HIGHER PHYSICS

UNIT 1 - MECHANICS and PROPERTIES OF MATTER

KINEMATICS

1) SCALARS and VECTORS

You must be able to:

- Explain the meaning of the terms scalar and vector quantities and know examples of each.
- Distinguish between distance and displacement.
- Distinguish between speed and velocity.
- Draw a scale diagram or use a calculation to find the resultant of several vectors (displacements, velocities and forces).
- Resolve a vector into components at right-angles (90°) to each other.

1) SCALAR and VECTOR QUANTITIES

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.

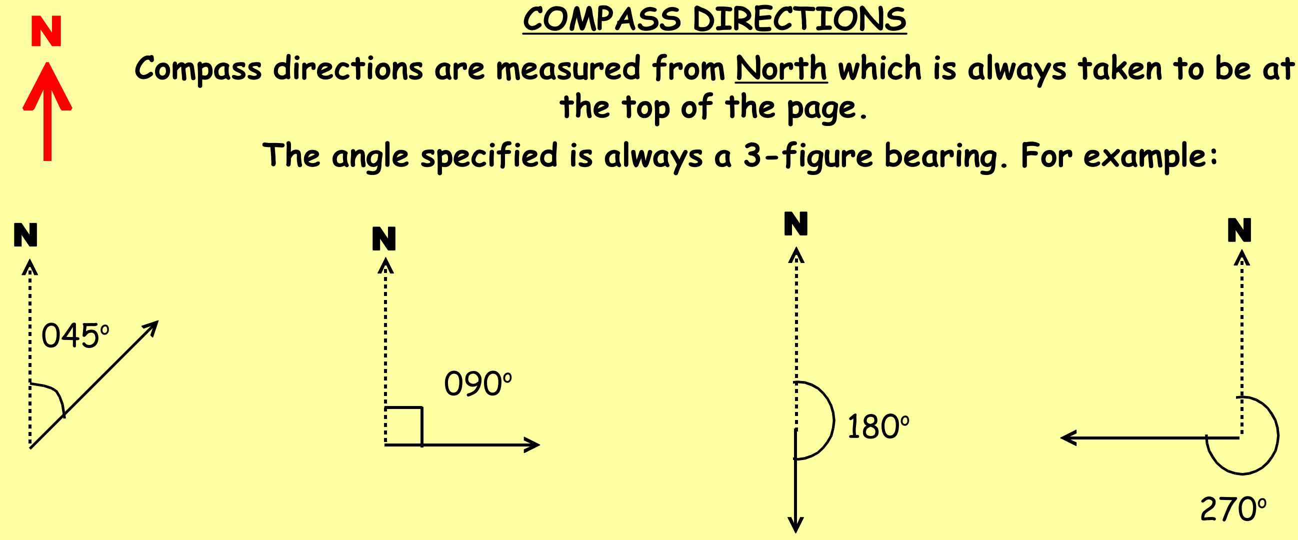
VECTORS

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. For example:

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

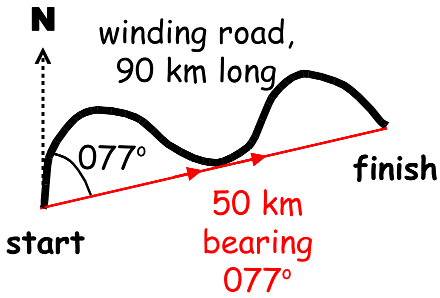
2) DISTANCE and DISPLACEMENT

●**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.]

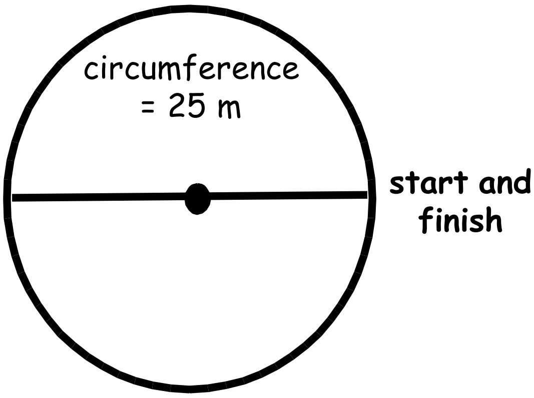
For example:

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).

3) SPEED and VELOCITY

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

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

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

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

- **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	Ben

4) 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

5) 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.

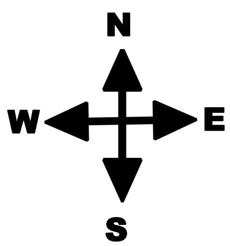
YOU MUST BE ABLE TO ADD VECTOR QUANTITIES USING BOTH A SCALE DIAGRAM AND MATHEMATICS - Pythogoras theorem, SOHCAHTOA, the Sine Rule and the Cosine Rule.

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

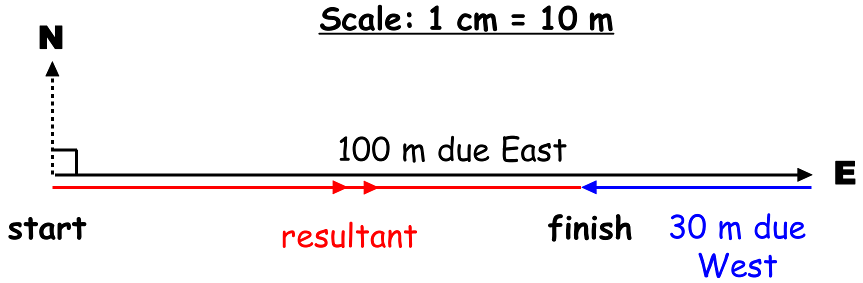
Example 1

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**.



Scale: 1 cm = 10 m



On scale diagram, resultant = 7 cm.

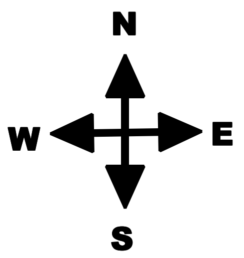
Scaling up, this represents a displacement of 70 m bearing 090°.

(Alternatively, we can say displacement = 70 m 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**.

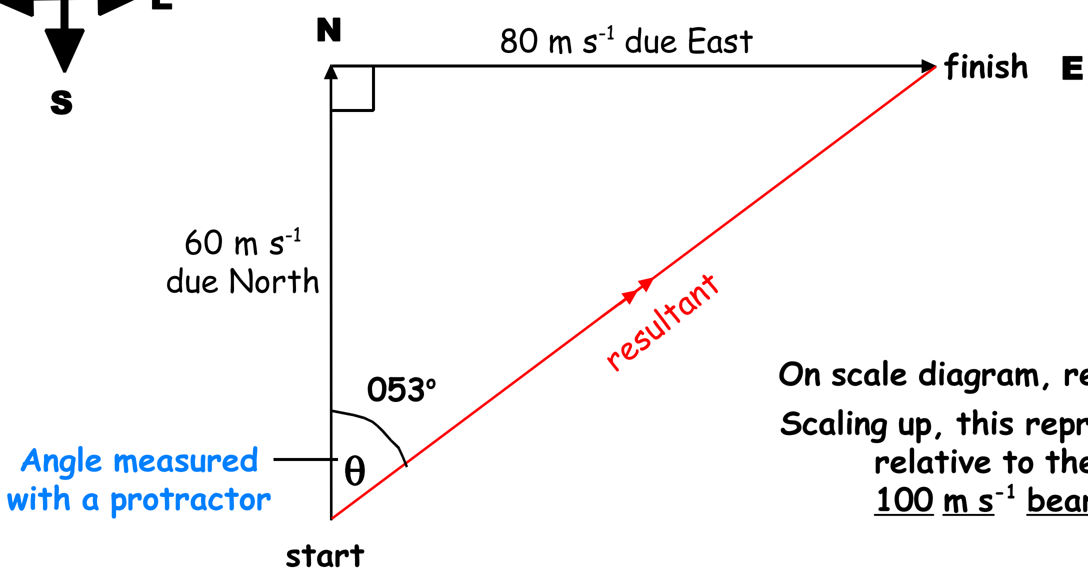
Example 2

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



Method 1 - by scale diagram

Scale: 1 cm = 10 m s^{-1}



On scale diagram, resultant = 10 cm.

Scaling up, this represents a velocity relative to the ground of 100 m s^{-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

resultant^2 = $60^2 + 80^2$
= 3600 + 6400
= 10 000

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

Next, Using SOHCAHTOA

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

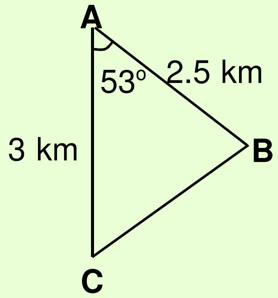
so, $\theta = \tan^{-1} 1.33$
= 53.1°

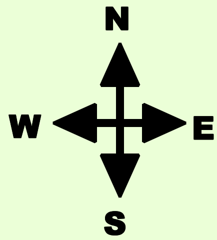
Resultant velocity relative to the ground = 100 m s^{-1} bearing 053.1°

Note - The mathematical method provides a more accurate answer for the angle. (You can't read a protractor to 0.1° !!!).

- **Solve this problem using MATHEMATICS. (Hint - The "Cosine Rule", then the "Sine Rule").**

The course for a cross-country race is shown.
Calculate the **displacement** of **point B** from **point C**.



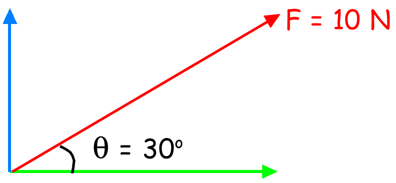


6) RESOLVING A VECTOR INTO 2 COMPONENTS AT RIGHT-ANGLES TO EACH OTHER

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

For example:

$F \sin\theta$
$= 10 \times \sin 30°$
$= 10 \times 0.500$
$= 5.00$ N



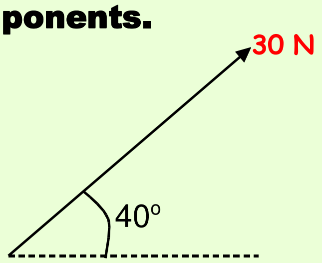
$F \cos\theta$
$= 10 \times \cos 30°$
$= 10 \times 0.866$
$= 8.66$ N

The **10 N** vector can be replaced by the 2 vectors: **5.00 N** acting **vertically** and **8.66 N** acting **horizontally**. (These 2 vectors are at right-angles to each other).

The **5.00 N** and **8.66 N** vectors are known as **components** of the **10 N** vector.

The **5.00 N** and **8.66 N** forces **acting together** have exactly the same effect as the **10 N** force **acting on its own**. **Acting together**, the **5.00 N** and **8.66 N** forces would move an object in exactly the same direction as the **10 N** force would, at exactly the same velocity.

- **Resolve the 30 N vector into vertical and horizontal components.**



HIGHER PHYSICS

UNIT 1 - MECHANICS and PROPERTIES OF MATTER

KINEMATICS

2) ACCELERATION and EQUATIONS OF MOTION

You must be able to:

- State that acceleration is the change in velocity per unit time.

- Describe a method for measuring acceleration.

- Use the terms uniform (constant) velocity and uniform (constant) acceleration to describe motion represented by a graph or by numbers in a table.

- For motion in a straight line, draw an acceleration-time graph using information from a velocity-time graph.

- Derive the three equations of motion:

  $v = u + at \qquad s = ut + 1/2at^2 \qquad v^2 = u^2 + 2as$.

- Use the three equations of motion to solve problems involving motion in a straight line with uniform (constant) acceleration - Including projectile motion.

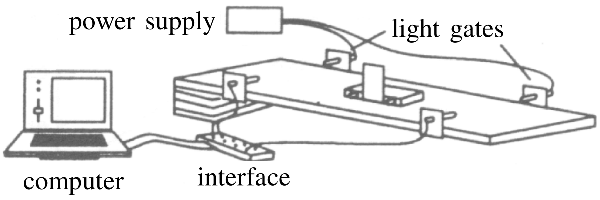
1) ACCELERATION

Acceleration is **the change of velocity per unit time.** Unit: **m s^{-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).

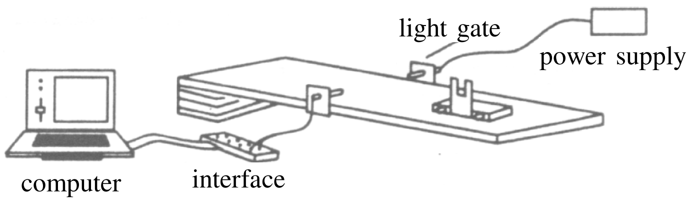


- length of card = _____ m.
- t_1 = time for card fixed on trolley to pass through first (top) light gate = ____ s.
- t_2 = time for card fixed on trolley to pass through second (bottom) light gate = ____ s.
- t_3 = time for card fixed on trolley to pass **between** the 2 light gates = ____ s.
- velocity of card through first (top) light gate (**u**) =

  $\frac{\text{length of card}}{t_1}$ = $\frac{\_\_\_\_\_\_}{}$ = _____ m s^{-1}.
- velocity of card through second (bottom) light gate (**v**) =

  $\frac{\text{length of card}}{t_2}$ = $\frac{\_\_\_\_\_\_}{}$ = _____ m s^{-1}.
- **acceleration** = $\frac{v - u}{t_3}$ = $\frac{\_\_\_\_\_\_\_}{}$ = _____ m s^{-2}.

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



- length of right edge of card (first edge to pass through light gate) = _____ m.
- length of left edge of card (second edge to pass through light gate) = _____ m.
- t_1 = time for first edge of card to pass through light gate = _____ s.
- t_2 = time for second edge of card to pass through light gate = _____ s.
- t_3 = time **between** first and second edges of card passing light gate = _____ s.
- velocity of first edge of card through light gate (**u**) =

  $\frac{\text{length of edge}}{t_1}$ = $\frac{\_\_\_\_\_\_}{}$ = _____ m s^{-1}.
- velocity of second edge of card through light gate (**v**) =

  $\frac{\text{length of edge}}{t_2}$ = $\frac{\_\_\_\_\_\_}{}$ = _____ m s^{-1}.
- **acceleration** = $\frac{v - u}{t_3}$ = $\frac{\_\_\_\_\_\_}{}$ = _____ m s^{-2}.

● **Describe one of these methods for determining the <u>acceleration</u> of a trolley on a slope:**

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**.

● **Perform such an experiment several times. Use your results to calculate a mean value (with uncertainty) for <u>gravitational</u> <u>acceleration</u>:**

2) USING NUMERICAL DATA (IN TABULAR FORM) TO DESCRIBE ACCELERATION

● **case 1**

time/ s	velocity/ m s^{-1}
0	15
1	15
2	15
3	15
4	15
5	15

Type of motion:

Reason:

● **case 2**

time/ s	velocity/ m s^{-1}
0	0
1	5
2	10
3	15
4	20
5	25

Type of motion:

Reason:

● **case 3**

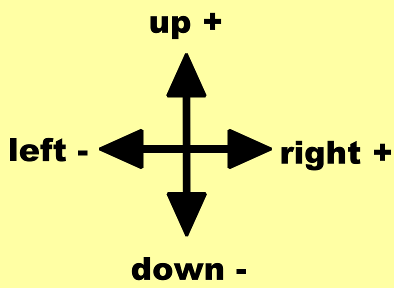
time/ s	velocity/ m s^{-1}
0	15
1	12
2	9
3	6
4	3
5	0

Type of motion:

Reason:

3) MOTION GRAPHS

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.

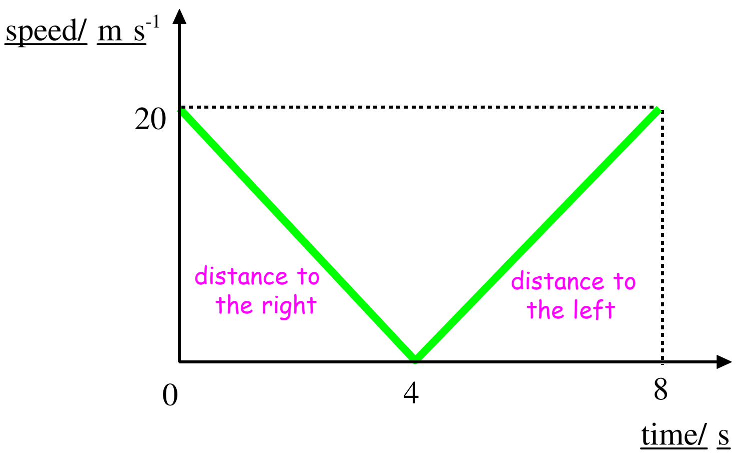
For example, for horizontal motion, +5 m s^{-1} represents a velocity of 5 m s^{-1} to the right and -5 m s^{-1} represents a velocity of 5 m s^{-1} to the left. For vertical motion, +10 m represents a displacement of 10 m up and -10 m represents a displacement of 10 m down.

(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 !!!)

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

Example - A car, initially travelling at 20 m s^{-1} in a straight line to the **right**, brakes and decelerates uniformly (constantly) at 5 m s^{-2}, coming to **rest** in 4 s. Immediately, it reverses, accelerating uniformly (constantly) at 5 m s^{-2} in a straight line to the **left** for 4 s, back to where it started.

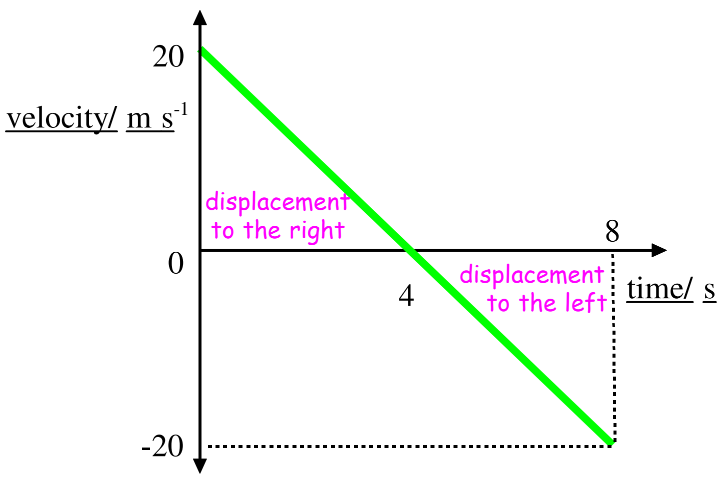
- **speed-time graph of motion**



- **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.

Determine the total distance travelled:

- **velocity-time graph of motion**

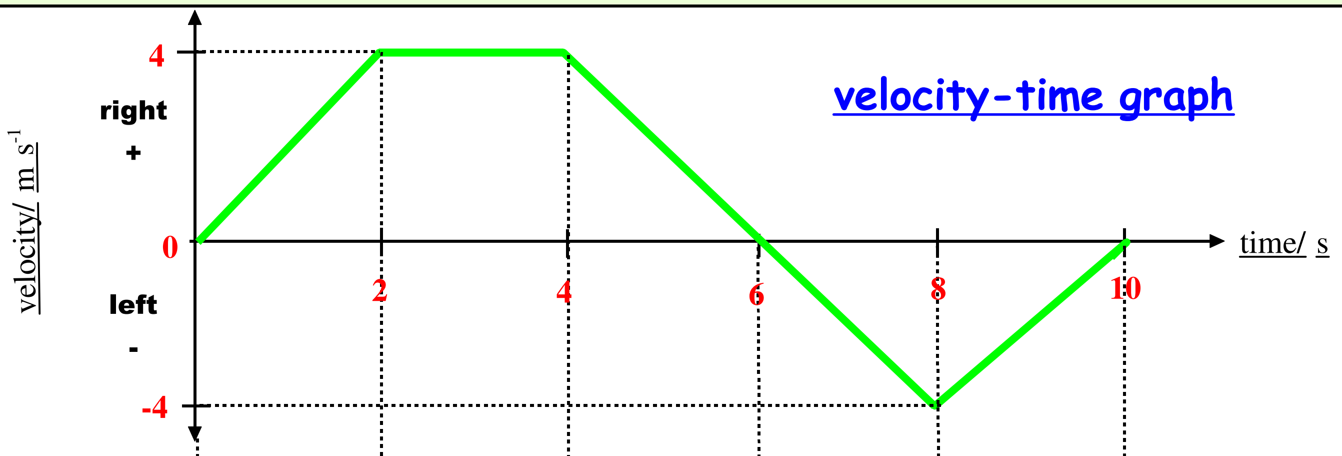


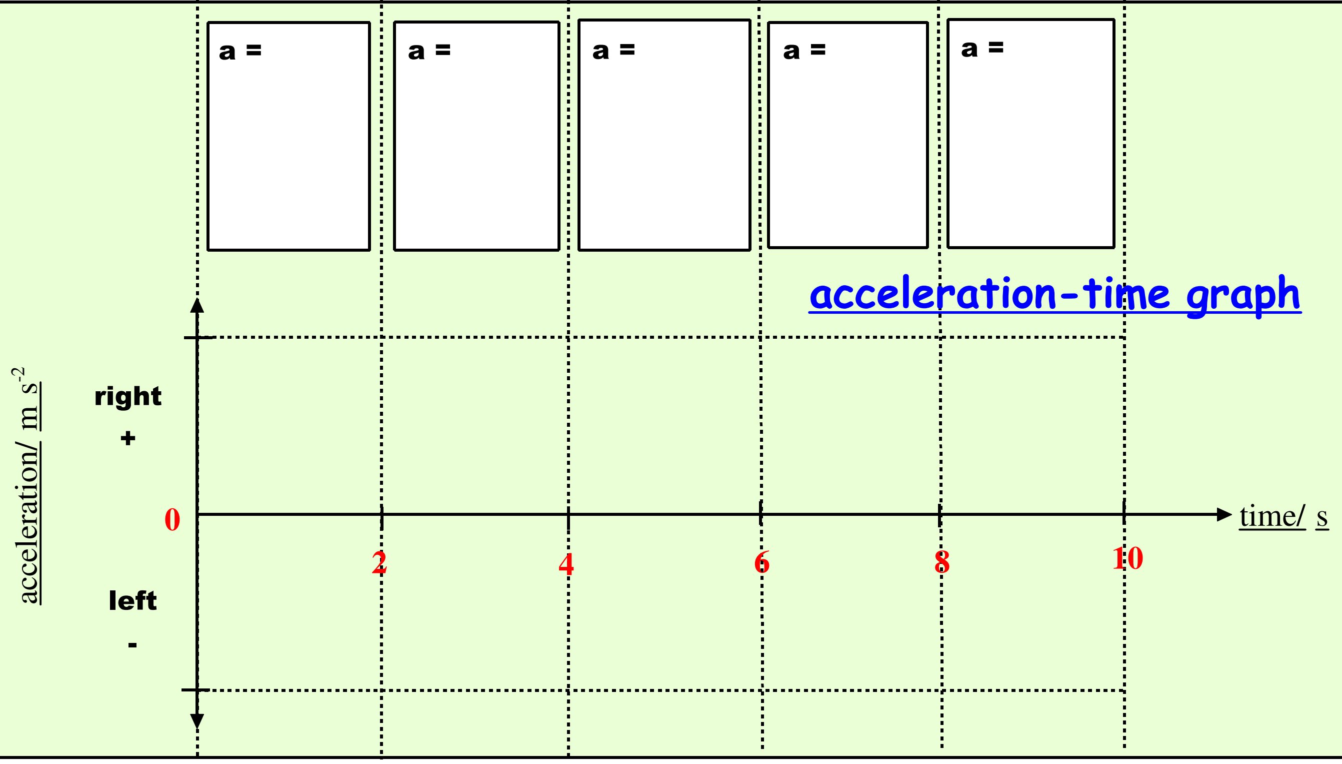
- **Velocity** is a **vector** quantity, so change in direction is taken into account. This is shown by the line crossing the time axis at 4 s.
- In this case, the deceleration and acceleration have the same numerical value, so the gradient of the line (which indicates their value) is uniform.
- The **total mathematical area** under the graph gives the displacement.

Show that the displacement is zero:

(b) 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:**





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

____

____

____

____

____

____

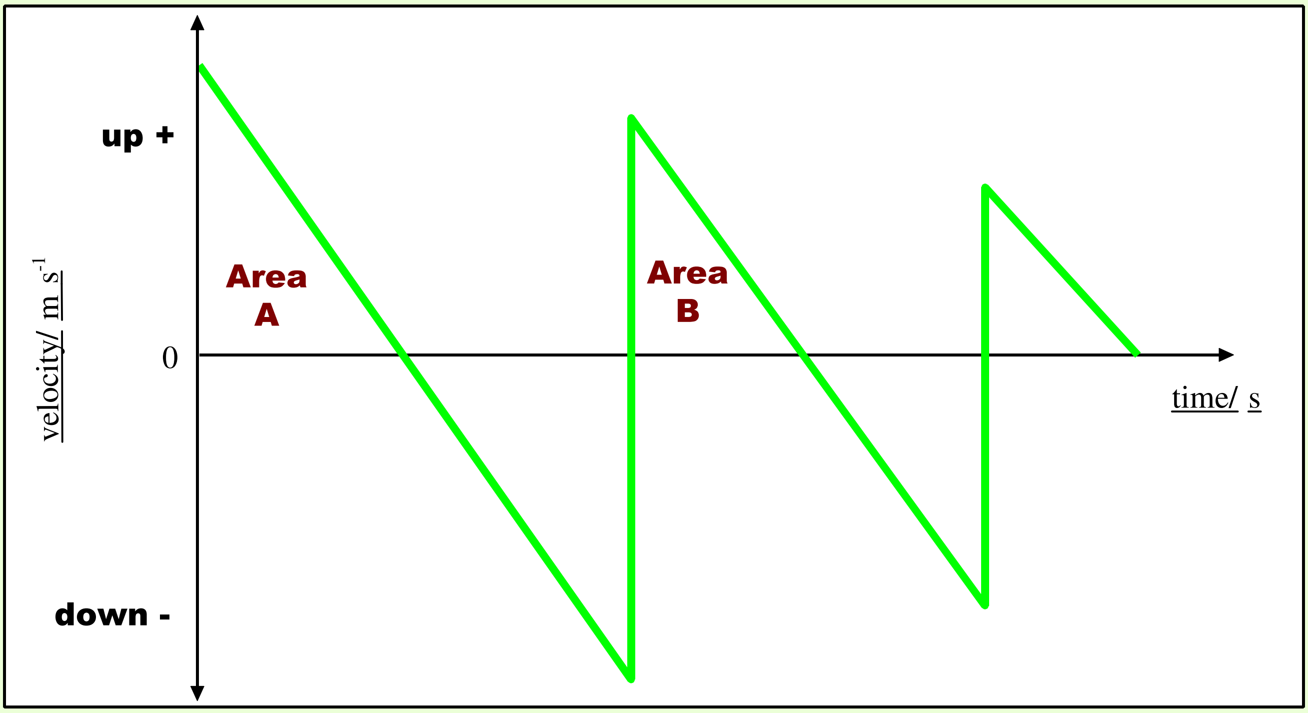
____

____

- **Determine the displacement of the object:**

Velocity-time graph for a bouncing ball

The velocity-time graph for the *vertical (up and down) motion* of a bouncing ball is shown. Initially, the ball was thrown *upwards*.



- **On each section of the graph, write a description of the ball's motion.**
- **What can you say about the ball's acceleration?**____________________
  How do you know?____

- **Area A is larger than area B. Why?**______________________________

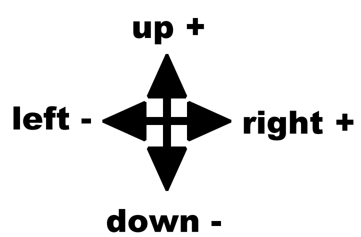
4) THE THREE EQUATIONS OF MOTION (FOR UNIFORM ACCELERATION IN A STRAIGHT LINE)

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

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

t = time for motion to take place/ s
u = initial velocity/ m s^{-1}
v = final velocity after time t/ m s^{-1}
a = uniform (constant) acceleration during time t/ m s^{-2}
s = displacement (in a straight line) during time t/ m

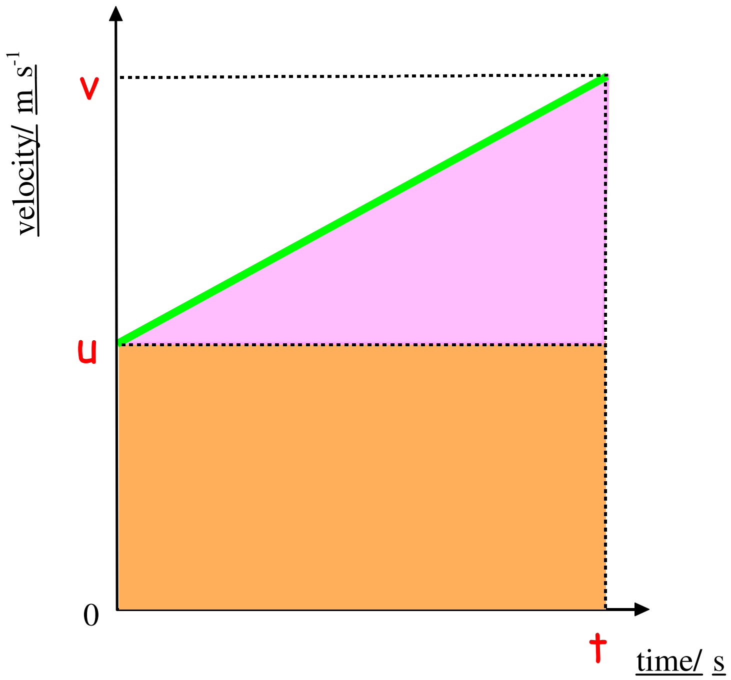
Because **u**, **v**, **a** and **s** are **vectors**, we must specify their direction by placing a **+** or **-** sign in front of the number representing them:



- **Show how the three equations of motion are derived:**

$v = u + at$

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



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

Examples/Problems

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.

$v = u + at$

A racing car starts from rest and accelerates uniformly in a straight line at 12 m s^{-2} for 5 s. Calculate the **final velocity** of the car.

$u = 0$ m s^{-1} (rest)
$a = 12$ m s^{-2}
$t = 5$ s
$v = ?$

$v = u + at$
$v = 0 + (12 \times 5)$
$v = 0 + 60$
$v = \underline{60 \text{ m s}^{-1}}$ (in direction of acceleration)

- **Karen is travelling at 4 m s^{-1} in her go-kart. She then accelerates uniformly in a straight line at 2 m s^{-2} for 6 s. Calculate Karen's final velocity.**

- **While ice skating, Martin accelerates uniformly at 1.5 m s^{-2} in a straight line from 1 m s^{-1} to 7 m s^{-1}. Calculate the time Martin takes to do this.**

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

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

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

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

- **Emily's kite is travelling at 2 m s^{-1}. It is caught by a gust of wind which accelerates it in a straight line in the same direction for 3 s. The kite travels a further 15 m. Calculate the acceleration of the kite.**

- **While jogging, Thomas accelerates at 2.5 m s^{-2} in the same direction for 2 s, travelling 12 m in a straight line. Calculate his initial velocity.**

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

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

$a = 2.5$ m s^{-2}
$v = 100$ m s^{-1}
$s = 1\ 875$ m
$u = ?$

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

- **Elizabeth is swimming slowly with uniform velocity across Kirkcaldy's Olympic-size swimming pool. She continues in the same direction, but accelerates at 1.5 m s^{-2} in a straight line for 6 m, to 4.5 m s^{-1}. Calculate Elizabeth's original velocity.**

- **When running in a straight line to catch the school bus home, David accelerates at 0.25 m s^{-2} from rest to 5 m s^{-1}. Calculate the displacement of David from his starting point.**

For the following 3 problems, you will have to decide on the most appropriate equation of motion to use:

- **While roller blading, Greg accelerates from rest to 8 m s^{-1}, travelling 15 m in a straight line. Calculate the value of Greg's acceleration.**

- **On a downhill ski slope, Shaun is moving with uniform velocity. He then accelerates at 3 m s^{-2} in a straight line for a time of 3 s, achieving 20 m s^{-1}. Calculate the value of Shaun's initial velocity.**

- **Mark's radio-controlled model car is travelling at 1.5 m s^{-1} along a track. It then accelerates at 2.5 m s^{-2} in its original direction for a time of 6 s. Calculate the displacement of the model car while it is accelerating.**

Decelerating Objects and Equations of Motion

When an object **decelerates**, its **acceleration decreases**. If the vector quantities in the **equations of motion** are **positive**, we represent the **decreasing acceleration** 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 m s^{-2} from 25 m s^{-1} for 3 s. Calculate the car's velocity after the 3 s.

$a = -2$ m s^{-2}	$v = u + at$
$u = 25$ m s^{-1}	$v = 25 + (-2 \times 3)$
$t = 3$ s	$v = 25 + (-6)$
$v = ?$	$v =$ 19 m s^{-1} (in direction of original velocity)

● A marble leaves Adam's hand at 1.75 m s^{-1} and then immediately decelerates uniformly at 0.5 m s^{-2} in a straight line for 2.5 s. Calculate the velocity of the marble after the 2.5 s.

● Suzie's sledge decelerates uniformly in a straight line from 7.5 m s^{-1} to rest in 2.5 s. Calculate the sledge's deceleration.

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

A greyhound is running at 6 m s^{-1}. It decelerates uniformly in a straight line at 0.5 m s^{-2} for 3 s. Calculate the **displacement** of the greyhound while it was decelerating.

$u = 6$ m s^{-1}	$s = ut + 1/2at^2$
$a = -0.5$ m s^{-2}	$s = (6 \times 3) + (0.5 \times -0.5 \times 3^2)$
$t = 3$ s	$s = 18 + (-2.25)$
$s = ?$	$s =$ 15.75 m (in direction of original velocity)

● Stephen's fishing rod pulls a fish towards him through the water in a straight line. Initially, the fish is travelling at 3 m s^{-1} but decelerates uniformly at 0.25 m s^{-2} for 4 s. Calculate the displacement of the fish over the 4 s.

● Karen's cat decelerates uniformly in a straight line from 2.75 m s^{-1} when it approaches a wall. The cat travels 6.9 m in 3 s while decelerating. Calculate its deceleration.

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

A curling stone leaves a player's hand at 5 m s^{-1} and decelerates uniformly at 0.75 m s^{-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.

$u = 5$ m s^{-1}

$a = -0.75$ m s^{-2}

$s = 16.5$ m

$v = ?$

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

$v^2 = 5^2 + (2 \times -0.75 \times 16.5)$

$v^2 = 25 + (-24.75)$

$v^2 = 0.25$

$v = \sqrt{0.25} = \underline{0.5 \text{ m s}^{-1}}$ (in direction of original velocity)

- **Mr. Cunningham's ferret decelerates uniformly at 0.2 m s^{-2} in a straight line from 1.5 m s^{-1}. It travels 5 m while doing so. Calculate the ferret's velocity at the end of its deceleration.**

- **Mr. Hood's race horse decelerates uniformly in a straight line at 4.5 m s^{-2} after winning a race. It comes to a halt after 25 m. Calculate the horse's velocity at the instant before it began to decelerate.**

For the following 3 problems, you will have to decide on the most appropriate equation of motion to use:

- **A nuclear submarine decelerates uniformly in a straight line from a velocity of 30 m s^{-1}, travelling 1 000 m in 50 s. Calculate the deceleration of the submarine over this distance.**

- **What time will it take a jet fighter aircraft to decelerate uniformly in a straight line at 60 m s^{-2} from a velocity of 340 m s^{-1} to 100 m s^{-1}?**

- **A tank, travelling at 12.5 m s^{-1}, comes to a halt when its driver applies the brakes, causing it to decelerate uniformly at 1.25 m s^{-2} in a straight line. What is the "stopping distance" of the tank?**

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 m s^{-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 m s^{-2}** for the **acceleration** of any object moving **freely** through the air.

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

(a) Dropped Objects

- At the instant an object is dropped, it is stationary - It is not moving downwards, so **initial downward velocity** (**u**) = **0 m s^{-1}**.
- The object will **accelerate** towards the ground under the influence of **gravity**. **a = -9.8 m s^{-2}**.

Example

A helicopter is hovering at a constant height. A wheel falls off and hits the ground below 4 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.

$u = 0$ m s^{-1}
$t = 4$ s
$a = -9.8$ m s^{-2}
$v = ?$
$s = ?$

(a) $v = u + at$

$v = 0 + (-9.8 \times 4)$

$v = 0 - 39.2$

$v = -39.2$ m s^{-1}

(i.e., 39.2 m s^{-1} downwards)

(b) $s = ut + 1/2at^2$

$s = (0 \times 4) + (0.5 \times -9.8 \times 4^2)$

$s = 0 + (-78.4)$

$s = -78.4$ m

(i.e., wheel falls 78.4 m downwards, so height = 78.4 m)

OR

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

$-39.2^2 = 0^2 + (2 \times -9.8 \times s)$

$1536.6 = 0 + (-19.6\ s)$

$1536.6 = -19.6\ s$

$s = 1536.6/-19.6 = -78.4$ m

(i.e., wheel falls 78.4 m downwards, so height = 78.4 m)

- **Adam drops his apple. It takes 0.5 s to hit the ground. Calculate:**

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

(b) the height Adam drops the apple from.

(b) 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 m s^{-2}**. **$a = -9.8$ m s^{-2}**.
- As a result, the **upward velocity** of the object will eventually become **0 m s^{-1}**. This happens at its **maximum height**. **$v = 0$ m s^{-1} at maximum height**.

Example

A firework rocket is launched vertically upwards from the ground at 49 m s^{-1}.

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

(b) Calculate:

(i) the time taken for the rocket to reach its maximum height;

(ii) the maximum height.

$u = 49$ m s^{-1}

$a = -9.8$ m s^{-2}

$t = ?$

$s = ?$

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

(b)(i) $v = u + at$

$0 = 49 + (-9.8 \times t)$

$0 = 49 - 9.8\,t$

$9.8\,t = 49$

$t = 49/9.8 = \underline{5\text{ s}}$.

(ii) $s = ut + 1/2at^2$

$s = (49 \times 5) + (0.5 \times -9.8 \times 5^2)$

$s = 245 + (-122.5)$

$s = \underline{122.5\text{ m}}$

(i.e., 122.5 m upwards, so height = 122.5 m)

OR

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

$0^2 = 49^2 + (2 \times -9.8 \times s)$

$0 = 2401 + (-19.6\,s)$

$19.6\,s = 2401$

$s = 2401/19.6 = \underline{122.5\text{ m}}$

(i.e., 122.5 m upwards, so height = 122.5 m)

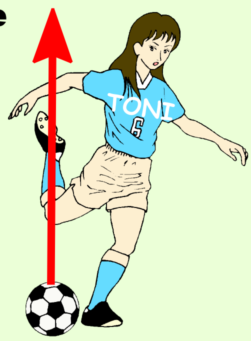
- **Toni chips a football straight up in the air. The ball leaves her foot at 8 m s^{-1}.**

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

(b) Calculate:

(i) the time taken for the ball to reach its maximum height;

(ii) the maximum height it reaches.



5) PROJECTILES

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 affect.
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.

(a) Horizontal Projectiles

A **horizontal projectile** (like a ball rolling off a table) travels both **horizontally** and **vertically** at the same time.

The table below shows the **horizontal** and **vertical** displacements of a **horizontal projectile** with time:

time/ s	horizontal displacement/ m	vertical displacement/ m
0	0	0
0.5	2.5	-1.2
1.0	5.0	-4.9
1.5	7.5	-11.0
2.0	10.0	-19.6
2.5	12.5	-30.6

The **-** sign indicates **downward displacement**.

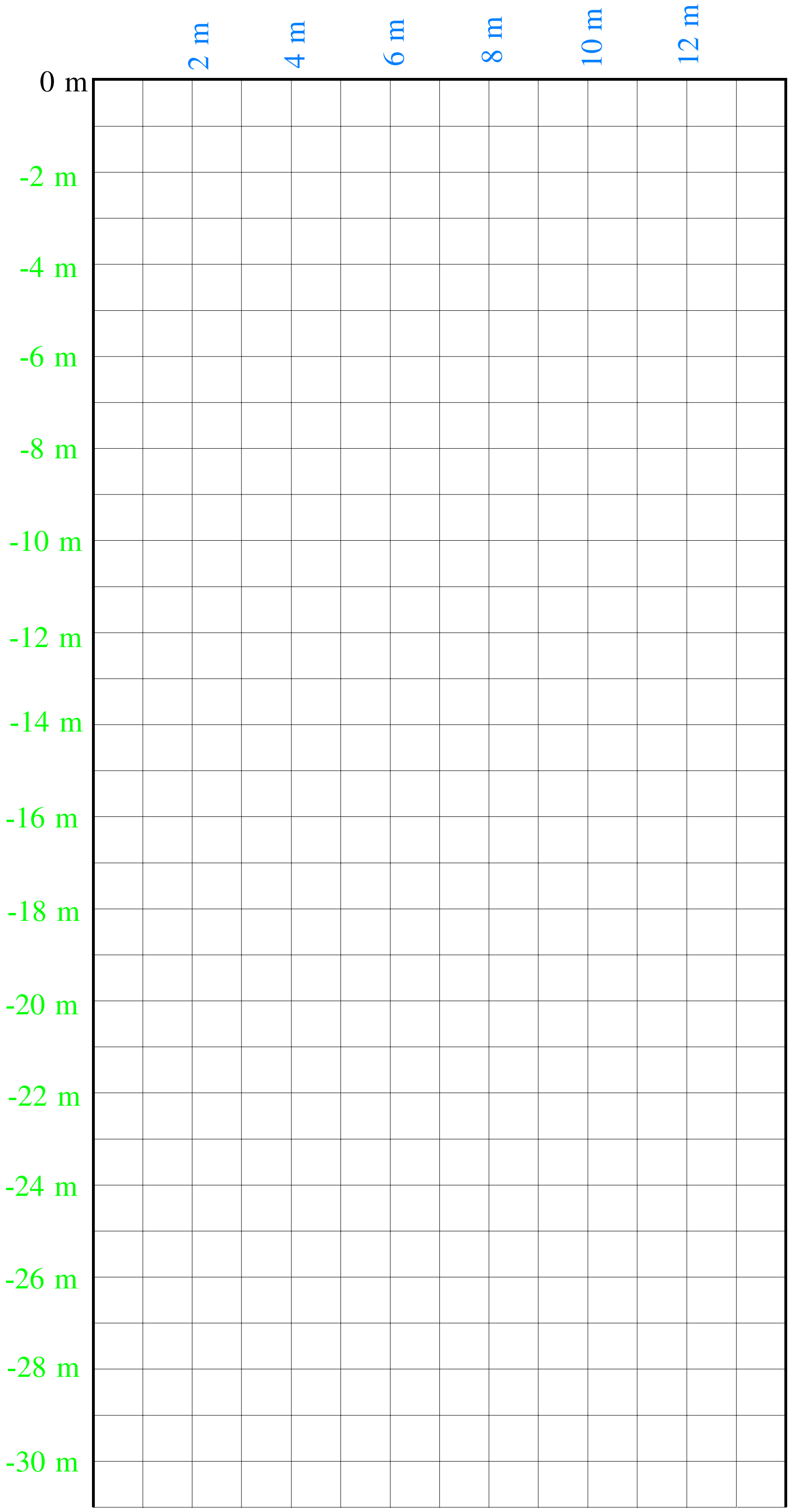
- **On the grid, use a *dot* to plot the position of the horizontal projectile as time passes.**

- **What can you say about the horizontal motion of the projectile?**

____
____
____

- **What can you say about the vertical motion of the projectile?**

____
____
____
____

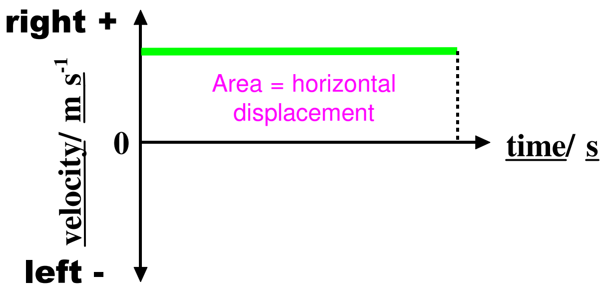


When dealing with **projectile motion** for an object projected **horizontally**, we treat the motion as independent **horizontal** and **vertical** components:

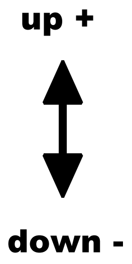
Horizontal motion

- **Always uniform (constant) velocity equal to the horizontal projection velocity**, i.e., if a projectile is fired **horizontally** at 5 m s^{-1} to the right, its **horizontal component of velocity** will remain at 5 m s^{-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:

horizontal displacement (s_h) = horizontal velocity (v_h) × time (t)

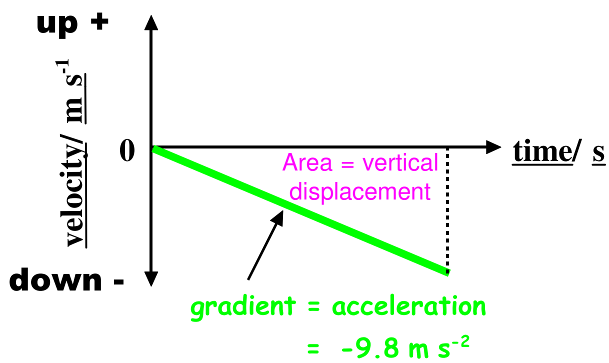


Vertical motion



- At the instant the projectile is launched **horizontally**, it is not moving downwards, so **initial downward velocity** (**u**) = **0 m s^{-1}**.
- The projectile **accelerates** towards the ground under the influence of **gravity**. Using the sign convention shown on the left, **a = -9.8 m s^{-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:

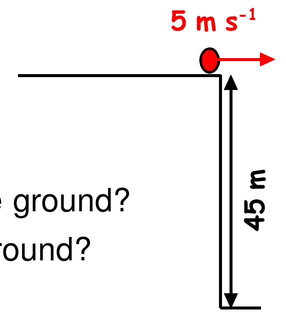
$$v = u + at, \quad s = ut + 1/2at^2, \quad v^2 = u^2 + 2as$$



- **As time passes, what happens to a projectile's horizontal component of velocity?** ______________________
- **Show this by sketching a velocity-time graph for the horizontal motion:**
- **What is the only equation you can apply to a projectile's horizontal motion?**

- **As time passes, what happens to a projectile's vertical component of velocity?** ______________________
- **Show this by sketching a velocity-time graph for the vertical motion:**
- **What equations can you apply to a projectile's vertical motion?**

Example



A projectile is fired **horizontally** from the top of a 45 m high wall at 5 m s^{-1}.

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

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

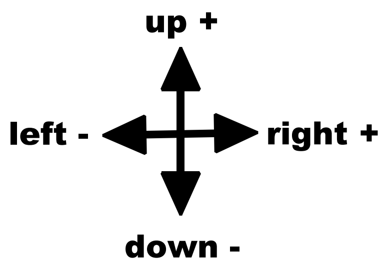
(c) What is the projectile's **horizontal component of velocity** just before hitting the ground?

(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 m s^{-1}, a = -9.8 m s^{-2}

$$s = ut + 1/2at^2$$
$$-45 = (0 \times t) + (0.5 \times -9.8 \times t^2)$$
$$-45 = 0 + (-4.9t^2)$$
$$-45 = -4.9t^2$$
$$t^2 = -45/-4.9 = 9.2$$
$$t = /9.2 = \underline{3\ s}$$



(b) For horizontal motion, v_h = 5 m s^{-1}, t = 3 s

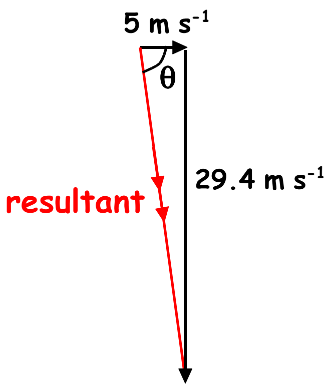
$$s_h = v_h \times t$$
$$= 5 \times 3$$
$$= \underline{15\ m\ right}$$

(c) Horizontal component of velocity remains constant, so v_h = <u>5 m s^{-1} right</u>

(d) For vertical motion, u = 0 m s^{-1}, a = -9.8 m s^{-2}, t = 3 s

$$v = u + at$$
$$= 0 + (-9.8 \times 3)$$
$$= 0 - 29.4$$
$$= \underline{-29.4\ ms^{-1}}\ (\text{i.e., } \underline{29.4\ m\ s^{-1}\ downwards})$$

(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:



$$resultant^2 = 5^2 + 29.4^2$$
$$= 25 + 864.4$$
$$= 889.4$$

so, resultant = /889.4

$$= \underline{29.8\ m\ s^{-1}}$$

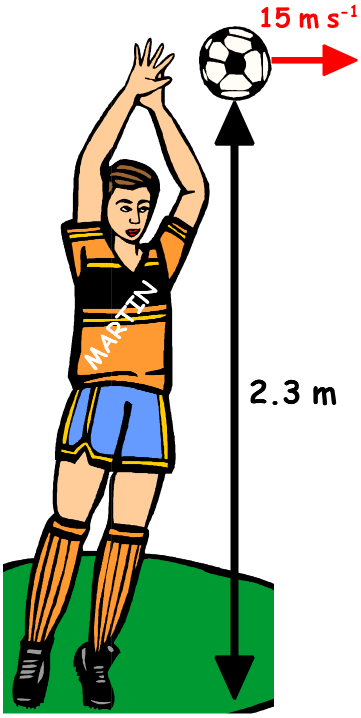
$$\tan\theta = \frac{O}{A} = \frac{29.4}{5} = 5.88$$

so, $\theta = \tan^{-1} 5.88$

$$= \underline{80.3^\circ}$$

Resultant velocity of projectile just before hitting ground is <u>29.8 m s^{-1} at 80.3° below the horizontal</u>.

- **During a football match, Ross takes a throw-in. The ball leaves his hands (which are 2.3 m above the ground) at 15 m s^{-1} in a horizontal direction. The ball hits the ground before it is played by a team mate.**



(a) From the instant Ross releases the ball, what time will it take to hit the ground?

(b) How far away from Ross will the ball be when it hits the ground?

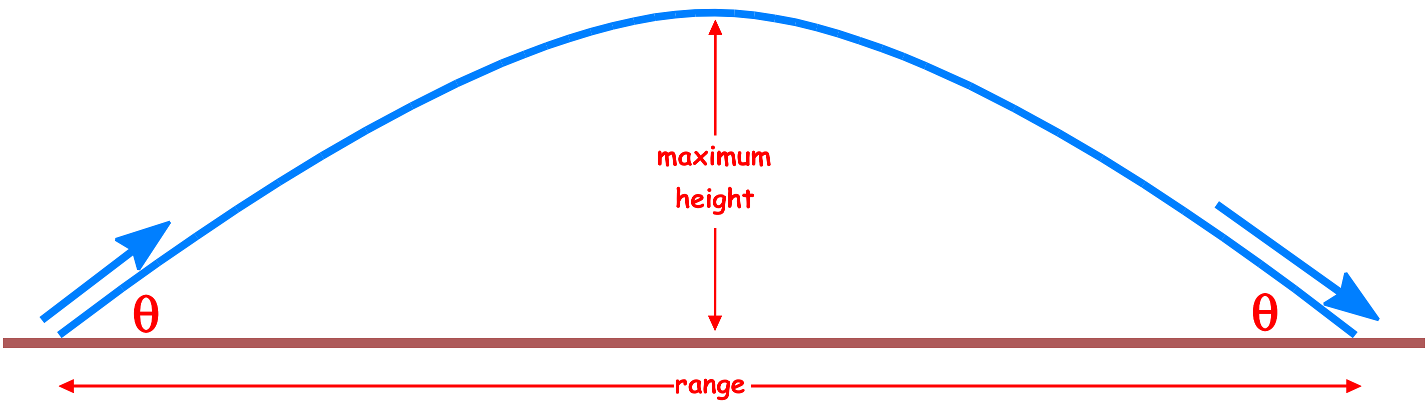
(c) What will be the ball's horizontal component of velocity just before it hits the ground?

(d) What will be the ball's vertical component of velocity just before it hits the ground?

(e) What will be the ball's resultant velocity just before it hits the ground? (You should include a sketch of a vector triangle.)

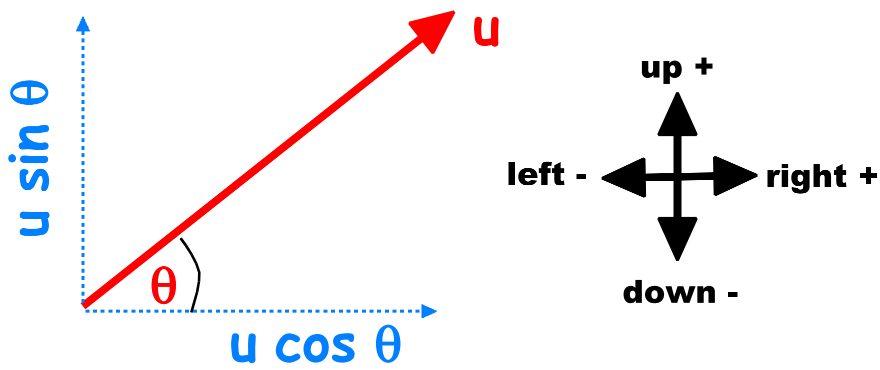
(b) Projectiles Fired at an Angle to the Ground

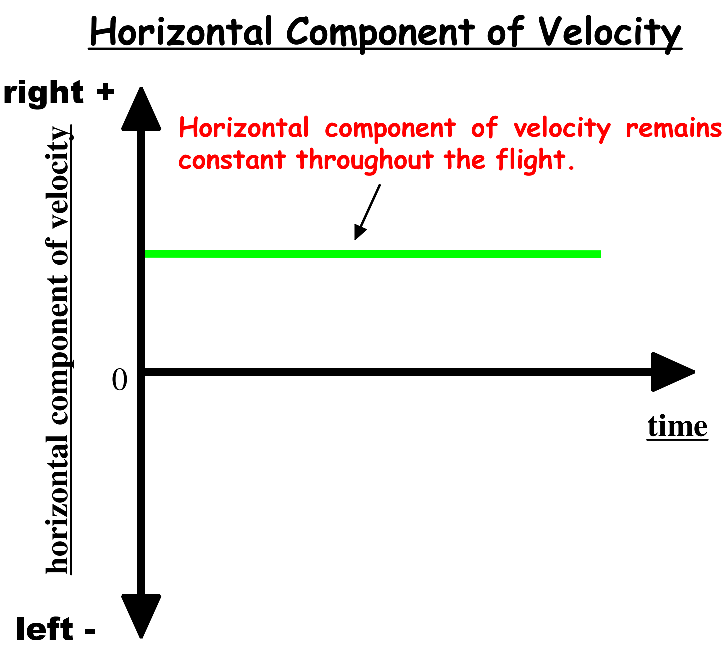
Any object projected into the air (other than vertically upwards) will have a **symmetrical** **parabolic trajectory**, like that shown below. **Air resistance** is **neglected**.

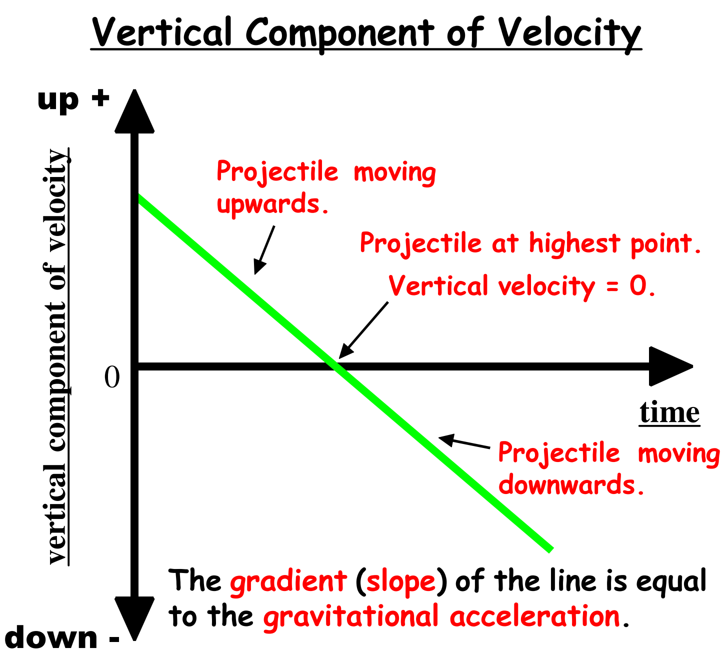


1) The **horizontal distance travelled** by the projectile is known as its **range**.
2) The projectile reaches its **maximum height** when it has travelled a **horizontal distance** equal to **half its range**.
3) The **time** taken for the projectile to reach its **maximum height** is therefore **half 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.

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







Example

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

(a) the greatest **height** the shell reaches;

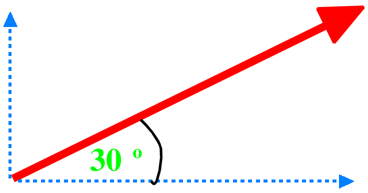
(b) the **time** taken to reach that height;

(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 m s^{-1}.

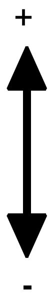


500 m s^{-1}

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

gravitational acceleration = -9.8 m s^{-2}

(a)



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 = **3 189 m** (to nearest metre).

(b) $v = u + at$

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

$0 = 250 - 9.8\,t$

$9.8\,t = 250$

t = 250/9.8 = **25.5 s**

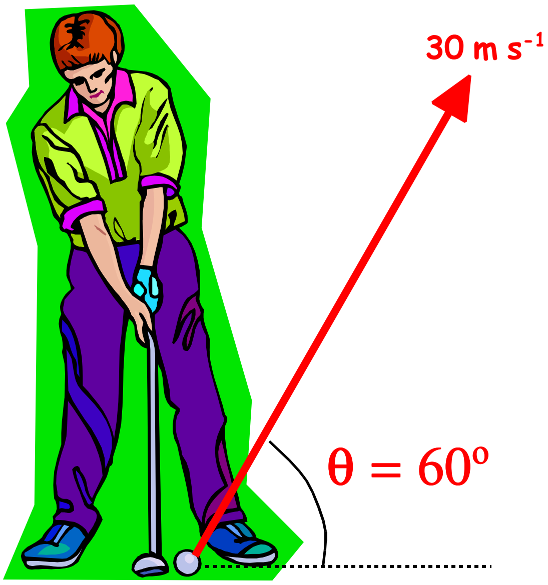
(c) Total time shell is in air = 2 x 25.5 s = **51 s**

(d) $s_h = v_h t$

$= 433 \times 51$

= **22 083 m right**

● **David hits a golf ball off horizontal ground. The ball leaves David's club with a velocity of 30 m s^{-1} at 60° above the horizontal.**



(a) Resolve the launch velocity into its horizontal and vertical components.

(b) Calculate the greatest height the golf ball will reach.

(c) Calculate the time the golf ball will take to reach this maximum height.

(d) Calculate the total time the golf ball will take to return to the ground.

(e) Calculate the horizontal distance the golf ball will travel while it is in the air.

HIGHER PHYSICS

UNIT 1 - MECHANICS and PROPERTIES OF MATTER

DYNAMICS

1) UNBALANCED FORCE and MOTION

You must be able to:

- Define the unit of force - the newton (N).
- Use a free body diagram to analyse the forces acting on an object.
- Find the resultant of several forces using a free body diagram.
- Resolve the weight of an object on a slope into components parallel and perpendicular (at 90°) to the slope.
- Solve force and acceleration problems using Newton's first law of motion and second law of motion ($F_{un} = ma$) - to include rockets, lifts, objects on slopes and objects linked together, e.g. train and carriages.
- Resolve a vector into components at right-angles (90°) to each other.

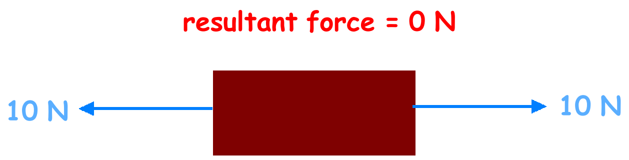
1) NEWTON'S FIRST LAW OF MOTION

Balanced and Unbalanced Forces

Balanced Forces

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

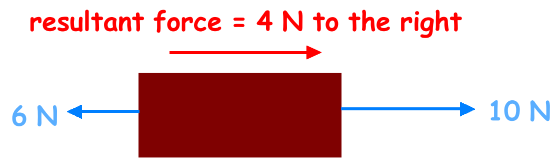
The forces are **balanced**.



Unbalanced Forces

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

The forces are **unbalanced**.



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.)

2) NEWTON'S SECOND LAW OF MOTION

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.

$$a \propto F_{un} \quad \text{and} \quad a \propto \frac{1}{m}$$

Defining the Newton

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

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

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 m s^{-2}.

3) 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. Only show the **forces acting on that single object** - ignore the forces acting on the other parts of the system. Use only these forces to determine the **unbalanced force** acting on the object. 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 3×10^6 kg is launched from the earth's surface when its engine produces an upward thrust of 3×10^7 N. Calculate the rocket's acceleration at launch.

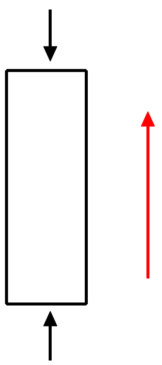
Free body diagram

(Represent the rocket by a box.)

weight = mg

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

$= (2.94 \times 10^7)\ \text{N}$



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

thrust = (3×10^7) 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)

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

Example 2

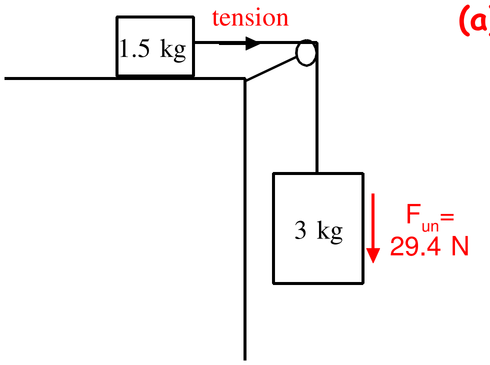
2 wooden blocks are tied together by piece of weightless string. One block (of mass 1.5 kg) sits on a horizontal table. There is no force of friction between the block and table. The other block (of mass 3 kg) is passed over a frictionless pulley. This block falls to the floor, dragging the 1.5 kg block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

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

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

tension = $m_{1.5kg}$ x a

= 1.5 kg x 6.5 m s^{-2}

= $\underline{9.8\ N}$

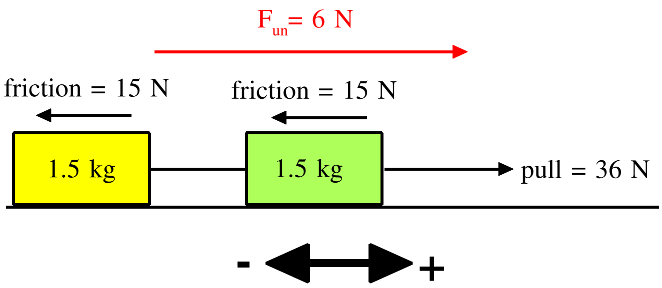
Example 3

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

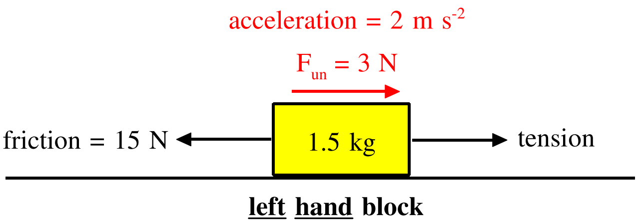
= 36 N - 30 N

= 6 N (to the right)

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

(b) **Free body diagram**

(Represent the <u>left</u> <u>hand</u> <u>block</u> by a box.)



Unbalanced force acting on left block (F_{un}) = $m_{1.5\ kg}$ a

= 1.5 kg x 2 m s^{-2}

= 3 N (to the right)

F_{un} = tension - friction

3 N = tension - 15 N

tension = 3 N - (-15) N

= 3 N + 15 N

= $\underline{18\ N}$

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

Example 4

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

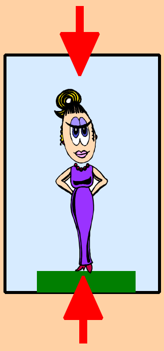
Two forces act:

- 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 Elizabeth to accelerate downwards at 9.8 m s^{-2}.

Free body diagram

w = mg

= 60 x 9.8

= 588 N

Both Elizabeth and the scales accelerate downwards at the same rate

⇨ There is no reaction force upwards

⇨ R = 0 N

2) Lift stationary

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

Free body diagram

w = mg

= 60 x 9.8

= 588 N

Lift is stationary

⇨ balanced forces

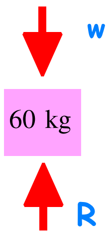
⇨ R = w

⇨ 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



w = mg

= 60 x 9.8

= 588 N

Constant velocity

⇨ balanced forces

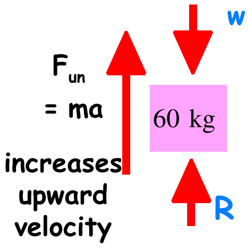
⇨ R = w

⇨ R = 588 N

4) Lift accelerating upwards

Calculate the reading on the scales (R) if the lift is accelerating upwards at 1.5 m s^{-2}.

Free body diagram



w = mg

= 60 x 9.8

= 588 N

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

ma = R - w

60 x 1.5 = R - 588

90 = R - 588

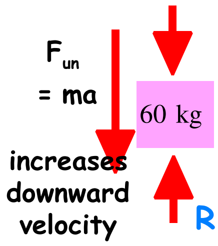
R = 90 + 588

R = 678 N

5) Lift accelerating downwards

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

Free body diagram



w = mg

= 60 x 9.8

= 588 N

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

ma = w - R

60 x 1.5 = 588 - R

90 = 588 - R

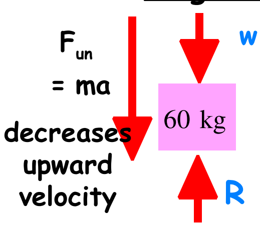
R = 588 - 90

R = 498 N

6) Lift decelerating upwards

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

Free body diagram



w = mg

= 60 x 9.8

= 588 N

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

ma = w - R

60 x 1.5 = 588 - R

90 = 588 - R

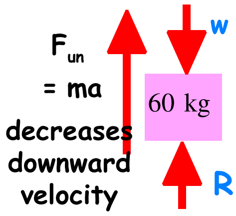
R = 588 - 90

R = 498 N

7) Lift decelerating downwards

Calculate the reading on the scales (R) if the lift is decelerating downwards at 1.5 m s^{-2}.

Free body diagram



w = mg

= 60 x 9.8

= 588 N

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

ma = R - w

60 x 1.5 = R - 588

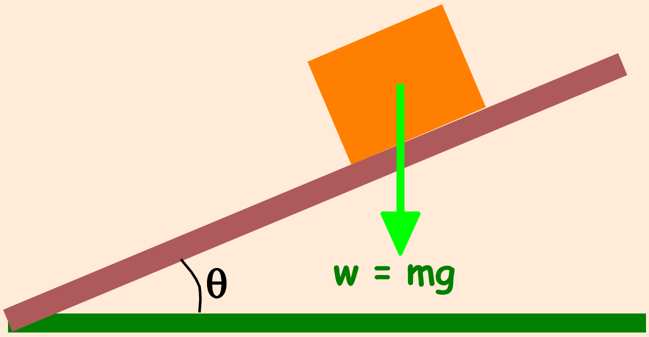
90 = R - 588

R = 90 + 588

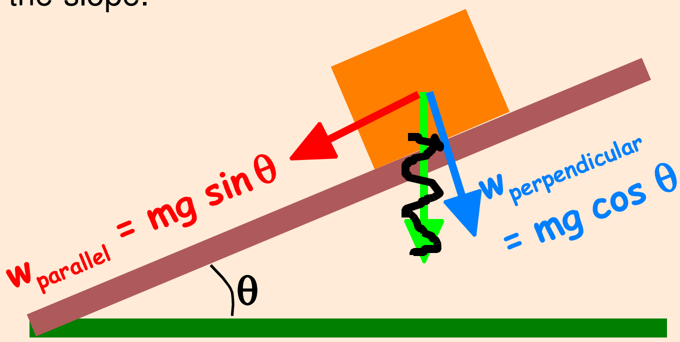
R = 678 N

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.



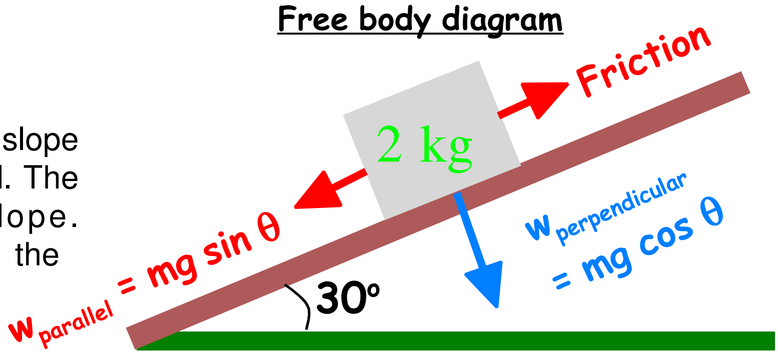
The **weight** of the object can be resolved into **right-angle components** acting **down** (**parallel to**) the slope and **perpendicular to** the slope.



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) $w_{parallel} = mg \sin\theta$

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

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

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

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

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

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

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

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

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

REVISION OF "STANDARD GRADE" FORMULAE

For each of these "Standard Grade" formulae, state what each symbol represents and give the correct unit:

Energy	Potential energy	Kinetic energy	Work done
$E = Pt$	$E_p = mgh$	$E_k = 1/2mv^2$	$W = Fs$

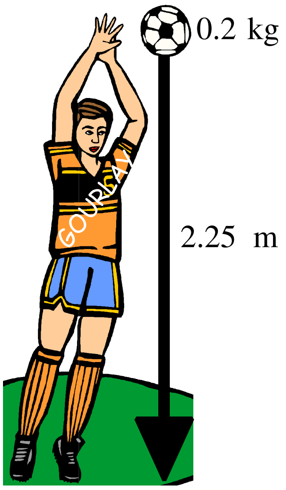
● LAW OF "CONSERVATION OF ENERGY"

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.

E_p lost = E_k gained

$mgh = 1/2mv^2$

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

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

$22.1 = 0.5\ v^2$

$v^2 = 22.1/0.5 = 44.2$

$v = \sqrt{44.2} = \underline{6.6\ m\ s^{-1}}$

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

Suzie's blazer (including pens, pencils, sweets, mobile phone and prefect badge) has a mass of 0.75 kg. Suzie accidentally drops the blazer from the top of the school stairs. It falls 8 m to the ground floor below.

(a) Calculate the velocity of Suzie's blazer at the instant before it hits the floor.

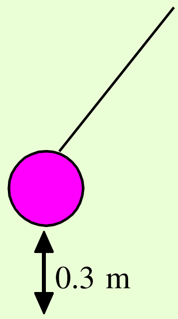
(AIR RESISTANCE CAN BE IGNORED).

(b) If Suzie had eaten the sweets stored in the blazer's inside pocket before she dropped it, explain whether it would have hit the floor with the same velocity.

Shaun releases a pendulum bob of mass 0.25 kg from 0.3 m above its lowest point.

(a) Use "conservation of energy" to calculate the velocity of the pendulum bob as it travels through its lowest point. (AIR RESISTANCE CAN BE IGNORED).

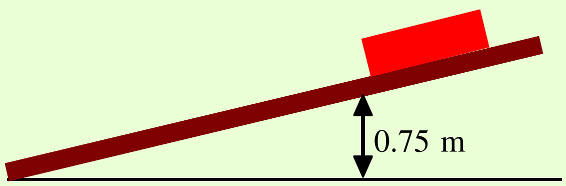
(b) How would this velocity be affected if Shaun repeated the procedure with a pendulum bob of half the mass?



Mark releases a trolley of mass 0.25 kg from a height of 0.75 m on a friction free slope.

(a) Use a "conservation of energy" method to calculate the velocity the trolley will have at the foot of the slope.

(b) Explain whether increasing the mass of the trolley will have any affect on the trolley's velocity at the foot of the slope.



UNIT 1 - MECHANICS and PROPERTIES OF MATTER

DYNAMICS

2) MOMENTUM and IMPULSE

You must be able to:

- Define momentum as the product of mass and velocity.
- State the law of conservation of linear momentum.
- Distinguish between elastic and inelastic collisions.
- Solve problems involving the law of conservation of linear momentum.
- State that impulse = force x time.
- State that impulse = change in momentum.
- Solve problems involving impulse.
- For a collision in a straight line, use the law of conservation of linear momentum to show that:
  (a) the changes in momentum for each object are equal in size and opposite in direction;
  (b) the forces acting on each object during the collision are equal in size and opposite in direction.

1) MOMENTUM

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

momentum = mass x velocity

DIRECTION IS VITAL !

- ⟷ +

Example

Calculate the momentum of a 70 kg ice skater when she is:
(a) moving to the right at 5 m s^{-1}; (b) moving to the left at 6 m s^{-1}.

(a) momentum = mv
= 70 kg x 5 m s^{-1}
= 350 kg m s^{-1}

i.e., 350 kg m s^{-1} to the right

(b) momentum = mv
= 70 kg x -6 m s^{-1}
= -420 kg m s^{-1}

i.e., 420 kg m s^{-1} to the left

● **Calculate the momentum of a 7 500 kg truck when it is:**
(a) moving to the right at 2 m s^{-1}; (b) moving to the left at 5 m s^{-1}.

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 which 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**.

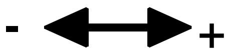
I. Elastic Collisions (1)

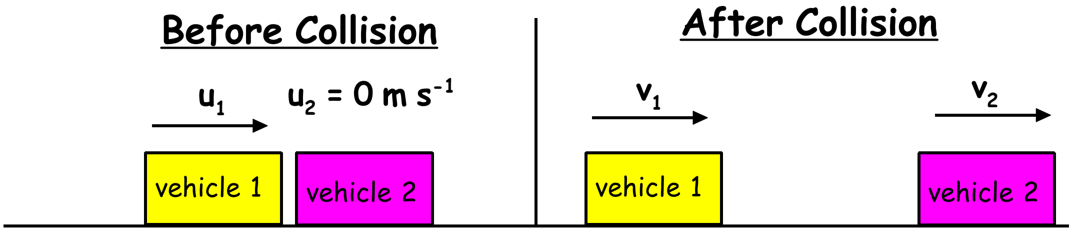
In an **elastic collision**:

- 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.)

Elastic Collisions Experiment 1 (First vehicle continues to travel in same direction):

DIRECTION IS VITAL !





m_1 (mass of vehicle 1) = _____ kg

m_2 (mass of vehicle 2) = _____ kg

u_1 (velocity of vehicle 1 just before collision) = _____ m s^{-1}

u_2 (velocity of vehicle 2 just before collision) = _____ m s^{-1}

v_1 (velocity of vehicle 1 just after collision) = _____ m s^{-1}

v_2 (velocity of vehicle 2 just after collision) = _____ m s^{-1}

Total momentum just **before** collision	Total momentum just **after** collision
$= m_1u_1 + m_2u_2$	$= m_1v_1 + m_2v_2$

- **How does the total momentum just before the collision compare with the total momentum just after the collision?**______________________________

____

Total kinetic energy just **before** collision	Total kinetic energy just **after** collision
$= 1/2m_1u_1^2 + 1/2\ m_2u_2^2$	$= 1/2m_1v_1^2 + 1/2\ m_2v_2^2$

- **How does the total kinetic energy just before the collision compare with the total kinetic energy just after the collision?**______________________________

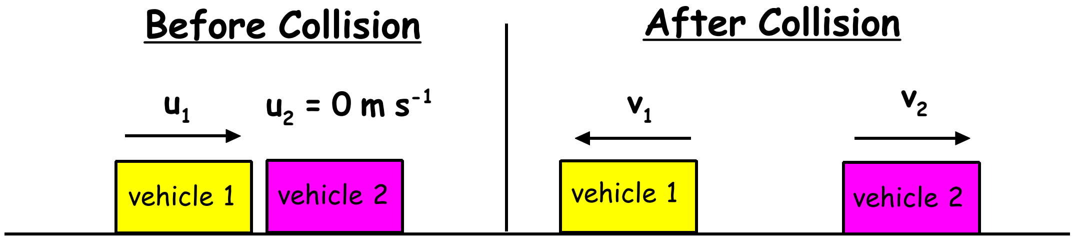
____

I. Elastic Collisions (2)

Elastic Collisions Experiment 2 (First vehicle rebounds in opposite direction):

DIRECTION IS VITAL !

- ⟷ +



m_1 (mass of vehicle 1) = _____ kg

m_2 (mass of vehicle 2) = _____ kg

u_1 (velocity of vehicle 1 just before collision) = _____ m s^{-1}

u_2 (velocity of vehicle 2 just before collision) = _____ m s^{-1}

v_1 (velocity of vehicle 1 just after collision) = _____ m s^{-1}

v_2 (velocity of vehicle 2 just after collision) = _____ m s^{-1}

Total momentum just **before** collision $= m_1u_1 + m_2u_2$	Total momentum just **after** collision $= m_1v_1 + m_2v_2$

- **How does the total momentum just before the collision compare with the total momentum just after the collision?**______________________________

____

Total kinetic energy just **before** collision $= 1/2m_1u_1^2 + 1/2\ m_2u_2^2$	Total kinetic energy just **after** collision $= 1/2m_1v_1^2 + 1/2\ m_2v_2^2$

- **How does the total kinetic energy just before the collision compare with the total kinetic energy just after the collision?**______________________________

____

- **What affect do external forces (e.g., friction and air resistance) have on the results of these experiments?**______________________________

____

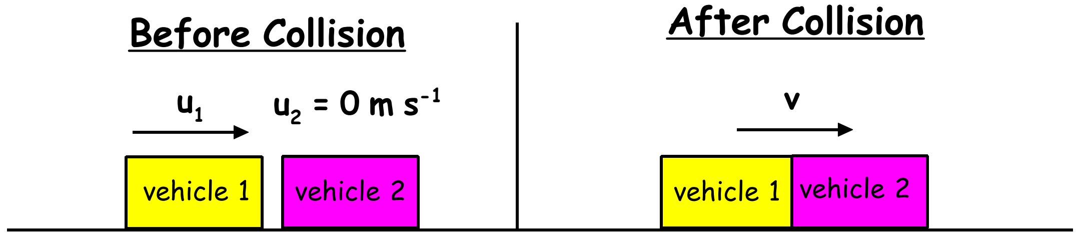
II. Inelastic Collisions

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.

Inelastic Collisions Experiment:

DIRECTION IS VITAL !



m_1 (mass of vehicle 1) = _____ kg

m_2 (mass of vehicle 2) = _____ kg

u_1 (velocity of vehicle 1 just before collision) = _____ m s^{-1}

u_2 (velocity of vehicle 2 just before collision) = _____ m s^{-1}

v (velocity of both joined together vehicles just after collision) = _____ m s^{-1}

Total momentum just **before** collision	Total momentum just **after** collision
$= m_1u_1 + m_2u_2$	$= (m_1 + m_2)\,v$

- **How does the total momentum just before the collision compare with the total momentum just after the collision?** ______________________________

____

Total kinetic energy just **before** collision	Total kinetic energy just **after** collision
$= 1/2m_1u_1^2 + 1/2\,m_2u_2^2$	$= 1/2(m_1 + m_2)\,v^2$

- **How does the total kinetic energy just before the collision compare with the total kinetic energy just after the collision?** ______________________________

____

III. Explosions

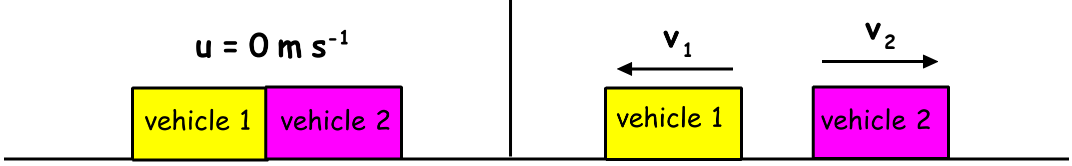
In an **explosion**:

- **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.

Explosion Experiment:

DIRECTION IS VITAL !

Before Explosion | **After Explosion**



m_1 (mass of vehicle 1) = _____ kg

m_2 (mass of vehicle 2) = _____ kg

u (velocity of both joined vehicles just before explosion) = _____ m s^{-1}

v_1 (velocity of vehicle 1 just after explosion) = _____ m s^{-1}

v_2 (velocity of vehicle 2 just after explosion) = _____ m s^{-1}

Total momentum just **before** explosion	Total momentum just **after** explosion
$= (m_1 + m_2)\,u$	$= m_1v_1 + m_2v_2$

- **How does the total momentum just before the explosion compare with the total momentum just after the explosion?**______________________________________

____

Total kinetic energy just **before** explosion	Total kinetic energy just **after** explosion
$= 1/2(m_1 + m_2)\,u^2$	$= 1/2m_1v_1^2 + 1/2m_2v_2^2$

- **How does the total kinetic energy just before the explosion compare with the total kinetic energy just after the explosion?**______________________________________

____

Example Momentum Problem

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

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

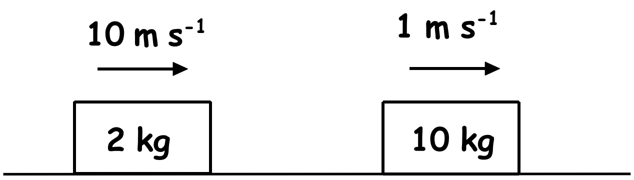
(a) Calculate the **velocity** of the **10 kg** trolley immediately **after** the collision.

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

DIRECTION IS VITAL !

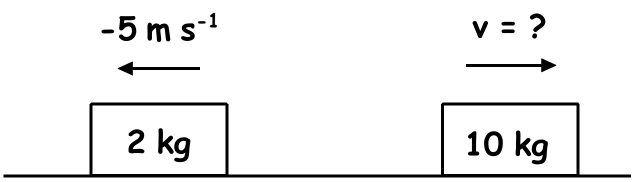
- ↔ +

Before Collision



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

After Collision



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

Total momentum just before collision = Total momentum just after collision

30 = (-10 + 10v)

10 v = 30 - (-10)

10v = 40

v = 40/10 = 4 m s^{-1} (ie., 4 m s^{-1} to the right)

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

Total kinetic energy = (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.

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 ! - ↔ +

2) 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: Ns. 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 N s

Example 2

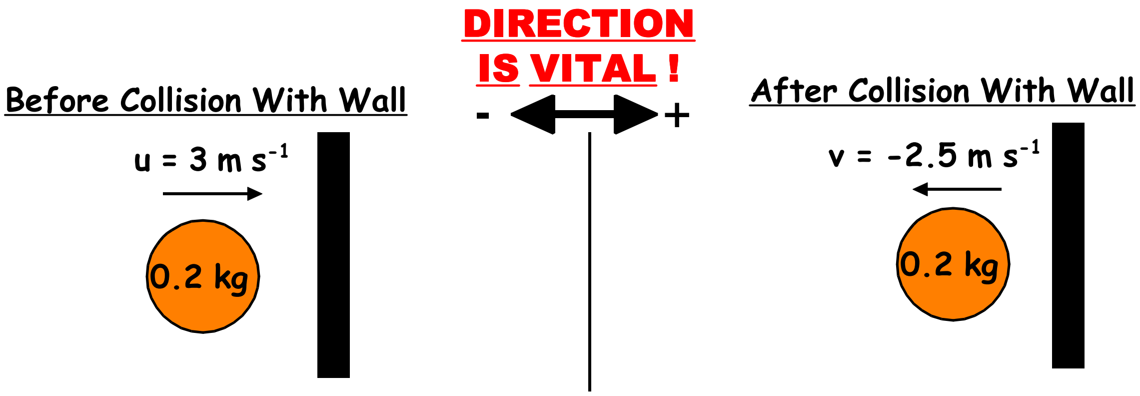
A ball of mass 0.2 kg is thrown against a brick wall. The ball is travelling horizontally to the right at 3 ms^{-1} when it strikes the wall. It rebounds horizontally to the left at 2.5 ms^{-1}.

(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?

(a)



Change in velocity = v - u

= (-2.5) - 3

= -5.5 m s^{-1} (i.e., 5.5 m s^{-1} to the left)

(b) Change in momentum = m(v - u)

= 0.2 x [(-2.5) - 3]

= 0.2 x -5.5

= -1.1 kg m s^{-1} (i.e., 1.1 kg m s^{-1} to the left)

(c) Impulse = change in momentum

= -1.1 N s (i.e., 1.1 N s to the left)

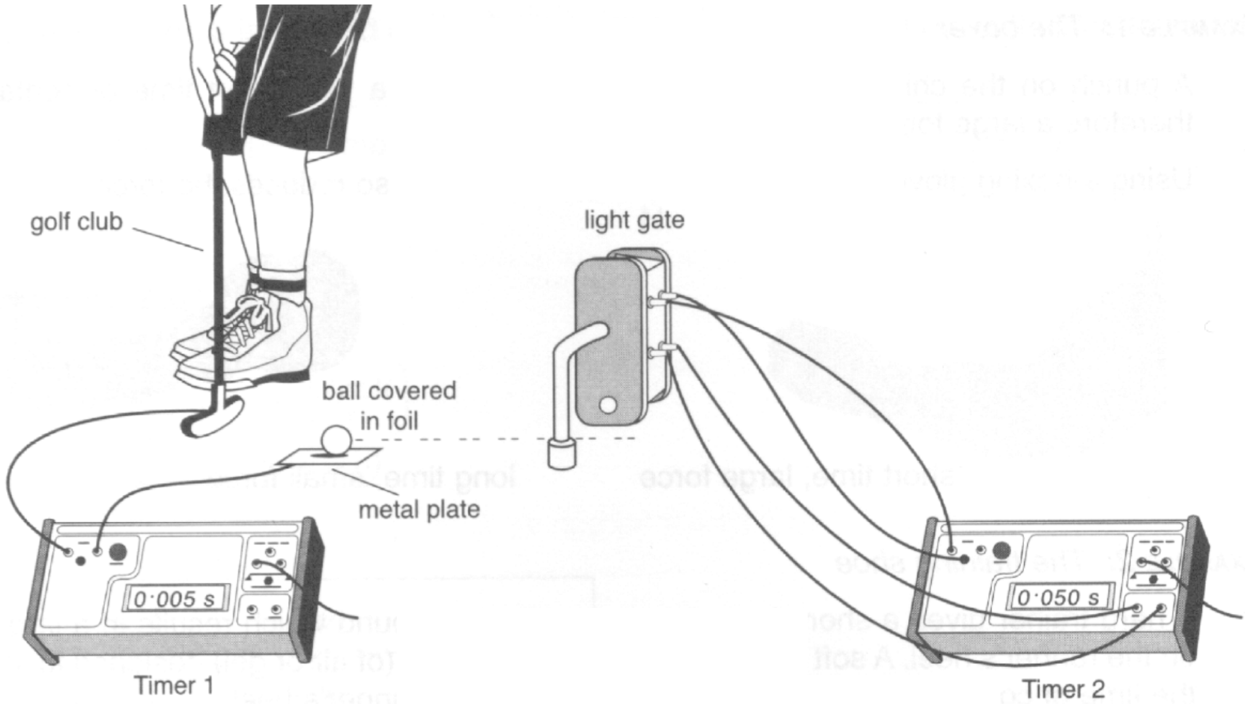
Example 3

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 m s^{-1}. The club and ball were in contact for 0.002 seconds.

Calculate the **average force** which the club exerted on the ball.

$$Ft = m(v - u)$$
$$F \times 0.002 = 0.1 \times (50 - 0)$$
$$0.002\,F = 5$$
$$F = 5/0.002 = \underline{2\,500\ N}$$

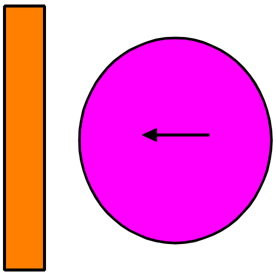
Experiment to determine the average force a golf club exerts on a golf ball



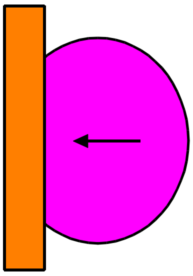
The Average Force Exerted During An Impact

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 which acts during an impact changes during the impact - so we are only able to determine an average value for the force.

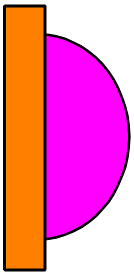
For example, imagine a ball striking a wall. The force the wall exerts on the ball is zero before the impact, rises to a maximum as the ball strikes the wall and is deformed (squashed), then decreases to zero as the ball rebounds from the wall, regaining its shape.



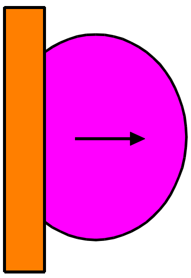
I. Ball moves towards wall. Force wall exerts on ball is zero.



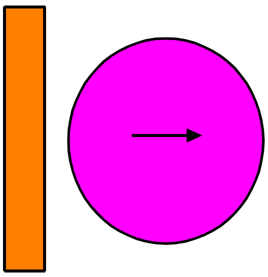
II. Ball strikes wall. Wall exerts force on ball, deforming ball. The deforming force increases, so ball deforms (squashes) more.



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.



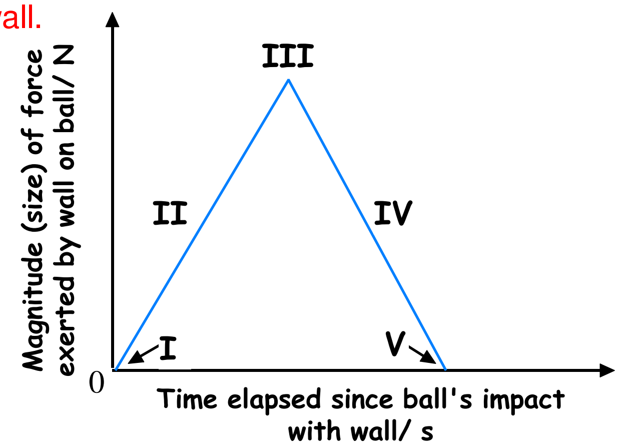
V. Ball has completely rebounded from wall. Force exerted by wall on ball is zero.

This can be represented on a force-time graph.

The area under the force-time graph represents:

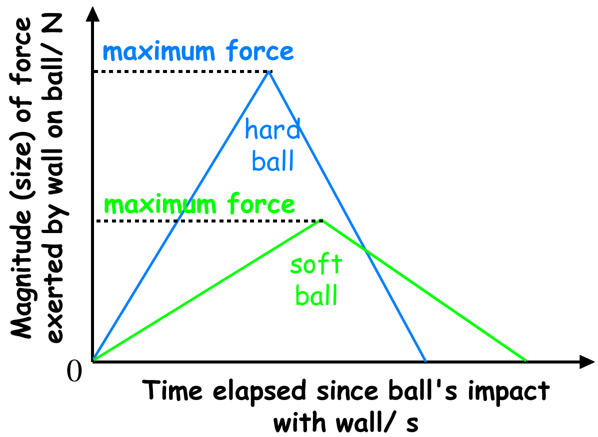
(a) The **impulse** of the force exerted by the wall on the ball during its time of contact.

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

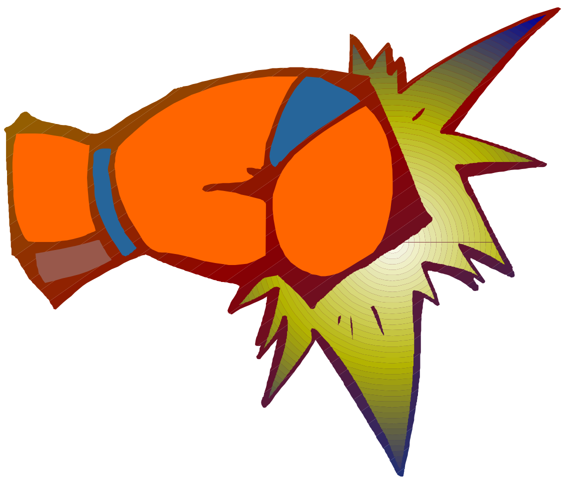


If the ball is **hard** (**rigid**), like a golf ball, the **time of contact** between the ball and wall will be **small** and the **maximum force** exerted by the wall on the ball will be **large** (see graph below).

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**.

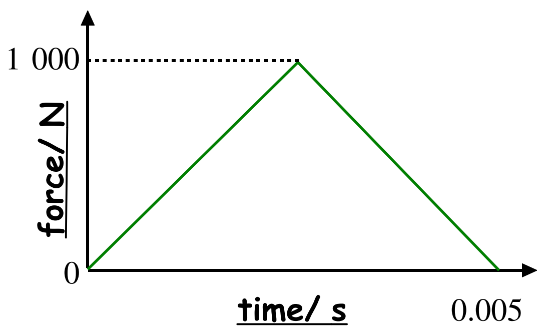
Example

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

3) MOMENTUM and NEWTON'S THIRD LAW

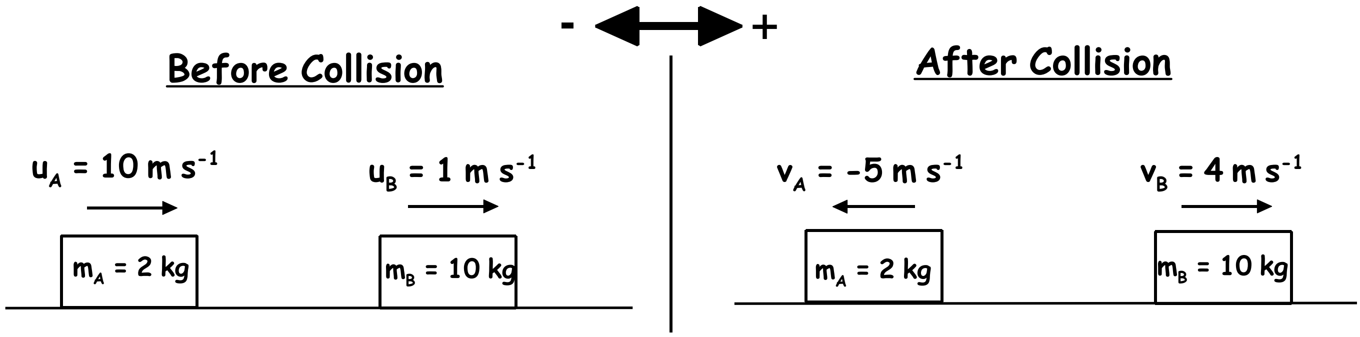
● **NEWTON'S THIRD LAW**

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."

For example:

DIRECTION IS VITAL !



Change in momentum of **A** = $m_A\ (v_A - u_A)$ = ______________ = ____ $kg\ m\ s^{-1}$

Change in momentum of **B** = $m_B\ (v_B - u_B)$ = ______________ = ____ $kg\ m\ s^{-1}$

● **The change in momentum of A is _________ in magnitude (size) but ___________ in direction to the change in momentum of B.**

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

Force acting on **A** = $m_A a = \dfrac{m_A\ (v_A - u_A)}{t}$ = ______ = ____ N

Force acting on **B** = $m_B a = \dfrac{m_B\ (v_B - u_B)}{t}$ = ______ = ____ N

● **The forces acting on A and B are __________ in magnitude (size) but ____________ in direction.**

HIGHER PHYSICS

UNIT 1 - MECHANICS and PROPERTIES OF MATTER

PROPERTIES OF MATTER

1) DENSITY, PRESSURE and UPTHRUST

You must be able to:

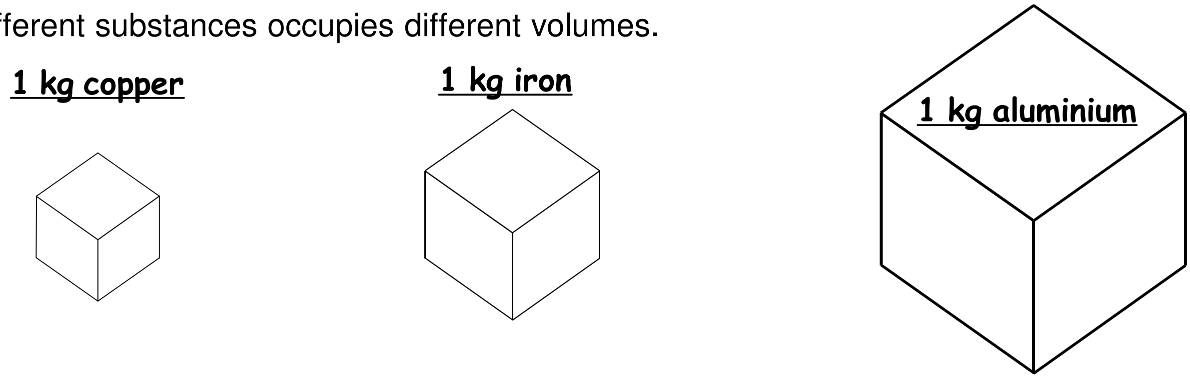
- State that density is mass per unit volume.
- Solve problems involving density, mass and volume.
- Describe an experiment to measure the density of air.
- State that when a substance changes from its solid or liquid state to its gaseous state, its volume increases by 1 000 and its density decreases by 1 000.
- Describe an experiment to show the above point.
- State that pressure is the force per unit area and has the unit newton per square metre ($N\ m^{-2}$) or pascal (Pa). $1\ N\ m^{-2} = 1\ Pa$.
- Solve problems involving pressure, force and area.
- State that the pressure at a point in a liquid is given by the formula $P = \rho g h$.
- Solve problems involving pressure, density and depth.
- Explain buoyancy force (upthrust) in terms of the pressure difference between the top and bottom surfaces of a submerged object.

1) PARTICLE SPACING - density, mass and volume

Every substance is made up of tiny, invisible particles - atoms and molecules.

(a) Density

1 kg of different substances occupies different volumes.



The **density** of a substance is defined as its **mass per unit volume**. It tells us how tightly-packed the particles in the substance are. **Unit: kg m^{-3}. (Scalar).**

$$\text{density (kg m}^{-3}) = \frac{\text{mass (kg)}}{\text{volume (m}^3)}$$

symbol "rho"

$$\rho = \frac{m}{v}$$

Example

Calculate the density of perspex.

(A 0.02 m^3 block of perspex has a mass of 23.8 kg.)

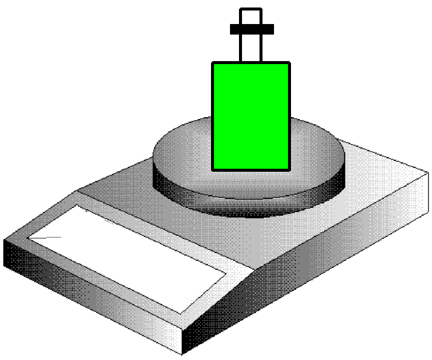
$$\text{density} = \frac{\text{mass}}{\text{volume}} = \frac{23.8 \text{ kg}}{0.02 \text{ m}^3} = \underline{1190 \text{ kg m}^{-3}}$$

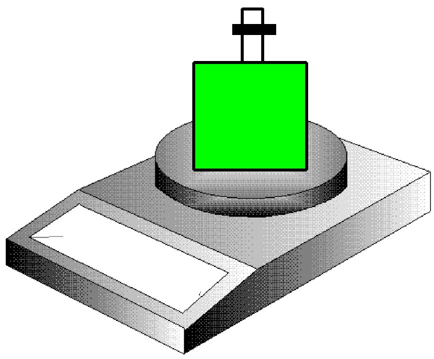
Experiment to determine the density of air (a gas)

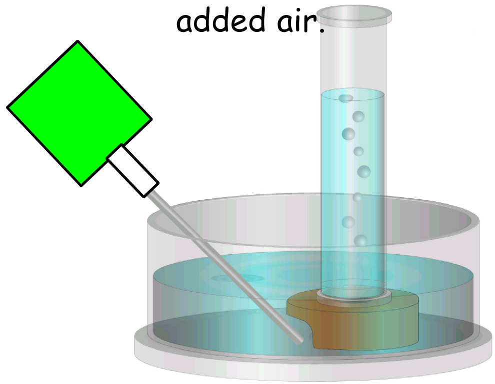
1) Find mass of sealed container full of air.

2) Pump extra air into container, seal it, then find new mass.

3) Bubble the extra air into a measuring cylinder full of water to find the volume of the extra added air.







Mass of sealed container containing air (m) = ______ kg.

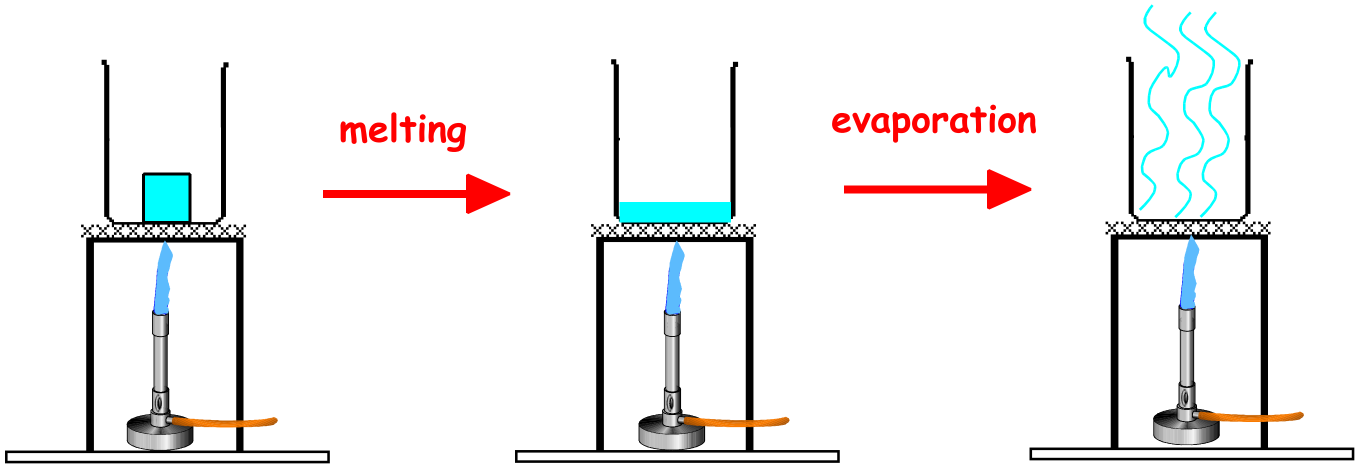
Mass of sealed container containing air + extra added air (M) = ______ kg.

Volume of extra added air= ______ cm^3 = ______________m^3.
(1 cm^3 = 0.000001 m^3)

$$\text{density of air} = \frac{\text{mass of extra added air (M-m)}}{\text{volume of extra added air}} = \frac{\_\_\_\_\_\_\_\_\_\_\_\_ \text{ kg}}{\text{m}^3} = \_\_\_\_\_\_ \text{ kg m}^{-3}.$$

- Data book value for density of air = ______ kg m^{-3}.

(b) Spacing of Particles in Solids, Liquids and Gases

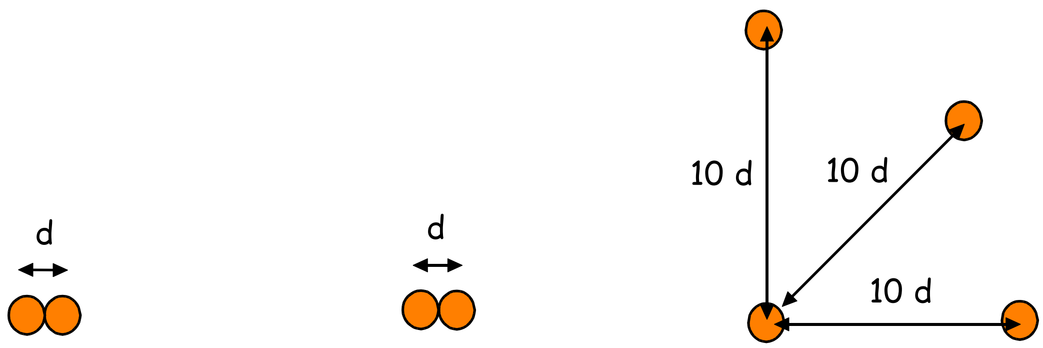


- When a **solid** substance changes to a **liquid**, the **volume** of the substance **stays the same**.

  When a substance is in its **solid** and **liquid** state, the particles must be spaced **the same distance apart** (so the **density** of a substance when **solid** must be **the same as** its **density** when **liquid**.)

- When a **liquid** substance changes to a **gas**, the **volume** of the substance **increases by 1 000**, (so the **density** of the **gaseous** substance is **1 000 times less** than the **density** of the **liquid** or **solid** substance.)

  When a substance is in its **gaseous** state, its particles must be spaced **10 times further apart in all directions** than they are when the substance is in its **solid** or **liquid** state.



particles in a solid

particles in a liquid

particles in a gas

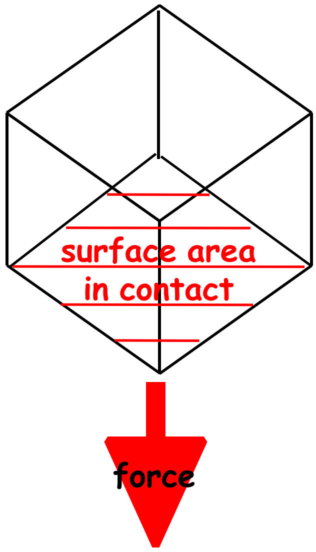
volume = 10 x 10 x 10 = 1 000

- **Use information from this page to complete the table:**

	SOLID	LIQUID	GAS
Spacing between particles	d		
Relative volume	1		
Relative density	1		

2) PRESSURE

(a) Pressure on Solid Surfaces

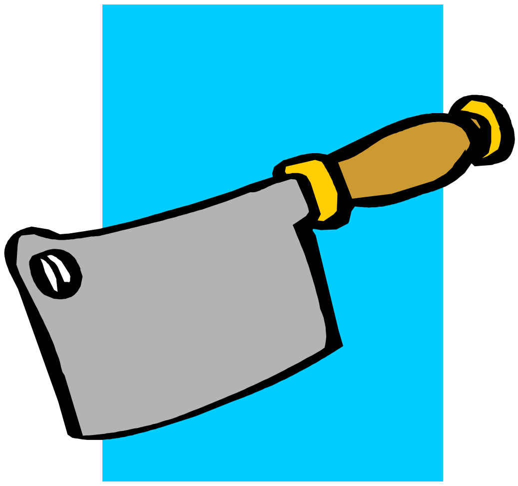


An object sitting on a flat, horizontal surface exerts a **downward force** on the surface due to the object's **weight**. This **downward force** is spread out over the entire **surface area** in contact.

Pressure is defined as **the force (at right-angles, 90°, to a surface) per unit area**. **Unit N m^{-2} or Pa (pascals). 1 N m^{-2} = 1 Pa. (Scalar).**

$$\text{Pressure (Pa)} = \frac{\text{Force (N)}}{\text{Area (m}^2\text{)}} \qquad P = \frac{F}{A}$$

Small surface area: High Pressure



A meat cleaver or knife has a small, sharp edge (small surface area) so that a high pressure is applied to meat being cut - This makes the cutting easy.

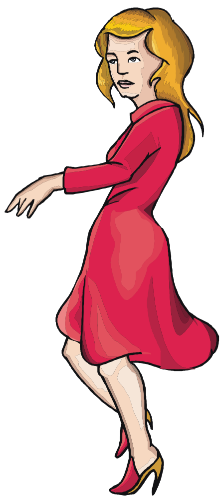
Large surface area: Low Pressure

Tractor tyres have a large surface area so that the weight (downward force) of the tractor acting on the soil exerts a low pressure on the soil - so the tractor does not sink.

Example

Virginia the vandal has a mass of 65 kg. Her favourite hobby is vandalising linoleum floors by applying all her weight on one heel of her stiletto shoe. The heel has an area of 1 cm^2.

Calculate the **pressure** Virginia exerts on a floor when she does this.



Force = weight = mg
= 65 kg x (9.8) N kg^{-1}
= 637 N down

Area = 1 cm^2 = 0.0001 m^2

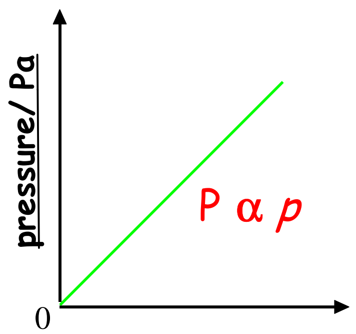
$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} = \frac{637\text{ N}}{0.0001\text{ m}^2} = \underline{6\ 370\ 000\text{ Pa}}$$

(b) Pressure at a Depth in Liquids

The **pressure** due to a **liquid** at any point **below** the surface of the liquid depends on:

- **the density of the liquid (ρ)**

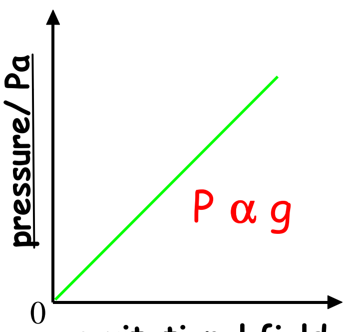
The **pressure** (**P**) at any point at a fixed depth in a liquid is directly proportional to the **density** (ρ) of the liquid - The higher the **density**, the higher the **pressure**.



density/ kgm^{-3}

- **the gravitational field strength (g)**

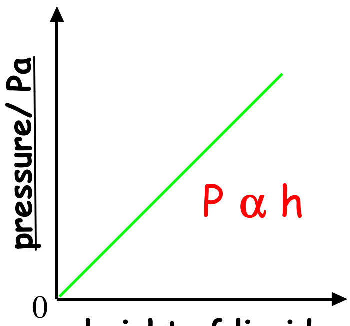
The **pressure** (**P**) at any point at a fixed depth in a liquid is directly proportional to the **gravitational field strength** (**g**) at the location - The higher the **gravitational field strength**, the higher the **pressure**.



gravitational field strength/ N kg^{-1}

- **the height of liquid above the point (h)**

The **pressure** (**P**) at any point in a liquid is directly proportional to the **height of liquid above the point** (**h**) - The greater the **height of liquid above the point**, the higher the **pressure**.



height of liquid above point/ m

Pressure at point in liquid due to liquid (Pa) = **density of liquid** (kg m^{-3}) × **gravitational field strength** (N kg^{-1}) × **height of liquid above point** (m)

$$P = \rho g h$$

This equation allows us to calculate the pressure at any point below the surface of a liquid due to the liquid alone.

To determine the actual pressure at this point, we must add on the pressure value at the water surface which is due to the atmosphere (so is called atmospheric pressure). Atmospheric pressure varies slightly over the earth's surface and changes due to weather conditions - The value used for Higher Physics calculations is 110 000 Pa = 1.1 x 10^5 Pa.

Example

(a) Calculate the pressure due to water (density = 1 000 kg m^{-3}) at a point 20 m below the water surface.

(a) $P = \rho g h$

$= 1\,000 \text{ kg m}^{-3} \times 9.8 \text{ N kg}^{-1} \times 20 \text{ m}$

$= \underline{196\,000 \text{ Pa}}$

(b) Calculate the actual pressure a diver would experience if she was at this point.

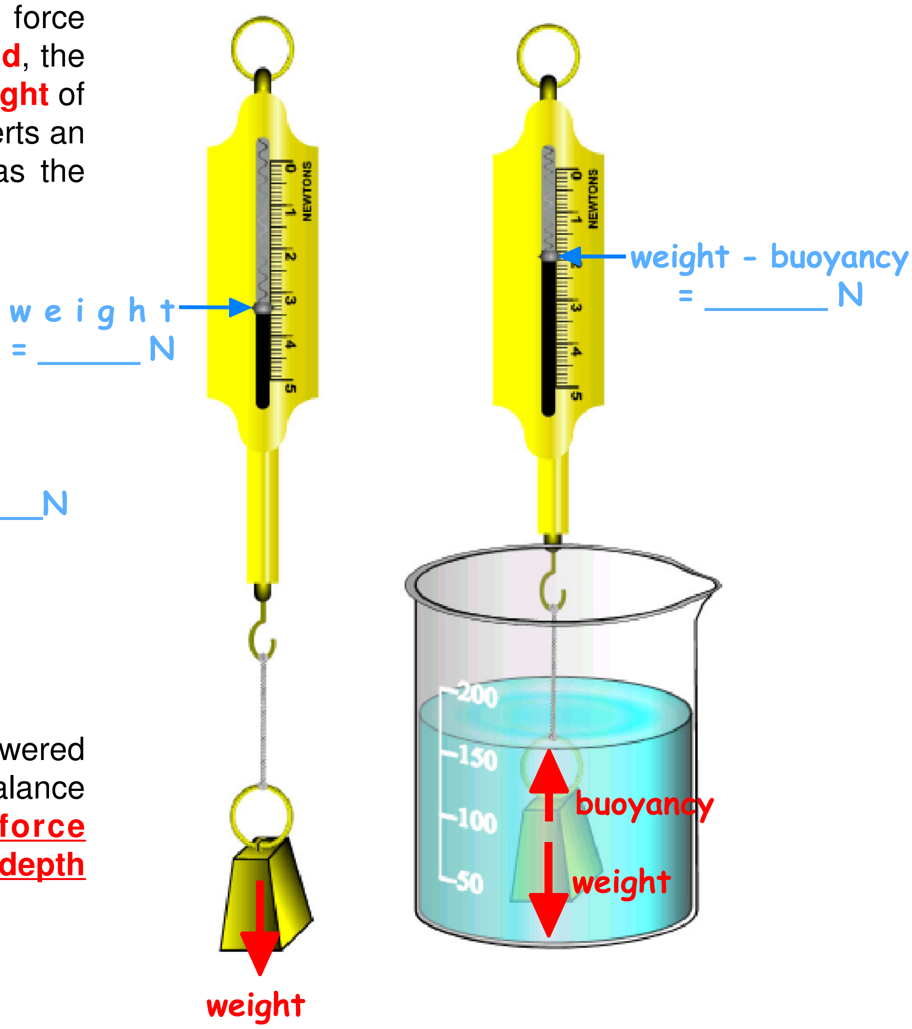
(b) Actual pressure = pressure due to water + atmospheric pressure

= 196 000 Pa + 110 000 Pa

= 306 000 Pa

3) BUOYANCY FORCE (UPTHRUST)

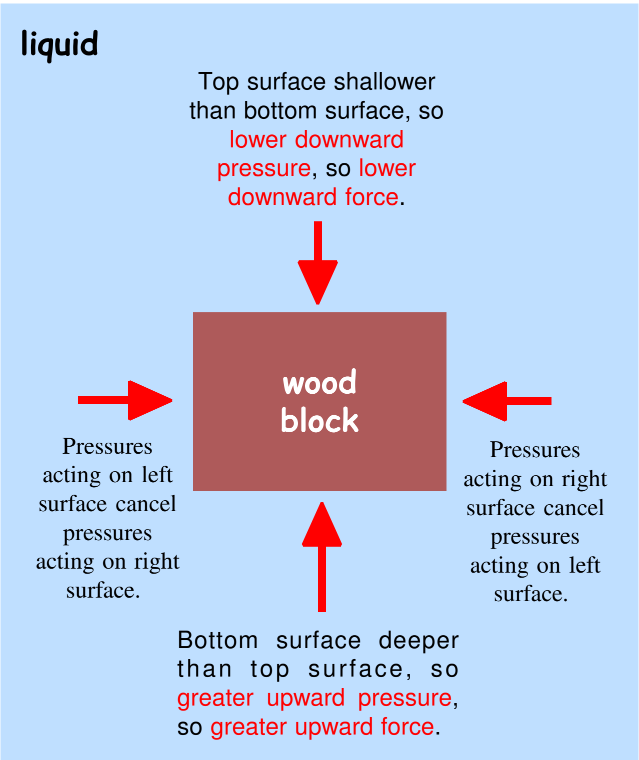
When an object hanging on a force (spring) balance is lowered into a **liquid**, the **force reading** on the balance (the **weight** of the object) **decreases** - The liquid exerts an **upward force** on the object known as the **buoyancy force** or **upthrust**.



Buoyancy (upthrust) = _____ N - _____N
= _____ N

No matter how deep the object is lowered into the liquid, the reading on the balance does not change - **Buoyancy force** (**upthrust**) **does not depend** on the **depth** of the object below the liquid surface.

Cause of Buoyancy Force (Upthrust)



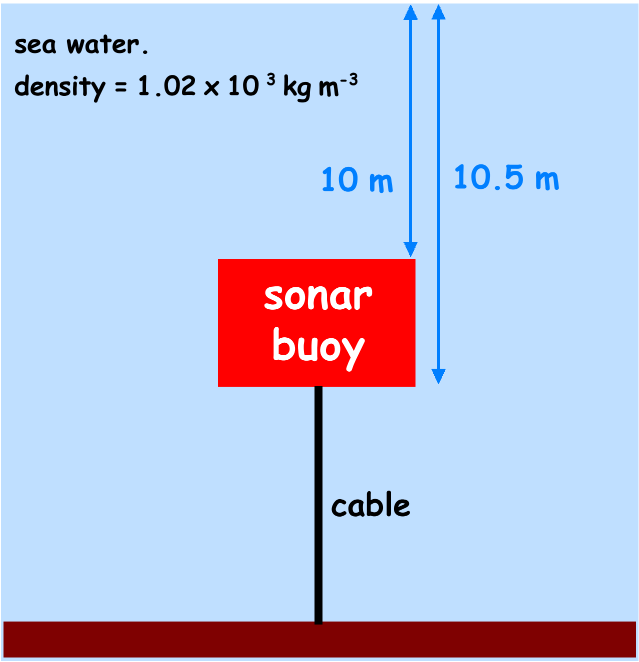
A wood block is submerged in a liquid.

- The pressures acting on the **left** and **right** surfaces of the block **cancel out**.
- **P = ρgh**

  The **bottom** surface of the block has a **greater height of liquid** above it than the **top** surface of the block - So the **pressure** acting on the **bottom** surface is **higher** than the **pressure** acting on the **top** surface.

- **F = PA**

  Because the **pressure** acting on the **bottom** surface is **higher** than the pressure acting on the **top** surface, the **force** acting on the **bottom** surface is **greater** than the **force** acting on the **top** surface - The wooden block experiences a **resultant upward force**: the **buoyancy force** (**upthrust**).



A sonar buoy is held under the sea by a cable connected to the sea bed. The top and bottom surfaces of the buoy both have an area of 1.5 m^2.

(a) Three forces act on the buoy: weight, buoyancy and tension in the cable. Show the direction of these forces on the diagram.

(b) What can you say about the pressures acting on the left and right surfaces of the buoy?________________________________

____

(c) Calculate the pressure acting on the top surface of the buoy due to the sea water alone.

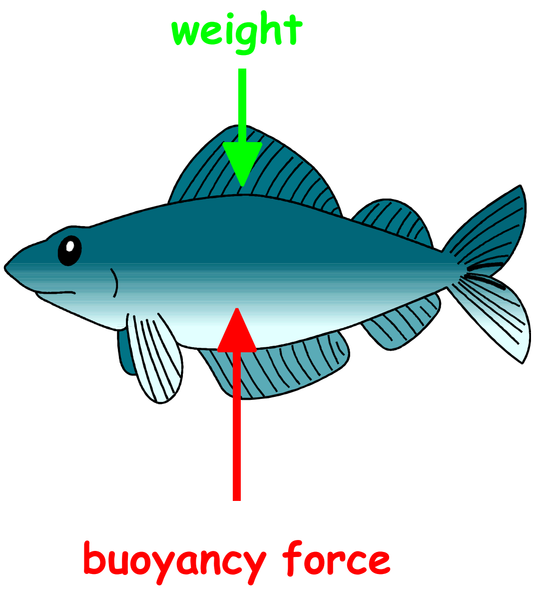
(d) Hence, calculate the force acting on the top surface of the buoy due to the sea water alone.

(e) Calculate the pressure acting on the bottom surface of the buoy due to the sea water alone.

(f) Hence, calculate the force acting on the bottom surface of the buoy due to the sea water alone.

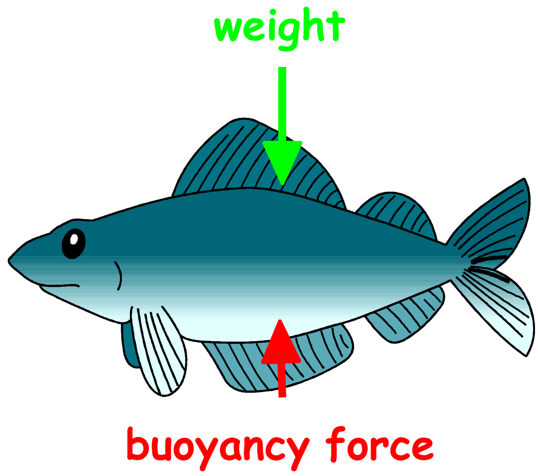
(g) Hence, calculate the magnitude (size) and direction of the buoyancy force acting on the buoy.

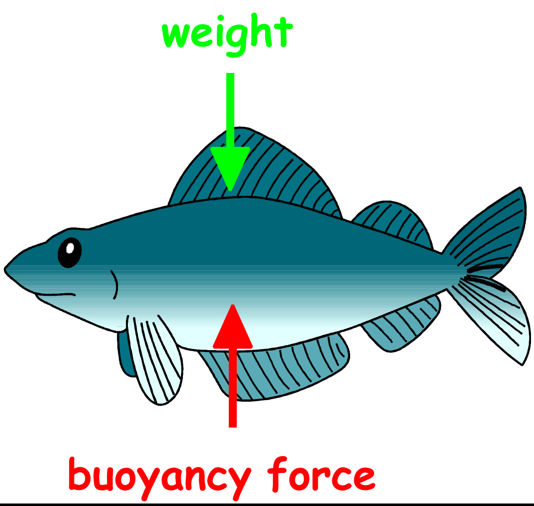
Buoyancy (Upthrust), Weight and Unbalanced Force



If **buoyancy force** is **greater than weight**, fish will **accelerate upwards**.

If **buoyancy force** is **less than weight**, fish will **accelerate downwards**.





If **buoyancy force** is **equal to weight**, fish will **remain stationary in the vertical direction** or **move at a uniform (constant) vertical velocity**.

- **"Jack the kipper" is swimming at a <u>constant</u> <u>depth</u> when he swallows a smaller fish. Describe and explain Jack's subsequent vertical motion immediately after he swallows the fish. (Assume the magnitude of the buoyancy force remains constant):**

____

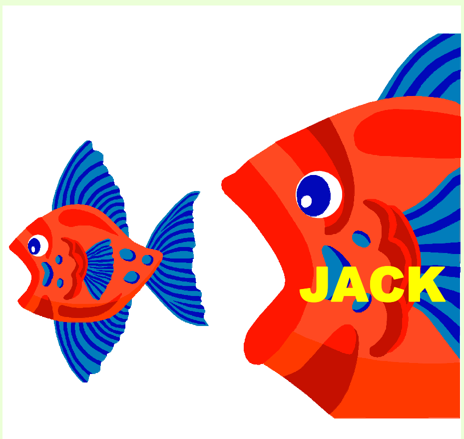
____

____

____

____

____



HIGHER PHYSICS

UNIT 1 - MECHANICS and PROPERTIES OF MATTER

PROPERTIES OF MATTER

2) KINETIC MODEL OF A GAS, GAS LAWS and KELVIN TEMPERATURE

You must be able to:

- Describe the kinetic model of a gas and how it accounts for the pressure of a gas.
- State that the pressure of a fixed mass of gas at constant temperature is inversely proportional to its volume.
- State that the pressure of a fixed mass of gas at constant volume is directly proportional to its kelvin temperature.
- State that the volume of a fixed mass of gas at constant pressure is directly proportional to its kelvin temperature.
- Describe experiments to verify the above relationships.
- Explain these relationships quantitatively in terms of the kinetic model of a gas.
- Explain what is meant by the absolute zero of temperature.
- Change temperatures in °C to kelvin (K) and vice versa.
- State the general gas equation and use it to solve problems.

1) KINETIC MODEL OF A GAS

KINETIC MODEL OF A GAS

Every gas is composed of very small particles which are spaced far apart and move randomly at high speed, colliding elastically with everything they meet.

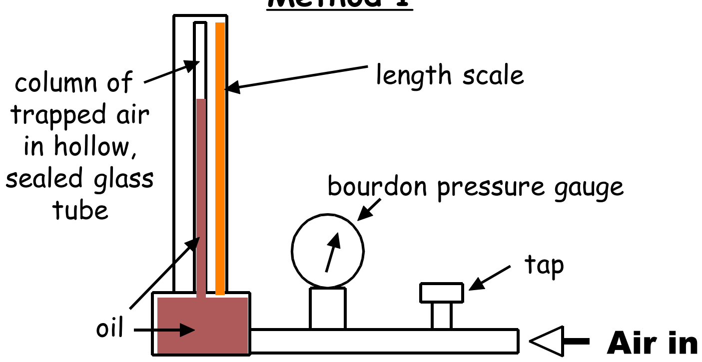
- **VOLUME** - A gas fills all its container.
- **TEMPERATURE** - The temperature of a gas depends on the kinetic energy of the gas particles. The greater the kinetic energy the higher the temperature.
- **PRESSURE** - Gas particles collide with the walls of their container, exerting a pressure on them. The more collisions there are, the higher the pressure. The harder the collisions, the higher the pressure.

2) THE GAS LAWS

(a) Pressure and Volume of a Fixed Mass of Gas at Constant Temperature (Boyle's Law)

In this experiment, the volume of a gas (air) is changed a number of times and its pressure at each volume is measured. **THE MASS AND TEMPERATURE OF THE GAS ARE "FIXED" (KEPT THE SAME).**

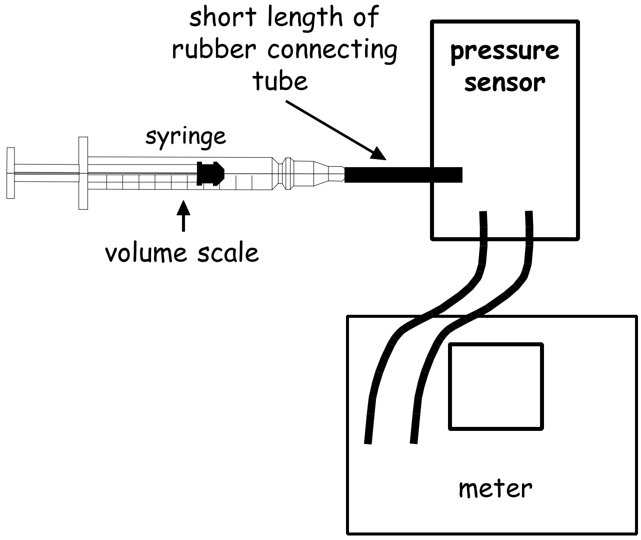
Method 1



- The tap is opened and air is pumped into the apparatus to push oil up the hollow, sealed glass tube. This compresses a column of trapped air at the top of the tube, increasing the pressure on it. The tap is closed.
- The tap is opened then closed several times, letting some air out of the apparatus - decreasing the pressure on and hence increasing the volume of the trapped air. Each time this happens, the temperature of the trapped air is allowed to stabilise for 1 minute, then the length of the column of trapped air is read from the length scale and the pressure of the trapped air is read from the bourdon pressure gauge.

The length of the column of trapped air is taken to represent its volume, since the length of trapped air is directly proportional to its volume in the tube which has a uniform cross-sectional area.

Method 2



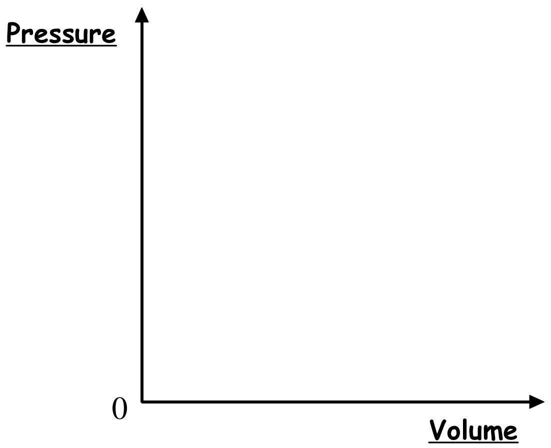
- The plunger of the syringe is pushed in and held in position several times. This compresses the trapped air in the syringe, increasing the pressure on it.
- Each time the plunger is pushed in and held, the temperature of the trapped air is allowed to stabilise for 1 minute, then the volume of trapped air is read from the volume scale on the syringe and the pressure of the trapped air is read from the meter connected to the pressure sensor.

My results:

Pressure/								
Volume/								
1/Volume/								
Pressure x Volume								

• Graph of Pressure versus Volume

A graph of **pressure** versus **volume** takes this form:

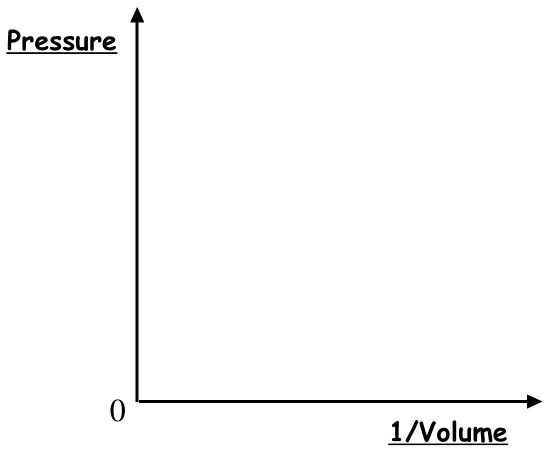


The downward __________ shows that **pressure (P) is inversely proportional to volume (V).**

$$P \propto \frac{1}{V}$$

• Graph of Pressure versus 1/Volume

A graph of **pressure** versus **1/volume** takes this form:



The ___________ line passing through the __________ shows that **pressure (P) is directly proportional to 1/volume (1/V).**

$$P \propto \frac{1}{V}$$

Pressure $\propto \frac{1}{\text{Volume}}$ so, Pressure = $\frac{\text{constant}}{\text{Volume}}$ so, Pressure x Volume = constant

*You can see this relationship from the last row of the table above.

PRESSURE - VOLUME LAW (BOYLE'S LAW)

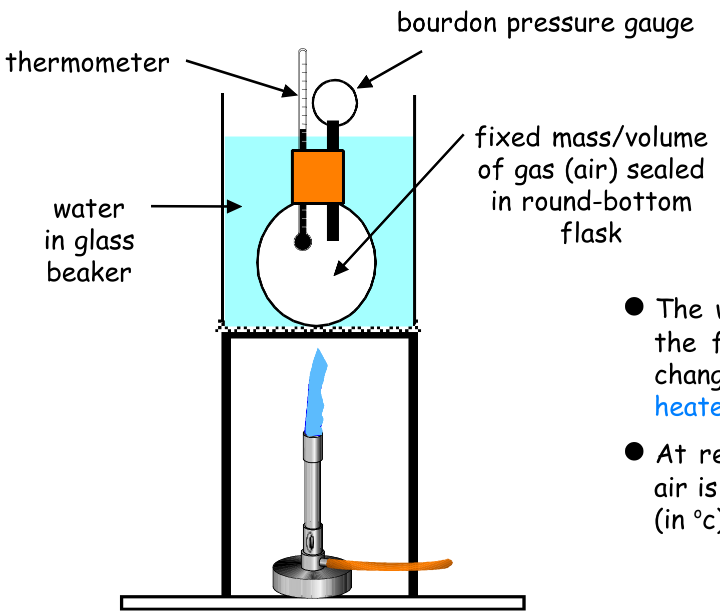
The pressure of a fixed mass of gas at constant temperature is inversely proportional to its volume.

PRESSURE - VOLUME (BOYLE'S) LAW IN TERMS OF PARTICLE MOVEMENT

If the **volume** of a sealed container full of gas is **decreased** (and the **temperature** stays the same), the gas molecules continue to travel with the same **velocity** but hit the walls of the container **more often** (**with a higher frequency**) - so the **pressure increases**.

(b) Pressure and Temperature of a Fixed Mass of Gas at Constant Volume (Pressure Law)

In this experiment, the temperature of a gas (air) is changed a number of times and its pressure at each temperature is measured. **THE MASS AND VOLUME OF THE GAS ARE "FIXED" (KEPT THE SAME).**



- The water is heated slowly. This increases the temperature of the fixed mass/volume of air in the round-bottom flask. This changes the pressure of the air. (Alternatively, the water is heated to its boiling point, then is left to cool slowly.)
- At regular intervals, the pressure of the fixed mass/volume of air is read from the bourdon pressure gauge and its temperature (in °c) is read from the thermometer.

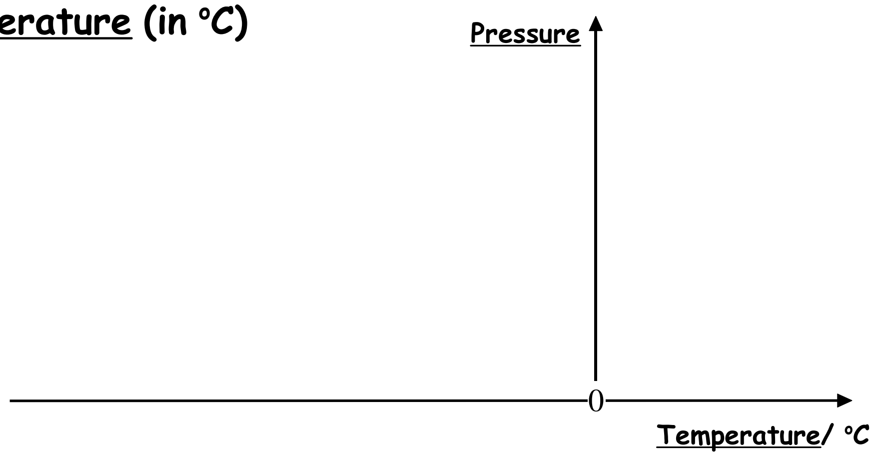
My results:

Pressure/								
Temperature/ °C								
Temperature/ K								
Pressure / Temperature (in kelvin)								

- **Graph of Pressure versus Temperature (in °C)**

A graph of **pressure** versus **temperature in °C**, when extrapolated back to the **temperature at which the pressure is zero**, takes this form:

The temperature at which the pressure is zero = _______ °C.



● The KELVIN TEMPERATURE SCALE

A gas exerts a pressure on the walls of its container because the gas particles are continuously colliding with the walls.

If the **pressure is zero**, the gas particles **cannot be colliding with the container walls** - They must have **stopped moving**.

At **-273 °C**, a gas exerts **zero pressure** on the walls of its container. There is **absolutely zero particle movement** - This temperature (the **coldest possible**) is known as **absolute zero**.

Physicists use a special temperature scale based on this fact - the **kelvin scale**.
Absolute zero (-273°C) is the zero on the kelvin scale (0 K). One division on the kelvin temperature scale is the same size as one division on the celsius temperature scale, so temperature differences are the same in kelvin as in degrees celsius (e.g., a rise in temperature of 5 K is the same as a rise in temperature of 5 °C.

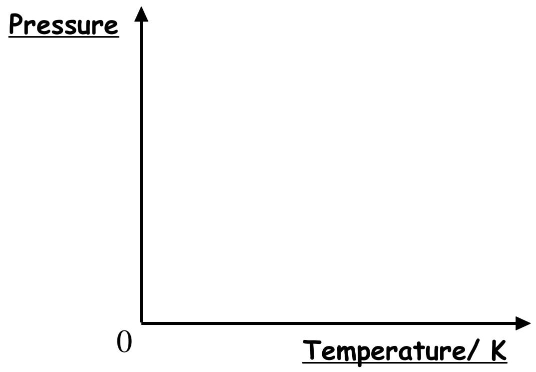
Note the unit of the kelvin temperature scale is the kelvin (K), not degrees kelvin (°K).

To convert from °C to K, add 273.

To convert from K to °C, subtract 273.

● Graph of Pressure versus Temperature (in K)

A graph of **pressure** versus **temperature in kelvin** takes this form:



The ___________ line passing through the __________ shows that **pressure (P) is directly proportional to the temperature (T) in kelvin.**

P α T (in K)

Pressure α Temperature (in kelvin)   **so, Pressure = constant x Temperature (in kelvin)**

$$\text{so,} \quad \frac{\text{Pressure}}{\text{Temperature (in kelvin)}} = \text{constant}$$

*You can see this relationship from the last row of the table.

PRESSURE - TEMPERATURE LAW (PRESSURE LAW)

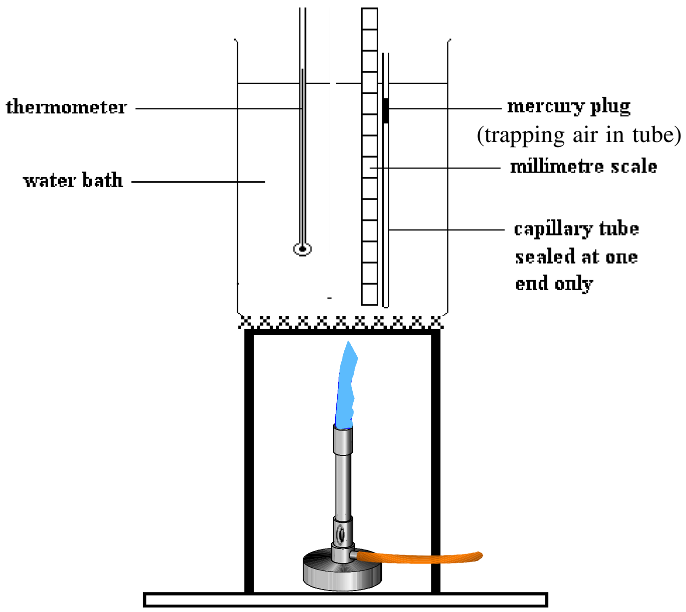
The pressure of a fixed mass of gas at constant volume is directly proportional to its temperature in kelvin.

PRESSURE - TEMPERATURE LAW IN TERMS OF PARTICLE MOVEMENT

If the **temperature** of a sealed container full of gas is **increased** (and the **volume** stays the same), the **kinetic energy** and hence **velocity** of the gas molecules **increases**.
The gas molecules therefore hit the walls of the container **harder** and **more often** (**with a higher frequency**) - so the **pressure increases**.

(c) Volume and Temperature of a Fixed Mass of Gas at Constant Pressure (Charles' Law)

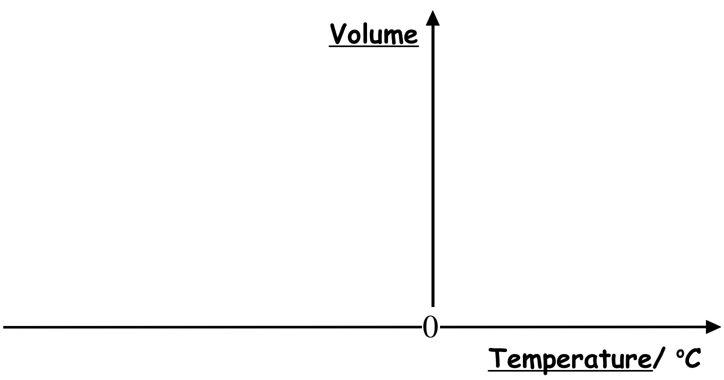
In this experiment, the temperature of a gas (air) is changed a number of times and its volume at each temperature is measured. **THE MASS AND PRESSURE OF THE GAS ARE "FIXED" (KEPT THE SAME).**



- A fixed mass of air is trapped in the glass capillary tube by a small plug of mercury which is free to move up and down the tube.
- The water is heated slowly. This increases the temperature of the the fixed mass of trapped air in the capillary tube. This changes the volume of the air. (Alternatively, the water is heated to its boiling point, then is left to cool slowly.)
- At regular intervals, the length of the column of trapped air is read from the length scale and its temperature (in °c) is read from the thermometer.

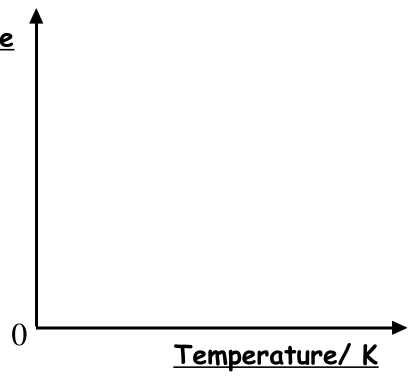
The length of the column of trapped air is taken to represent the volume, since the length of trapped air is directly proportional to its volume in the capillary tube which has a uniform cross-sectional area.

- **Graph of Volume versus Temperature (in °C)**



When graph is extrapolated back to where the volume is zero (i.e., when the gas particles are packed tightly together, not moving), the line crosses the temperature axis at ________°C.

- **Graph of Volume versus Temperature (in K)**



The ___________ line passing through the __________ shows that **volume (V) is directly proportional to the temperature (T) in kelvin.**

V α T (in K)

Volume α Temperature (in kelvin)   so, Volume = constant x Temperature (in kelvin)

$$\text{so,} \quad \frac{\text{Volume}}{\text{Temperature (in kelvin)}} = \text{constant}$$

VOLUME - TEMPERATURE LAW (CHARLES' LAW)

The volume of a fixed mass of gas at constant pressure is directly proportional to its temperature in kelvin.

VOLUME - TEMPERATURE LAW IN TERMS OF PARTICLE MOVEMENT

If the **temperature** of a sealed container full of gas is **increased** (and the **pressure** stays the same), the **kinetic energy** and hence **velocity** of the gas molecules **increases**. The gas molecules therefore hit the walls of the container **harder** and **more often** (**with a higher frequency**) - so the walls of the container are pushed outwards **(volume increases)**.

3) THE GENERAL GAS EQUATION

The **gas law experiments** give us three equations:

Pressure (P) x Volume (V) = constant

$$\frac{\text{Pressure (P)}}{\text{Temperature (T) in kelvin}} = \text{constant}$$

$$\frac{\text{Volume (V)}}{\text{Temperature (T) in kelvin}} = \text{constant}$$

These can be combined into one equation which can be applied to all gases - The **general gas equation**:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

- P_1, V_1 and T_1 refer to the **initial** conditions of a gas.
- P_2, V_2 and T_2 refer to the **final** conditions of a gas.

When using the "general gas equation", all temperatures must be in kelvin.

Example 1

A cylinder contains 0.2 m^3 of nitrogen gas at a pressure of 3×10^5 Pa. Without any change in temperature, the volume is increased to 0.3 m^3. What will be the new pressure of the nitrogen gas at this volume?

Temperature does not change, so miss it out of "general gas equation":

$P_1 V_1 = P_2 V_2$

$(3 \times 10^5) \times 0.2 = P_2 \times 0.3$

$(6 \times 10^4) = 0.3\, P_2$

$P_2 = \dfrac{(6 \times 10^4)}{0.3}$

$= \underline{(2 \times 10^5)\text{ Pa}}$ (Use the same unit given in the question).

Example 2

Carbon dioxide gas is sealed in a container. Its pressure is 1.5×10^5 Pa and its temperature is 25 °C. What will be the new pressure of the carbon dioxide gas when it is heated to a temperature of 70 °C? The volume remains constant.

25 °C = 25 + 273 = 298 K and 70 °C = 70 + 273 = 343 K

Volume does not change, so miss it out of "general gas equation":

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{(1.5 \times 10^6)}{298} = \frac{P_2}{343}$$

$$298\,P_2 = (1.5 \times 10^6) \times 343$$

$$P_2 = \frac{(1.5 \times 10^6) \times 343}{298} = \underline{(1.73 \times 10^6)\ \text{Pa}}$$

(Use the same unit given in the question).

Example 3

1.5 m^3 of helium gas is sealed in a weather balloon at a temperature of 20 °C. The temperature of the helium gas increases, causing the volume to increase to 1.75 m^3. The pressure remains constant. Calculate the new temperature of the weather balloon.

20 °C = 20 + 273 = 293 K

Pressure does not change, so miss it out of "general gas equation":

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{1.5}{293} = \frac{1.75}{T_2}$$

$$1.5\,T_2 = 293 \times 1.75$$

$$T_2 = \frac{293 \times 1.75}{1.5} = \underline{342\ \text{K}}$$