National 5 Physics

"DYNAMICS"

'Vectors and Scalars'

Name: ______________________________

This section of the "Dynamics" unit starts by introducing the term 'average speed' for objects travelling a large distance, over which their speed is likely to change. Two methods of measuring 'average speed' are described.

The term 'instantaneous speed' is then introduced to describe the speed of an object at a particular instant in time. One method of measuring instantaneous speed is described.

The terms 'vector' quantity and 'scalar' quantity are explained, with appropriate examples.

The calculation of the resultant of two vector quantities at right-angles to one another is explained.

The determination of 'displacement' and/or 'distance' and 'velocity' and/or 'speed' using scale diagram or calculation is explained.

The use of equations to solve problems involving 'velocity', 'speed', 'displacement', 'distance' and 'time' is explained.

By the end of this section, you should be able to:

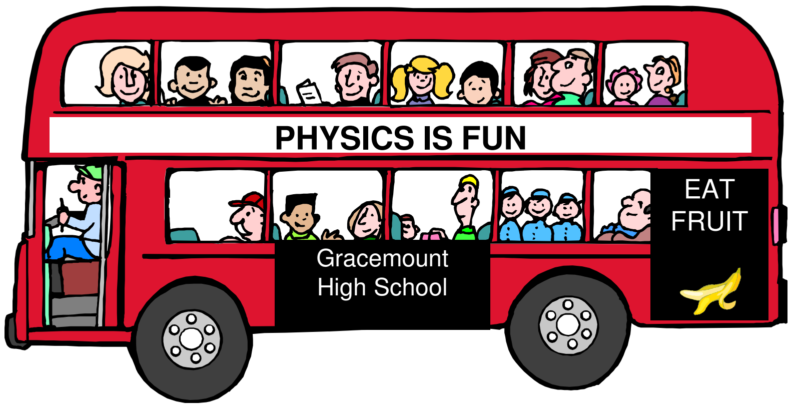
- ☐ explain the terms 'average speed' and 'instantaneous speed'
- ☐ describe experiments to measure 'average' and 'instantaneous' speed
- ☐ define the terms 'vector' quantity and 'scalar' quantity
- ☐ identify 'force', 'velocity', 'displacement' and 'acceleration' as vector quantities and 'speed', 'distance', 'mass' and 'time' as scalar quantities
- ☐ calculate the resultant of two vector quantities at right-angles to one another
- ☐ determine 'displacement' and/or 'distance' using scale diagram or calculation
- ☐ determine 'velocity' and/or 'speed' using scale diagram or calculation
- ☐ use appropriate formulas to solve problems involving 'velocity', 'speed', 'displacement', 'distance' and 'time'

$s = v\,t \qquad s = \bar{v}\,t \qquad d = \bar{v}\,t$

Why Use the Term "Average Speed"?

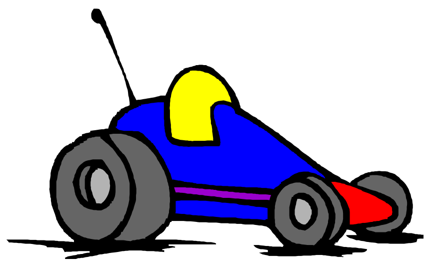
When an object moves over a large distance, its speed rarely stays the same.

For example, the number 11 bus travelling from Hyvots Bank to Edinburgh city centre will change its speed many times during its journey as it negotiates traffic and stops/starts to collect and drop off passengers.



This is why we use the term **average speed** when describing the movement of objects which travel a large distance.

Even for objects which only travel a short distance (like a radio-controlled toy car), we still use the term **average speed** because the speed will change, even over the short distance travelled.



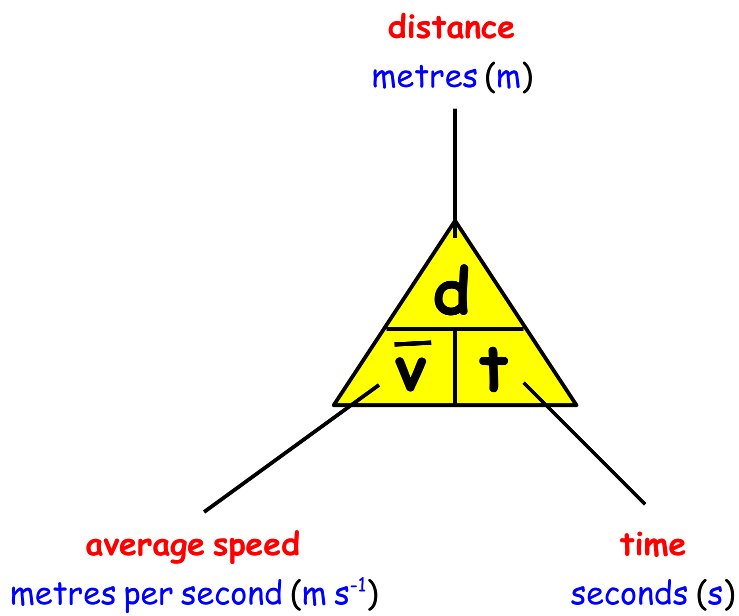
Average Speed Calculations

The **average speed** ($\bar{v}$) of a moving object is the **distance** it travels in a given **time**.

Note the use of the bar (-) above the v to represent "average speed"... We pronounce this as "v bar".

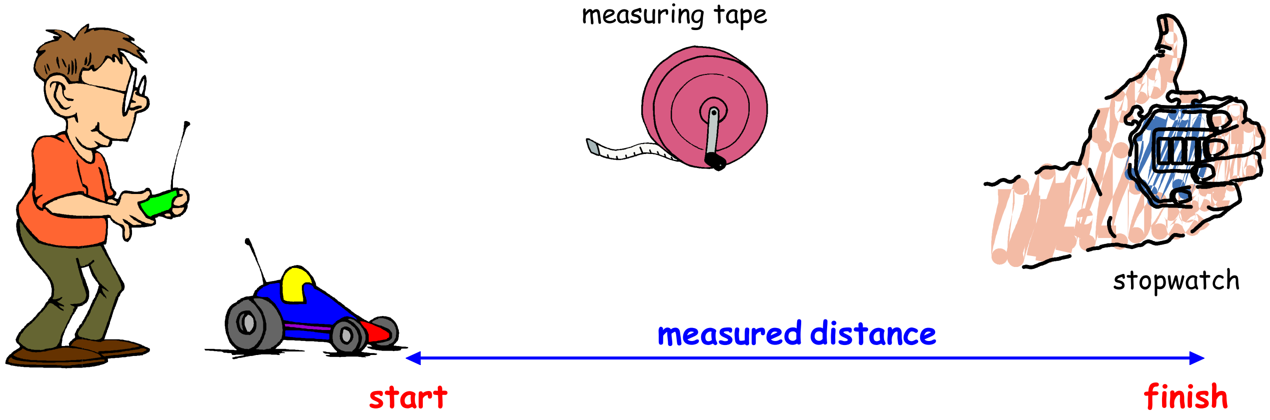
$$\text{average speed} = \frac{\text{distance}}{\text{time}}$$

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



Measuring Average Speed: Human Timing

To measure the **average speed** ($\bar{v}$) of a moving object (for example, a **radio-controlled toy car**), we can use a **measuring tape** and **stopwatch**:



1) With a **m** _ _ _ _ _ _ _ _ _ **t** _ _ _ , measure (and mark with chalk) a distance of several metres on the ground.

2) With a **s** _ _ _ _ _ _ _ _ _ , time how long it takes the radio-controlled toy car to travel this distance.

3) Calculate the **average speed** of the toy car using the formula:

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

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

Sample Readings and Calculation

- distance travelled (d) = 6 m
- time taken (t) = 1.5 s
- average speed ($\bar{v}$) = ?

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

$$= \frac{6}{1.5}$$

$$= \underline{\underline{4 \text{ m s}^{-1}}}$$

1) The following readings were obtained during 3 runs of the radio-controlled car.

For each set of readings, calculate the **average speed** of the radio-controlled car:

Run 1

- distance travelled (d) = 9 m
- time taken (t) = 1.8 s

Run 2

- distance travelled (d) = 12 m
- time taken (t) = 2.5 s

Run 3

- distance travelled (d) = 15 m
- time taken (t) = 6.0 s

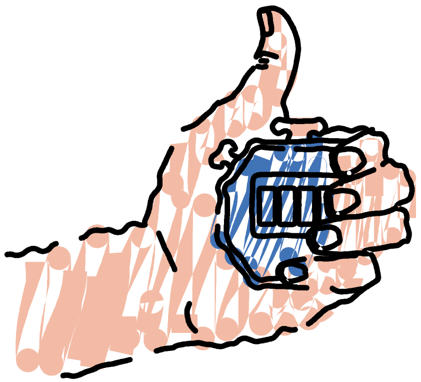
Measuring Average Speed: Electronic Timing

Stopwatches and Human Reaction Time

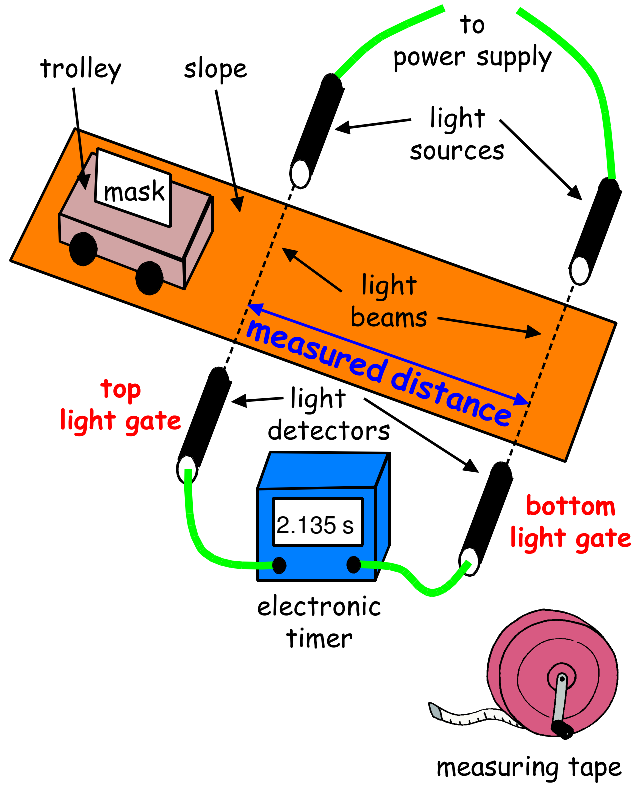
Using a **stopwatch** to time moving objects does **not** give us a very **accurate** value for the time taken. This is due to **human reaction time**.

For example, imagine you are timing a radio-controlled toy car from the moment it starts to the moment it has travelled 5 metres. When your eyes see the car start to move, they send a message to your brain. Your brain processes this message then sends another message to your finger telling it to press the **start button** on the stopwatch - but it takes a fraction of a second for all this to happen, so the car is **already moving** before the **start button** is pressed. When the car reaches the 5 metre mark, the same signalling/reaction process takes place in your body - the car will have **travelled past** the 5 metre mark before the **stop button** is pressed. Because of this, the timing of the car journey is **not accurate**.

This is particularly important when timing sprint races where a difference of less than 0.001 seconds can mean the difference between first and second place! In cases like this, **electronic timing** is used - this does not involve humans pressing buttons (no **human reaction time**) so is far **more accurate** than **human timing**.



To measure the **average speed** ($\bar{v}$) of a moving object (for example, a **trolley** rolling down a slope) with **electronic timing**, we use a **measuring tape** and **2 light gates** connected to an **electronic timer**. A **mask** (**thick card**) is fixed on top of the trolley - no light can pass through the mask.



When the **mask** breaks the **light beam** of the **top light gate**, the electronic timer is automatically switched **on**.

When the **mask** breaks the **light beam** of the **bottom light gate**, the electronic timer is automatically switched **off**.

The electronic timer shows the time the trolley takes to travel from the **top light gate** to the **bottom light gate**.

1) With a **m** _ _ _ _ _ _ _ _ _ **t** _ _ _ , measure the distance between the 2 light gates.

2) Put the trolley at the top of the slope and let it run down the slope (so that the mask passes through the **l** _ _ _ _ **b** _ _ _ of both **l** _ _ _ _ **g** _ _ _ _).

3) Read the **time** taken for the trolley to travel from the top light gate to the bottom light gate from the **e** _ _ _ _ _ _ _ _ _ _ **t** _ _ _ _ _ .

3) Calculate the **average speed** of the trolley using the formula:

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

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

Sample Readings and Calculation

- distance travelled (d) between light gates = 1.25 m
- time taken (t) to travel between light gates = 0.500 s
- average speed ($\bar{v}$) = ?

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

$$= \frac{1.25}{0.500}$$

$$= 2.5 \text{ m s}^{-1}$$

2) The following readings were obtained during 3 separate runs of the trolley down the slope.

For each set of readings, calculate the **average speed** of the trolley as it ran down the slope:

Run 1

- distance travelled (d) between light gates = 1.25 m
- time taken (t) to travel between light gates = 0.250 s

Run 2

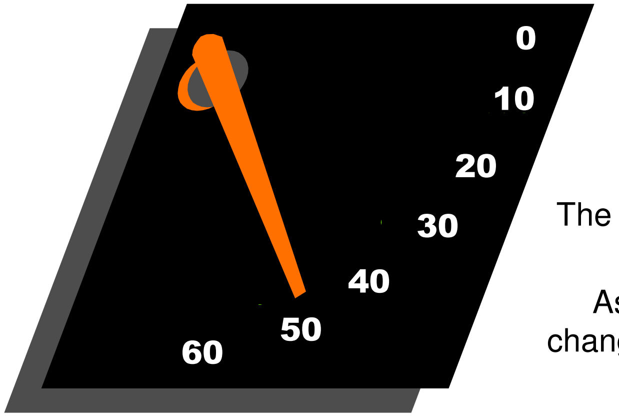
- distance travelled (d) between light gates = 0.80 m
- time taken (t) to travel between light gates = 0.500 s

Run 3

- distance travelled (d) between light gates = 1.50 m
- time taken (t) to travel between light gates = 0.750 s

Instantaneous Speed

The **instantaneous speed** (**v**) of a moving object is its **speed** at a **particular instant of time**.



a car speedometer

The **instantaneous speed** of a car is shown on its **speedometer**.

As the **instantaneous speed** of the car changes, the **speedometer reading** changes.

The **instantaneous speed** of a moving object is estimated by measuring the **distance** the object travels in a **very short time** - much less than **1 second**.

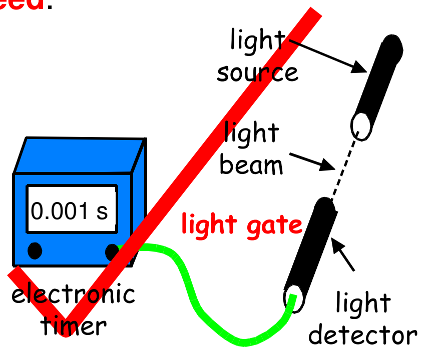
The **smaller** the **measured time**, the better will be the estimate for the object's **instantaneous speed**.

For times **longer than** about **0.005 seconds**, the **speed** determined is really the **average speed**.

The method used to measure the **time of travel** has an effect on the estimated value for **instantaneous speed**.

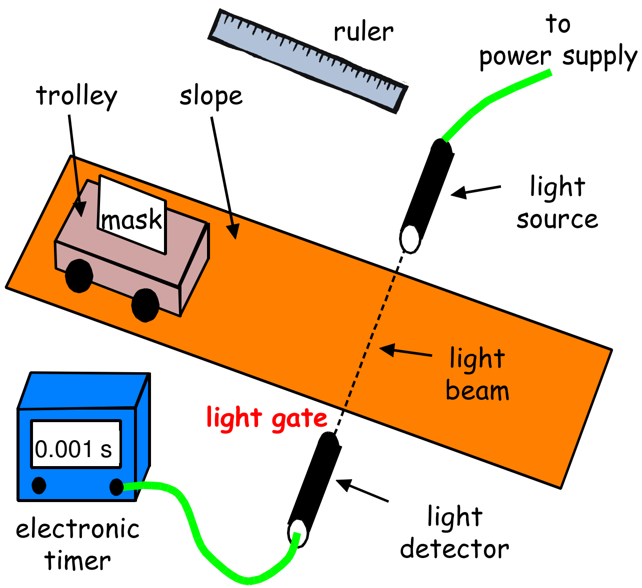
A **stopwatch** cannot be used because we are not able to press the start and stop buttons quickly enough - slow **human reaction time**.

We have to use **electronic timing** which can measure very small time intervals - for example, **0.001 seconds**.



Measuring Instantaneous Speed: Electronic Timing

To measure the **instantaneous speed** (**v**) of a moving object (for example, a **trolley** rolling down a slope) at a **particular point** on the slope, we employ **electronic timing** - **1 light gate** is connected to an **electronic timer**. A **short mask** (about a 1 or 2 cm length of **thick card**) is fixed on top of the trolley - No light can pass through the mask.



When the front edge of the **mask** enters the **light beam** of the **light gate**, the electronic timer is automatically switched **on**.

When the back edge of the **mask** leaves the **light beam** of the **light gate**, the electronic timer is automatically switched **off**.

The electronic timer shows the time the **mask** takes to travel through the **light gate**.

1) With a **r** _ _ _ _ , measure the **l** _ _ _ _ _ of the short mask.

2) Place the **l** _ _ _ _ **g** _ _ _ at the particular point on the slope where you want to measure the trolley's **i** _ _ _ _ _ _ _ _ _ _ _ _ **speed**.

3) Put the trolley at the top of the slope and let it run down the slope (so that the short mask passes through the **l** _ _ _ _ **b** _ _ _ of the **l** _ _ _ _ **g** _ _ _.)

3) Calculate the **instantaneous speed** of the trolley using the formula:

$$\text{instantaneous speed} = \frac{\text{distance (length of mask)}}{\text{time taken for mask to travel through light gate}}$$

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

Sample Readings and Calculation

- distance (length of mask) = 0.01 m
- time taken (t) for mask to travel through light gate = 0.002 s
- instantaneous speed (v) = ?

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

$$= \frac{0.01}{0.002}$$

$$= 5\ \text{m s}^{-1}$$

3) The following readings were obtained during 3 separate runs of the trolley down the slope.

For each set of readings, calculate the **instantaneous speed** of the trolley as it passed through the light gate:

Run 1

- distance (length of mask) = 0.01 m
- time taken (t) for mask to travel through light gate = 0.001 s

Run 2

- distance (length of mask) = 0.015 m
- time taken (t) for mask to travel through light gate = 0.003 s

Run 3

- distance (length of mask) = 0.02 m
- time taken (t) for mask to travel through light gate = 0.005 s

Scalar and Vector Quantities

The following are *some* of the **quantities** you will meet in the National 5 Physics course:

distance displacement

speed velocity

time mass energy power force acceleration

Quantities can be divided into two 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.

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 North)
speed (e.g., 10 m s^{-1})	velocity (e.g., 10 m s^{-1} East)
time (e.g., 12 s)	NONE
mass (e.g., 5 kg)	NONE
energy (e.g., 25 J)	NONE
power (e.g., 200 W)	NONE
NONE	force (e.g., 10 N to the right)
NONE	acceleration (e.g., 1 m s^{-2} West)

DISTANCE and DISPLACEMENT

- **Distance** (a **scalar** quantity) is **the total length of path travelled by an object**.

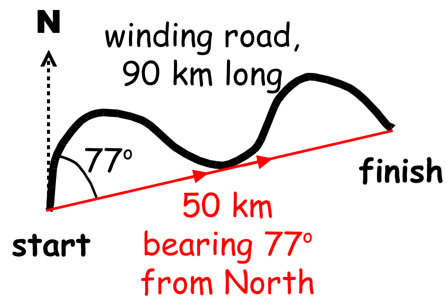
[A **unit** must always be stated], e.g., 250 m or 0.25 km.

- **Displacement** (a **vector** quantity) is **the length and direction of a straight line drawn from an object's starting point to its finishing point**.

[A **unit** and **direction** must always be stated, unless the **displacement is zero**, in which case there is **no direction**], e.g., 500 m (or 0.5 km) bearing 150° from North.

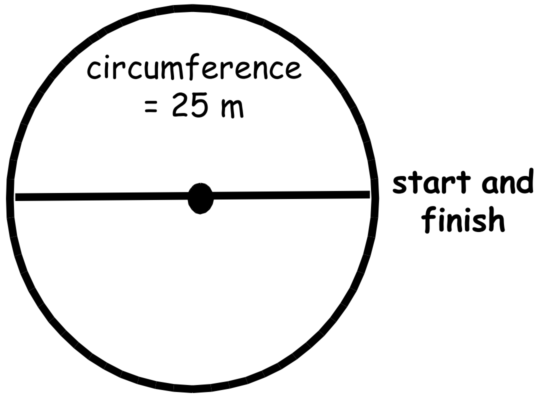
For example:

1) Bill drives 90 km along a winding road.



- Distance travelled = 90 km
- Displacement = 50 km bearing 77° from North

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



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

SPEED and VELOCITY

● **Speed** (a **scalar** quantity) is **the distance travelled by an object per second** (or sometimes **per hour**).

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

[A **unit** must always be stated], e.g., 5 m s^{-1}.

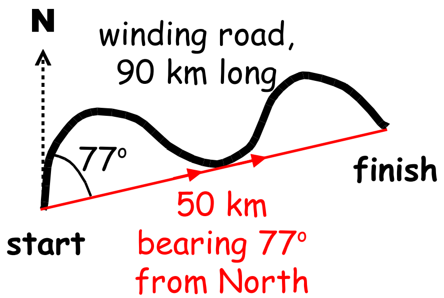
● **Velocity** (a **vector** quantity) is **the displacement of an object per second** (or sometimes **per hour**).

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

[A **unit** and **direction** must always be stated, unless the **velocity is zero**, in which case there is **no direction**], e.g., 5 m s^{-1} bearing 100° from North.

For example:

Bill drives 90 km along a winding road in a time of 2 hours:



● Distance travelled = 90 km

● Displacement = 50 km bearing 77° from North

$$\text{average speed} = \frac{\text{distance}}{\text{time}} = \frac{90}{2} = \underline{\underline{45 \text{ km h}^{-1}}}$$

$$\text{velocity} = \frac{\text{displacement}}{\text{time}} = \frac{50}{2} = \underline{\underline{25 \text{ km h}^{-1}}}$$

$\underline{\underline{\text{bearing } 77^\circ \text{ from North}}}$

4) (a) How would you specify a **scalar** quantity? ______________________

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(b) Give six examples of **scalar** quantities: ______________________

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5) (a) How would you specify a **vector** quantity? ______________________

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(b) Give four examples of **vector** quantities: ______________________

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6) State the difference between **distance** and **displacement**:

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7) Explain the terms **speed** and **velocity**: ______________________

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Finding the Resultant of Two Forces Acting At Right-Angles To Each Other

The magnitude (size) and direction of the resultant of two forces (vectors) acting at right-angles to each other can be obtained using the **"tip to tail" rule**.

The "TIP TO TAIL" RULE

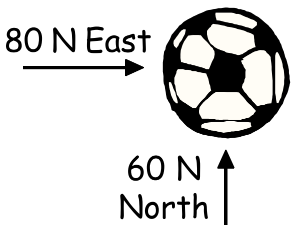
- Each vector must be represented by a straight line of suitable scale. The straight line must have an arrow head to show its direction.
- The vectors must be joined so that the tip of the first vector touches the tail of the second vector.
- A straight line is drawn from the starting point to the finishing 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.

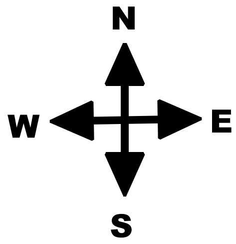
YOU SHOULD BE ABLE TO ADD THE TWO FORCES USING A SCALE DIAGRAM OR MATHEMATICS - Pythogoras theorem and SOHCAHTOA.

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

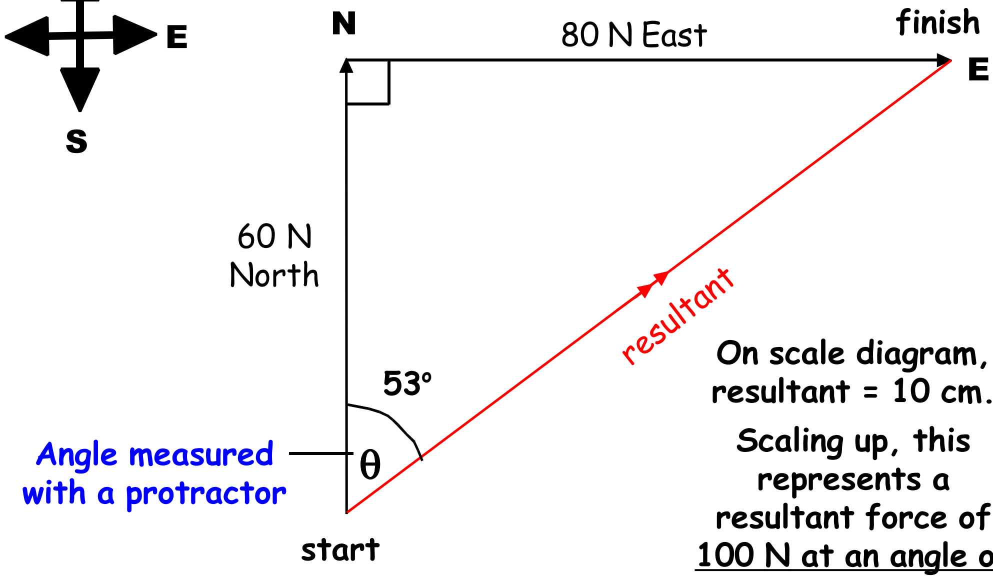
Example

A force of 60 N pushes a football along the ground to the North. A second force of 80 N pushes the football along the ground to the East. Determine the ***magnitude*** (***size***) and ***direction*** of the **resultant force** acting on the football.





Method 1 - by scale diagram **Scale: 1 cm = 10 N**



On scale diagram, resultant = 10 cm.

Scaling up, this represents a resultant force of **100 N at an angle of 53° to the 60 N force**.

Method 2 - Using mathematics

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

First, Using PYTHAGORAS THEOREM

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

$$\text{so, resultant} = \sqrt{10\,000}$$
$$= \underline{100}\ \text{N}$$

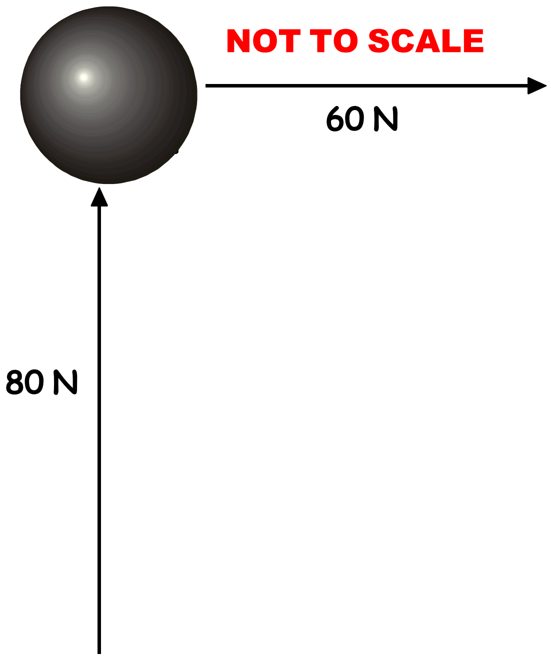
Next, Using SOHCAHTOA

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

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

Resultant force = 100 N at an angle of 53° to the 60 N force.

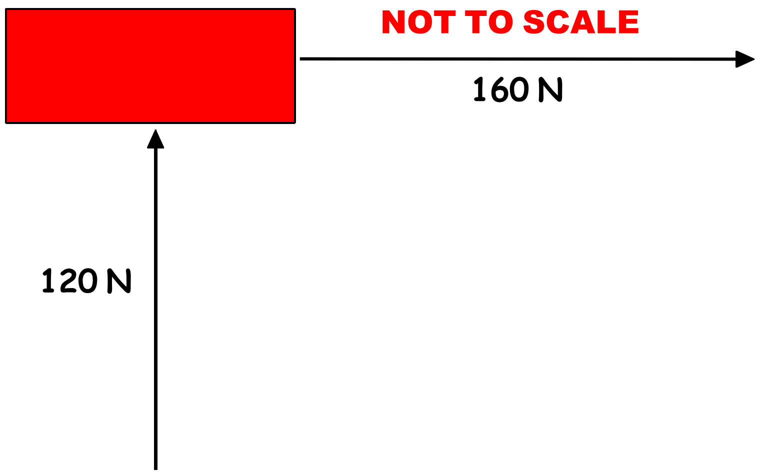
8) Two forces act on a bowling ball at right-angles to each other, as shown in the diagram below:



Find the ***magnitude*** (***size***) and ***direction*** of the **resultant force** relative to the 80 N force.

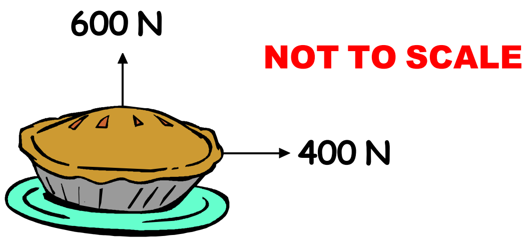
9) Two teachers are both trying to grab the last box of Physics Department pencils. The diagram shows the size and direction of the two forces being exerted on the pencil box. (The forces act at right-angles to each other).

Determine the ***magnitude*** (***size)*** and ***direction*** of the **resultant force** acting on the pencil box relative to the120 N force.



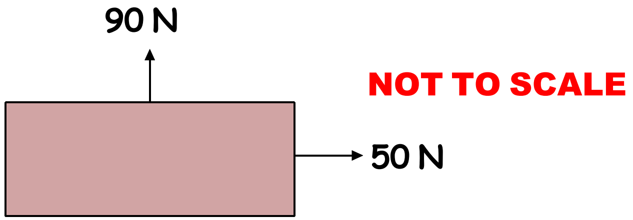
10) In the school dinner hall, two pupils both grab the last pie at the same time. The diagram shows the size and direction of the two forces being exerted on the pie.
(The forces act at right-angles to each other).

Determine the ***magnitude* *(size)*** and ***direction*** of the **resultant force** acting on the pie, relative to the 600 N force.



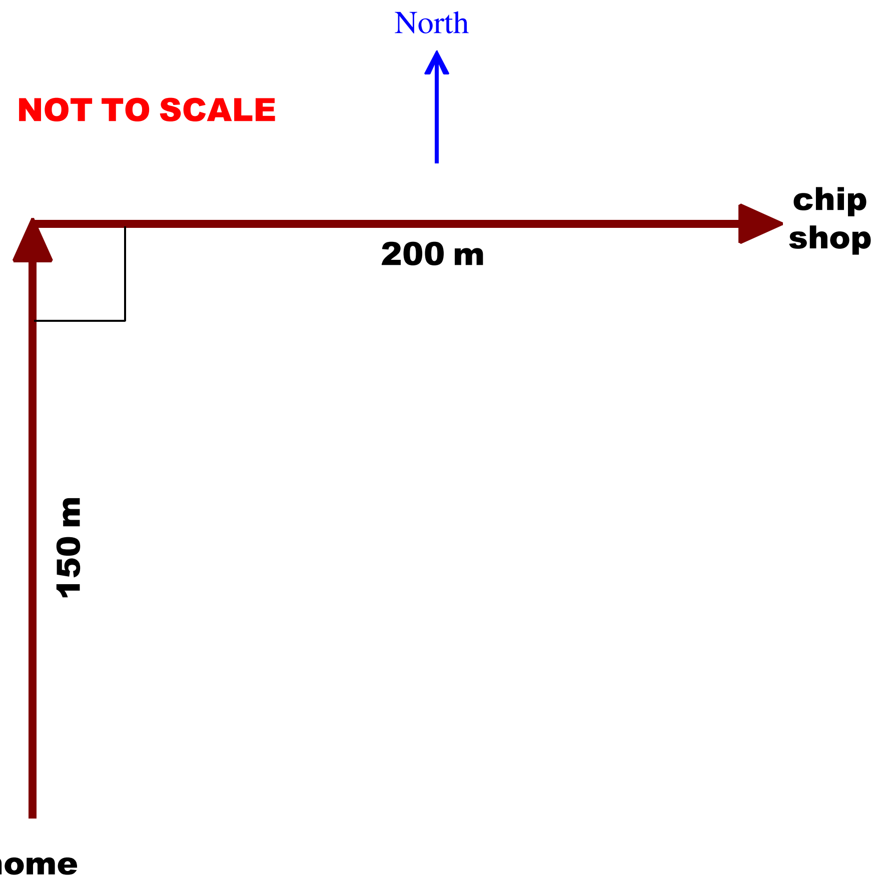
11) The diagram shows the size and direction of two forces being exerted on a wooden block.
(The forces act at right-angles to each other).

Find the ***magnitude*** (***size)*** and ***direction*** of the **resultant force** acting on the wooden block, relative to the 90 N force.



Problems Involving Distance and Speed PLUS Displacement and Velocity Vectors

12) Mr. Cunningham jogs from his home to his local chip shop, as shown on the diagram. This takes him a total time of 100 s.



(a) Calculate the total **distance** Mr. Cunningham travels from his home to the chip shop.

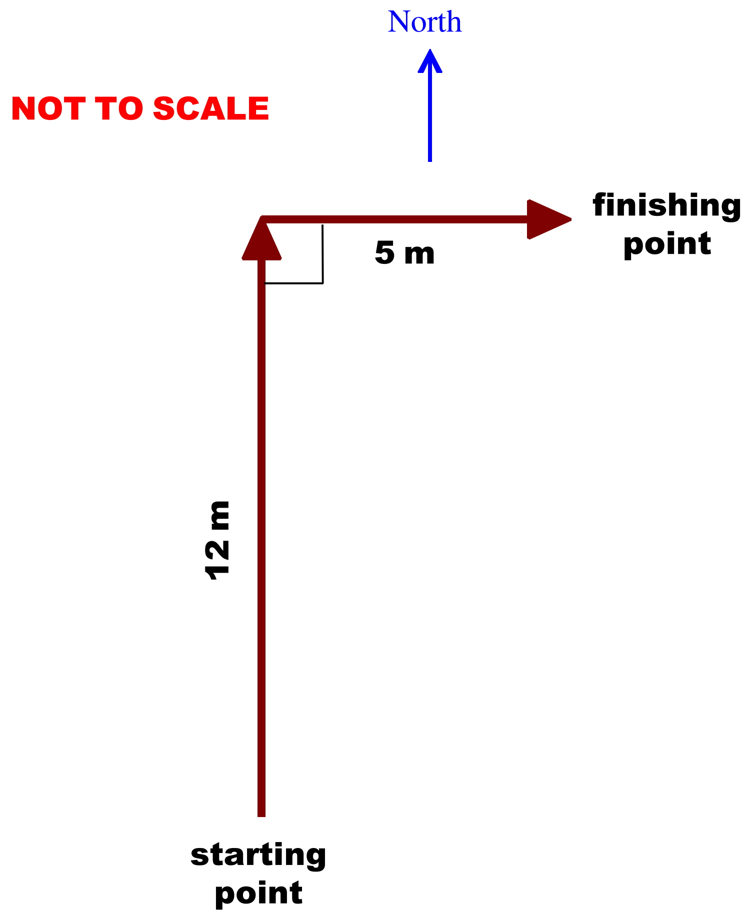
(b) Calculate Mr. Cunningham's **displacement** from his home when he arrives at the chip shop. (You must give a numerical value and a direction from North.)

YOU MAY DRAW ON AND MARK THE DIAGRAM.

(c) Calculate Mr. Cunningham's **average speed** for his journey.

(d) Calculate Mr. Cunningham's **velocity** for his journey. (You must give a numerical value and a direction from North.)

13) Mrs. Edwards, the Science Technician, pushes a trolley containing Physics apparatus along the corridor, then into Lab 1, as shown in the diagram. This takes a total time of 20 s.



(a) Calculate the total **distance** Mrs. Edwards pushes the trolley.

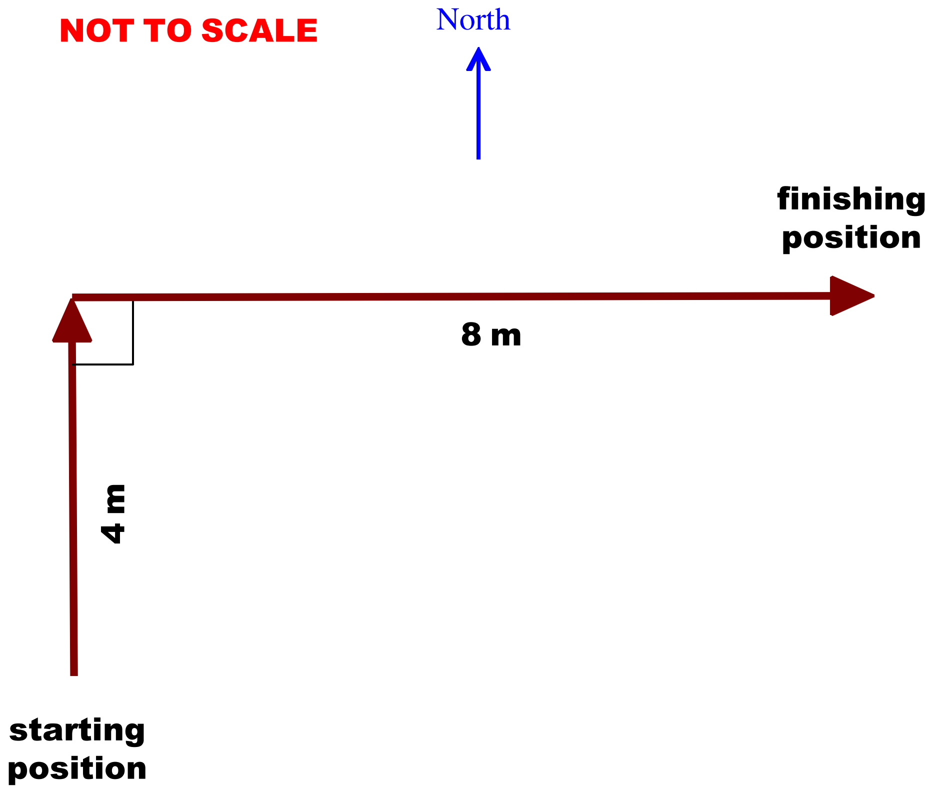
(b) Calculate Mrs. Edwards' **displacement** from her starting point to her finishing point.
(You must give a numerical value and a direction from North.)

YOU MAY DRAW ON AND MARK THE DIAGRAM.

(c) Calculate Mrs. Edwards' **average speed** for her journey.

(d) Calculate Mrs. Edwards' **velocity** for her journey.
(You must give a numerical value and a direction from North.)

14) Mr. Ioannis walks from one desk in his classroom to another desk, as shown in the diagram. This takes a total time of 6.0 s.



(a) Calculate the total **distance** Mr. Ioannis walks from desk to desk.

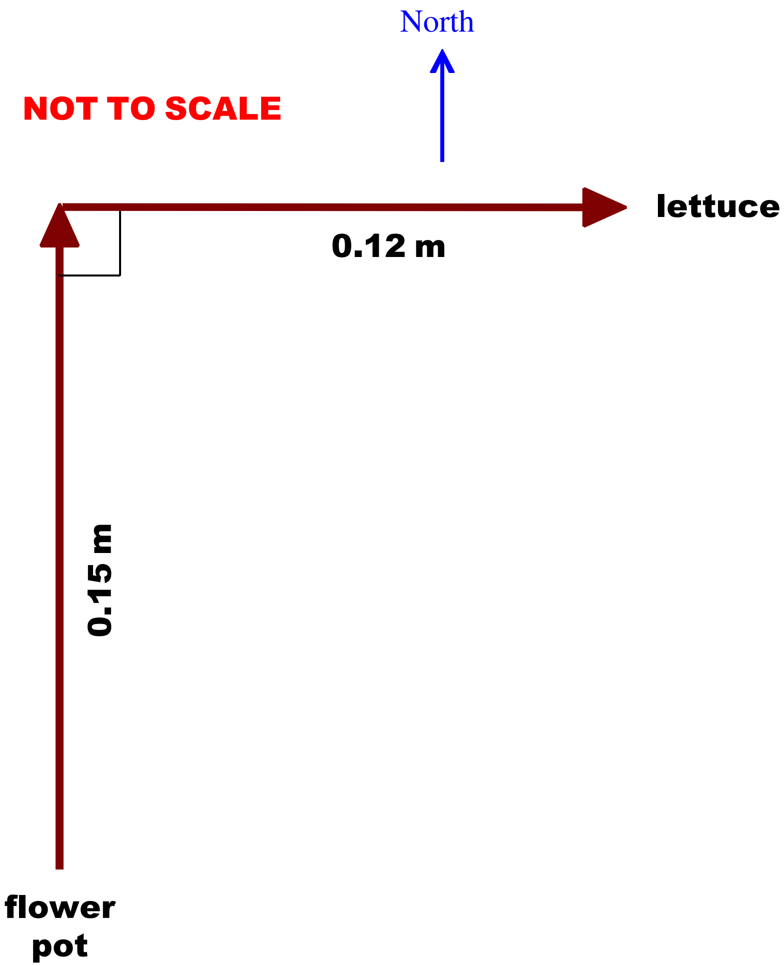
(b) Calculate the **displacement** of Mr. Ioannis from his starting position to his finishing position.
(You must give a numerical value and a direction from North.)

YOU MAY DRAW ON AND MARK THE DIAGRAM.

(c) Calculate the **average speed** of Mr. Ioannis during his walk.

(d) Calculate the **velocity** of Mr. Ioannis for his walk.
(You must give a numerical value and a direction from North.)

15) A centipede follows the course shown in the diagram, from a flower pot to a lettuce. This takes a total time of 60 s.



(a) Calculate the total **distance** the centipede travels between the flower pot and the lettuce.

(b) Calculate the centipede's **displacement** from the flower pot to the lettuce.
(You must give a numerical value and a direction from North.)

YOU MAY DRAW ON AND MARK THE DIAGRAM.

(c) Calculate the centipede's **average speed** for its journey.

(d) Calculate the centipede's **velocity** for its journey.
(You must give a numerical value and a direction from North.)

Notes

Notes