-1}$ at 36.9° above the horizontal

(c) 40 $m\ s^{-1}$ (d) 45 m (e) 240 m

6. (a) 20 $m\ s^{-1}$ (b) 20.4 m (c) 4·1 s (d) 142 m
7. (a) 8 s (b) 379 m
8. (a) 15·6 $m\ s^{-1}$

12. 2 s

**Gravity and mass**

3. $2{\cdot}67 \times 10^{-4}$ N
4. $3{\cdot}61 \times 10^{-47}$ N
5. $3{\cdot}53 \times 10^{22}$ N
6. $4{\cdot}00 \times 10^{-15}$ m