



# 1

# Physics and physical measurement

## 1.1 Fundamental quantities

### Assessment statements

- 1.1.1 State and compare quantities to the nearest order of magnitude.
- 1.1.2 State the ranges of magnitude of distances, masses and times that occur in the universe, from the smallest to the greatest.
- 1.1.3 State ratios of quantities as differences of orders of magnitude.
- 1.1.4 Estimate approximate values of everyday quantities to one or two significant figures and/or to the nearest order of magnitude.
- 1.2.1 State the fundamental units in the SI system.
- 1.2.2 Distinguish between fundamental and derived units and give examples of derived units.
- 1.2.3 Convert between different units of quantities.
- 1.2.4 State units in the accepted SI format.
- 1.2.5 State values in scientific notation and in multiples of units with appropriate prefixes.

## Position

Physics is about modelling our universe. To do this, we need to define the things inside it. Each thing is different for many reasons, but one of the most important differences is their different positions. To define position, we use the quantity *distance*; this is how far the object is away from us. To quantify (put a number to) this difference we compare the distance with some standard measure (the metre rule). All distances can then be quoted as multiples of this *fundamental unit*, for example:

The distance from Earth to the Sun =  $1.5 \times 10^{11}$  m

The size of a grain of sand =  $2 \times 10^{-4}$  m

The distance to the nearest star =  $4 \times 10^{16}$  m

The radius of the Earth =  $6.378 \times 10^6$  m

## Standard form

The quantities above are expressed in standard form. This means that there is only one number to the left of the decimal place. For example:

1600 m in standard form is  $1.6 \times 10^3$  m

## Exercise

- 1 Convert the following into metres (m) and write in standard form:
  - (a) Distance from London to New York = 5585 km
  - (b) Height of Einstein was 175 cm
  - (c) Thickness of a human hair = 25.4  $\mu$ m
  - (d) Distance to edge of the universe = 100 000 million million million km



### The metre

The metre was originally defined in terms of several pieces of metal positioned around Paris. This wasn't very accurate so now one metre is defined as the distance travelled by light in a vacuum in  $\frac{1}{299\,792\,458}$  of a second.



It is also acceptable to use a prefix to denote powers of 10

Prefix	Value
T (tera)	$10^{12}$
G (giga)	$10^9$
M (mega)	$10^6$
k (kilo)	$10^3$
c (centi)	$10^{-2}$
m (milli)	$10^{-3}$
$\mu$ (micro)	$10^{-6}$
n (nano)	$10^{-9}$
p (pico)	$10^{-12}$
f (femto)	$10^{-15}$

**The second**

The second was originally defined as a fraction of a day but today's definition is 'the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom'.



If nothing ever happened, would there be time?

**The kilogram**

The kilogram is the only fundamental quantity that is still based on an object kept in Paris. Moves are underway to change the definition to something that is more constant and better defined but does it really matter? Would anything change if the size of the 'Paris mass' changed?



## Time

When something happens we call it an *event*. To distinguish between different events we use time. The time between two events is measured by comparing to some fixed value, the second. Time is also a fundamental quantity.

Some examples of times:

Time between beats of a human heart = 1 s

Time for the Earth to go around the Sun = 1 year

Time for the Moon to go around the Earth = 1 month

### Exercise

- 2 Convert the following times into seconds (s) and write in standard form:
- (a) 85 years, how long Newton lived
  - (b) 2.5 ms, the time taken for a mosquito's wing to go up and down
  - (c) 4 days, the time it took to travel to the Moon
  - (d) 2 hours 52 min 59 s, the time for Concord to fly from London to New York

## Mass

If we pick different things up we find another difference. Some things are easy to lift up and others are difficult. This seems to be related to how much matter the objects consist of. To quantify this we define mass measured by comparing different objects to a piece of metal in Paris, the standard kilogram.

Some examples of mass:

Approximate mass of a man = 75 kg

Mass of the Earth =  $5.97 \times 10^{24}$  kg

Mass of the Sun =  $1.98 \times 10^{30}$  kg

### Exercise

- 3 Convert the following masses to kilograms (kg) and write in standard form:
- (a) The mass of an apple = 200 g
  - (b) The mass of a grain of sand = 0.00001 g
  - (c) The mass of a family car = 2 tonnes

## Volume

The space taken up by an object is defined by the volume. Volume is measured in cubic metres ( $\text{m}^3$ ). Volume is not a fundamental unit since it can be split into smaller units ( $\text{m} \times \text{m} \times \text{m}$ ). We call units like this *derived units*.

### Exercises

- 4 Calculate the volume of a room of length 5 m, width 10 m and height 3 m.
- 5 Using the information from page 1, calculate:
- (a) the volume of a human hair of length 20 cm
  - (b) the volume of the Earth.

## Density

By measuring the mass and volume of many different objects we find that if the objects are made of the same material, the ratio mass/volume is the same. This quantity is called the *density*. The unit of density is  $\text{kg m}^{-3}$ . This is another derived unit.

Examples include:

Density of water =  $1.0 \times 10^3 \text{ kg m}^{-3}$

Density of air =  $1.2 \text{ kg m}^{-3}$

Density of gold =  $1.93 \times 10^4 \text{ kg m}^{-3}$

### Exercises

- 6 Calculate the mass of air in a room of length 5 m, width 10 m and height 3 m.
- 7 Calculate the mass of a gold bar of length 30 cm, width 15 cm and height 10 cm.
- 8 Calculate the average density of the Earth.

## Displacement

So far all that we have modelled is the position of things and when events take place, but what if something moves from one place to another? To describe the movement of a body, we define the quantity *displacement*. This is the distance moved in a particular direction.

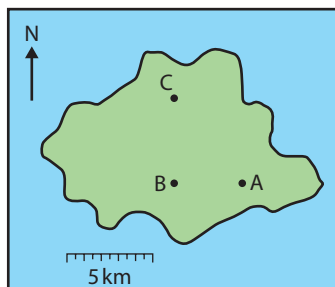
The unit of displacement is the same as length: the metre.

Example:

Referring to the map in Figure 1.1:

If you move from B to C,  
your displacement will be 5 km north.

If you move from A to B,  
your displacement will be 4 km west.



**Figure 1.1** Displacements on a map.

## Summary of SI units

The International System of units is the set of units that are internationally agreed to be used in science. It is still OK to use other systems in everyday life (miles, pounds, Fahrenheit) but in science we must always use SI. There are seven fundamental quantities.

Base quantity	Name	Symbol
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

All other SI units are derived units; these are based on the fundamental units and will be introduced and defined where relevant. So far we have come across just two.

Derived quantity	Symbol	Base units
volume	$\text{m}^3$	$\text{m} \times \text{m} \times \text{m}$
density	$\text{kg m}^{-3}$	$\frac{\text{kg}}{\text{m} \times \text{m} \times \text{m}}$

## 1.2 Measurement

### Assessment statements

- 1.2.6 Describe and give examples of random and systematic errors.
- 1.2.7 Distinguish between precision and accuracy.
- 1.2.8 Explain how the effects of random errors may be reduced.
- 1.2.9 Calculate quantities and results of calculations to the appropriate number of significant figures.

Even this huge device at CERN has uncertainties.



## Uncertainty and error in measurement

The SI system of units is defined so that we all use the same sized units when building our models of the physical world. However, before we can understand the relationship between different quantities, we must measure how big they are. To make measurements we use a variety of instruments. To measure length, we can use a ruler and to measure time, a clock. If our findings are to be trusted, then our measurements must be accurate, and the accuracy of our measurement depends on the instrument used and how we use it. Consider the following examples.

### Estimating uncertainty

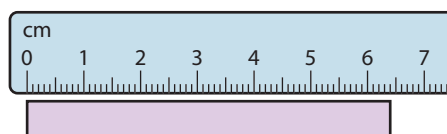
When using a scale such as a ruler the uncertainty in the reading is  $\frac{1}{2}$  of the smallest division. In this case the smallest division is 1 mm so the uncertainty is 0.5 mm.



## Measuring length using a ruler

### Example 1

A good straight ruler marked in mm is used to measure the length of a rectangular piece of paper as in Figure 1.2.

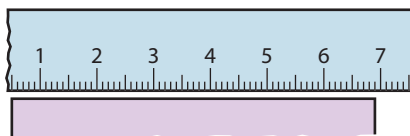


**Figure 1.2** Length =  $6.40 \pm 0.05$  cm.

The ruler measures to within 0.5 mm (we call this the uncertainty in the measurement) so the length in cm is quoted to 2 dp. This measurement is precise and accurate.

## Example 2

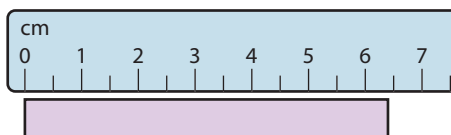
Figure 1.3 shows how a ruler with a broken end is used to measure the length of the same piece of paper. When using the ruler, you fail to notice the end is broken and think that the 0.5 cm mark is the zero mark.



This measurement is precise since the uncertainty is small but is not accurate since the value 6.90 cm is wrong.

## Example 3

A cheap ruler marked only in  $\frac{1}{2}$  cm is used to measure the length of the paper as in Figure 1.4.



These measurements are not precise but accurate, since you would get the same value every time.

## Example 4

In Figure 1.5, a good ruler is used to measure the maximum height of a bouncing ball. Even though the ruler is good it is very difficult to measure the height of the bouncing ball. Even though you can use the scale to within 0.5 mm, the results are not precise (may be about  $\pm 0.2$  cm). However, if you do enough runs of the same experiment, your final answer could be accurate.

## Errors in measurement

There are two types of measurement error – random and systematic.

### Random error

If you measure a quantity many times and get lots of slightly different readings then this is called a *random error*. For example, when measuring the bounce of a ball it is very difficult to get the same value every time even if the ball is doing the same thing.

### Systematic error

This is when there is something wrong with the measuring device or method. Using a ruler with a broken end can lead to a ‘zero error’ as in Example 2 above. Even with no random error in the results, you’d still get the wrong answer.

### Reducing errors

To reduce random errors you can repeat your measurements. If the uncertainty is truly random, they will lie either side of the true reading and the mean of these values will be close to the actual value. To reduce a systematic error you need to find

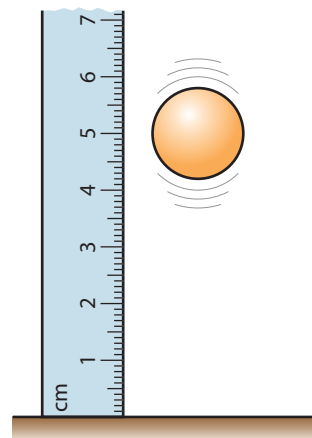
**Figure 1.3** Length =  $6.90 \pm 0.05$  cm.



If you measure the same thing many times and get the same value, then the measurement is precise.

If the measured value is close to the expected, then the measurement is accurate. If a football player hit the post 10 times in a row when trying to score a goal, you could say the shots are precise but not accurate.

**Figure 1.4** Length =  $6.5 \pm 0.25$  cm.



**Figure 1.5** Height =  $5.0 \pm 0.2$  cm.



It is not possible to measure anything exactly. This is not because our instruments are not exact enough but because the quantities themselves do not exist as exact quantities.

out what is causing it and correct your measurements accordingly. A systematic error is not easy to spot by looking at the measurements, but is sometimes apparent when you look at the graph of your results or the final calculated value.

## 1.3 Collecting data

### Assessment statements

- 1.2.10 State uncertainties as absolute, fractional and percentage uncertainties.
- 1.2.11 Determine the uncertainties in results.

### Measurement in practice

Approximately one quarter of this course will be taken up with practical work, where you will be measuring quantities and doing calculations. There are certain accepted ways of handling data and the uncertainties they contain. In the following section we will go through the way to make tables, draw graphs and handle uncertainties. If you follow this method you will gain good marks in the internally assessed part of the course.

To illustrate the method we will consider a simple experiment. You are presented with 6 metal cubes and asked to find the density of the metal. The apparatus supplied is a good ruler and an electronic balance. The ruler has millimetre divisions and the balance measures down to 0.1 g.

Density is defined as mass/volume, so to find density we must measure mass and volume. As the samples are cubes we only need to measure one side. We can then find the volume by cubing this value.

### Repeating measurements

Each cube has a different side length and mass. To make sure each mass is connected to the correct side length we put our data into a table; it is also simpler if we use a spreadsheet to perform calculations.

The cubes are not perfectly uniform so the side length depends upon which length we choose. To reduce the uncertainty in this measurement we measure the cube four times and find the average side length. However, if we measure the mass of the cube we get exactly the same measurement each time and there is therefore no point in repeating this measurement.

● **Examiner's hint:** It's OK to use non-SI units such as grams when collecting data. However, your final result (density) should be in SI units.

● **Examiner's hint:** The number of decimal places in the data should be consistent with the uncertainty. It would be wrong to write 2.4000 cm since the uncertainty is  $\pm 0.05$  cm

Table 1.1

Mass/g $\pm 0.1$ g	Length 1/cm $\pm 0.05$ cm	Length 2/cm $\pm 0.05$ cm	Length 3/cm $\pm 0.05$ cm	Length 4/cm $\pm 0.05$ cm
124.1	2.40	2.30	2.50	2.40
235.2	3.00	3.10	2.90	3.00
344.0	3.40	3.30	3.40	3.50
463.2	3.70	3.80	3.60	3.70
571.2	4.00	4.10	3.90	4.00
660.0	4.20	4.30	4.10	4.20

Note: The uncertainty in each length measurement is 0.05 cm. However the actual uncertainty is greater as the spread of values demonstrates.

## Processing data

In this example we are first going to find the average side length and then the volume. If we look at the data we can see that the spread of data is more than the uncertainty in the ruler scale so we will also calculate the uncertainty in these values. When we know that, we can find out the uncertainty in the volume. This is found by calculating the maximum and minimum volumes using the maximum and minimum values for length. Even in this simple experiment there will be a lot of calculations, so it is advisable to use a spreadsheet (such as Excel) for doing this.

This is calculated using the formula  
$$\frac{((\text{max length})^3 - (\text{min length})^3)}{2}$$

This is found by calculating  
$$\frac{(\text{max length} - \text{min length})}{2}$$

Mass/g $\pm 0.1$ g	Mean length/cm	Uncertainty in length/ $\pm$ cm	Volume/cm <sup>3</sup>	Uncertainty in volume/ $\pm$ cm <sup>3</sup>
124.1	2.4	0.1	14	2
235.2	3.0	0.1	27	3
344.0	3.4	0.1	39	3
463.2	3.7	0.1	51	4
571.2	4.0	0.1	64	5
660.0	4.2	0.1	74	5

● **Examiner's hint:** It is well worth learning how to use a spreadsheet programme for analysing data.

● **Examiner's hint:** The number of decimal places in the data must not exceed the uncertainty and the uncertainty has been rounded off to 1 significant figure.

Table 1.2

## 1.4 Presenting processed data

### Assessment statements

- 1.2.12 Identify uncertainties as error bars in graphs.
- 1.2.13 State random uncertainty as an uncertainty range ( $\pm$ ) and represent it graphically as an 'error bar'.
- 1.2.14 Determine the uncertainties in the gradient and intercepts of a straight-line graph.

You could simply calculate the density of the metal for each cube and find the average but there are many advantages to using a graphical method. In this example, we know that the mass and volume are related by the equation  $m = \rho V$  where  $\rho$  is the density.

This means that mass is proportional to volume, so plotting a graph of mass (on the  $y$ -axis) against volume (on the  $x$ -axis) will give a straight line. The gradient of the line will be the density and the  $y$ -intercept will be zero. Because there are uncertainties in the data, we don't know exactly where to plot the line; for this reason we plot error bars on each point as shown in Figure 1.6. This graph has been plotted with a computer program (e.g. Graphical Analysis by Vernier) that automatically plots the best fit line and the error bars.

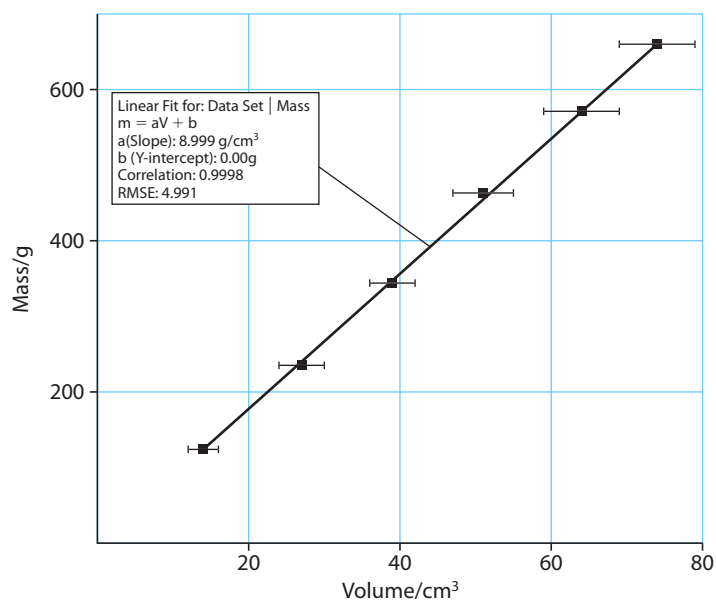


The general equation of a straight line is  
$$y = mx + c$$
Where  $m$  is the gradient and  $c$  is the  $y$ -intercept. Any equation that has the same form will also be linear.

● **Examiner's hint:** As with spreadsheets, it is also worth practising with graph plotting software.

**Figure 1.6** Graph of mass vs volume with error bars

As we can see, the gradient or slope of the line is  $8.999 \text{ g cm}^{-3}$ ; this is the density of the metal.



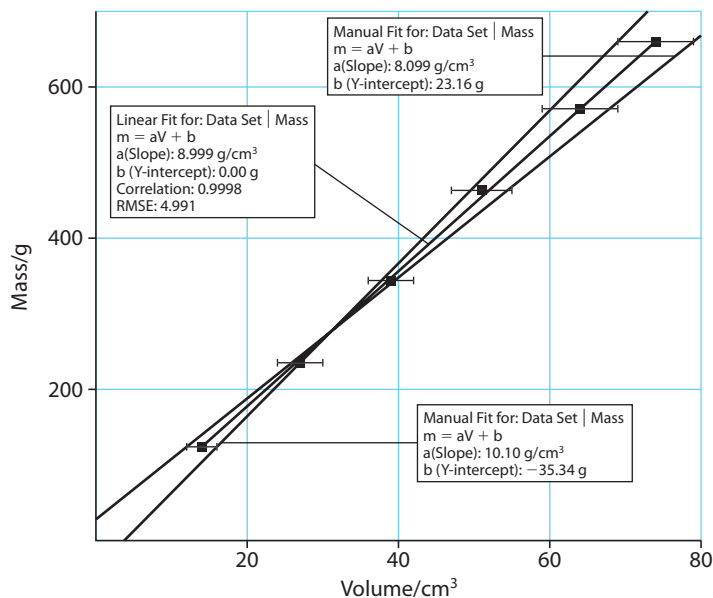
To find out more about graph plotting visit [www.heinemann.co.uk/hotlinks](http://www.heinemann.co.uk/hotlinks), enter the express code 4426P and click on Weblink 1.1.



## Uncertainties in gradients

We can see from Figure 1.6 that the line shown is not the only straight line that can be drawn through the error bars; there are in fact a whole range of them. Using the steepest and least steep lines that we can draw will give us the uncertainty in the gradient. The computer program also enables us to do that, as shown in Figure 1.7.

**Figure 1.7** Graph of mass vs volume with steepest and least steep lines.



The maximum gradient is 10.1 and the minimum is 8.1 so the uncertainty is

$$\frac{(10.1 - 8.1)}{2} = 1 \text{ g cm}^{-3}$$

So our final result is that the density of the metal in SI units is  $9000 \pm 1000 \text{ kg m}^{-3}$ .

Note the number of significant figures is reduced so that it is consistent with the uncertainty.



If we look up the density of metals we find that the density of copper is  $8920 \text{ kg m}^{-3}$ . This is only  $80 \text{ kg m}^{-3}$  less than our value. We can therefore conclude that within the uncertainties of our experiment the cubes could be made of copper.

## Percentage uncertainties

In the example above, the uncertainties were expressed as  $\pm 1000 \text{ kg m}^{-3}$ . This is called an *absolute uncertainty*. Uncertainties can also be expressed as a simple percentage. In this case the percentage uncertainty would be  $\left(\frac{1000}{9000}\right) \times 100 = 11\%$

When you multiply values, you can find the uncertainty of the result by adding the percentage uncertainties. However when dealing with tables of data, it is simpler to use the method described previously. So if the uncertainty in length is 4%, the uncertainty in volume is  $3 \times 4\% = 12\%$ .

● **Examiner's hint:** Even though you use absolute uncertainties in all your practical work you might be asked how to manipulate percentage uncertainties in the exam.

### Exercise

9 To measure the volume of an object, two lengths  $l_1$  and  $l_2$  are measured.

$$l_1 = 10.25 \pm 0.05 \text{ cm}$$

$$l_2 = 15.45 \pm 0.05 \text{ cm}$$

Calculate:

- (a) the % uncertainty in  $l_1$
- (b) the % uncertainty in  $l_2$
- (c) the area of the object
- (d) the % uncertainty in the area.

## Other information from graphs

A graph is not only a way to find a value, it also gives us information about the validity of the data. Here are some examples.

### An outlier

If you have made a mistake, it will show on the graph as an *outlier*. This is a point that does not fit the line, like the one in Figure 1.8.

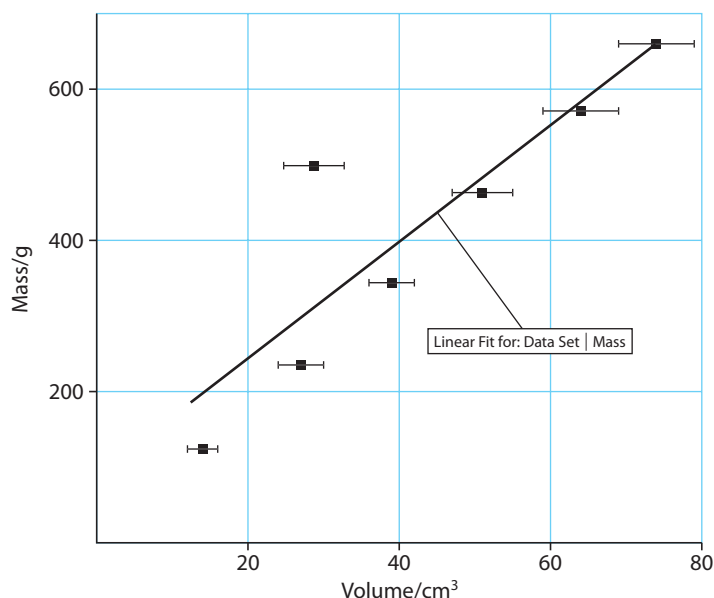
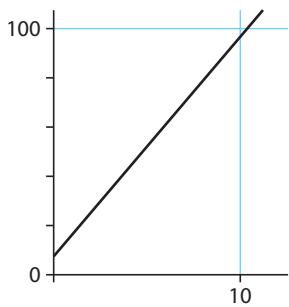


Figure 1.8 Graph with an outlier.



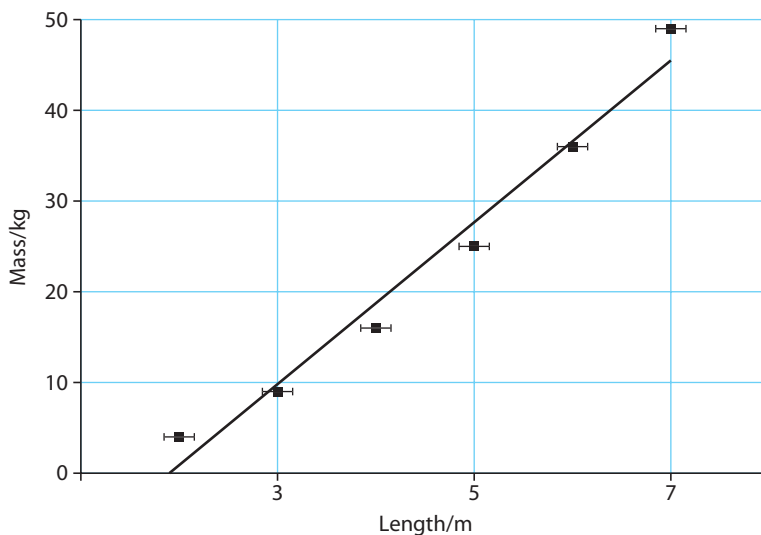
**Figure 1.9** A non-zero intercept.

### A non-zero intercept

If the intercept is supposed to be zero but isn't, this could be due to a systematic error. For example, if all the mass measurements had been 10 g too big, we would get an intercept of 10 g as in Figure 1.9.

### A non-linear trend

Relationships in physics are not always linear. This is shown by the graph in Figure 1.10, where the straight line does not fit, but there is a clear relationship.



**Figure 1.10** Graph with a non-linear trend – the line does not pass through the error bars.

## 1.5 Vectors and scalars

### Scalar

A quantity with magnitude only.

### Vector

A quantity with magnitude and direction.



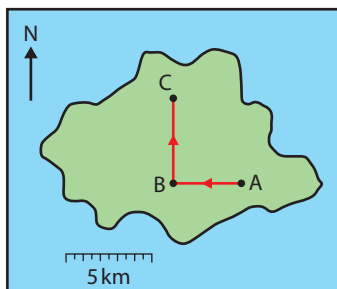
### Assessment statements

- 1.3.1 Distinguish between vector and scalar quantities, and give examples of each.
- 1.3.2 Determine the sum or difference of two vectors by a graphical method.
- 1.3.3 Resolve vectors into perpendicular components along chosen axes.

So far we have dealt with six different quantities:

- Length
- Time
- Mass
- Volume
- Density
- Displacement

All of these quantities have a size, but displacement also has a direction. Quantities that have size and direction are *vectors* and those with only size are *scalars*; all quantities are either vectors or scalars. It will be apparent why it is important to make this distinction when we add displacements together.



**Figure 1.11** Displacements shown on a map.

## Example

Consider two displacements one after another as shown in Figure 1.11. Starting from A walk 4 km west to B, then 5 km north to C.

The total displacement from the start is not  $5 + 4$  but can be found by drawing a line from A to C.

We will find that there are many other vector quantities that can be added in the same way.

## Addition of vectors

Vectors can be represented by drawing arrows. The length of the arrow is proportional to the magnitude of the quantity and the direction of the arrow is the direction of the quantity.

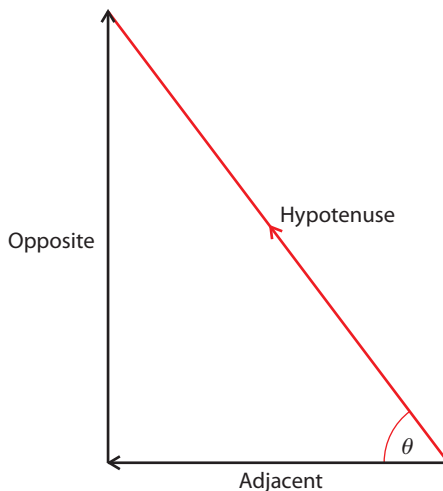
To add vectors the arrows are simply arranged so that the point of one touches the tail of the other. The resultant vector is found by drawing a line joining the free tail to the free point.

## Example

Figure 1.11 is a map illustrating the different displacements. We can represent the displacements by the vectors in Figure 1.12.

Calculating the resultant:

If the two vectors are at right angles to each other then the resultant will be the hypotenuse of a right-angled triangle. This means that we can use simple trigonometry to relate the different sides.



You will find *cos*, *sin* and *tan* buttons on your calculator. These are used to calculate unknown sides of right-angled triangles.

$$\sin \theta = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

$$\cos \theta = \frac{\text{Adjacent}}{\text{Hypotenuse}}$$

$$\tan \theta = \frac{\text{Opposite}}{\text{Adjacent}}$$

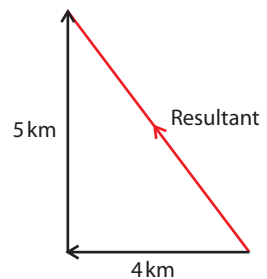


Figure 1.12 Vector addition.

● **Examiner's hint:** Not all vectors add up to give right-angled triangles but as these are the easy ones to solve we will consider only these in this course.

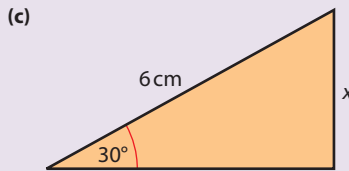
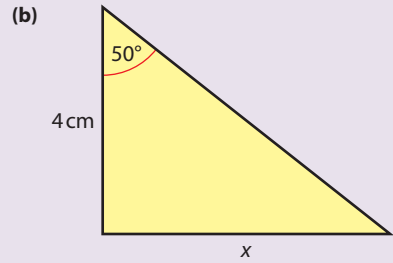
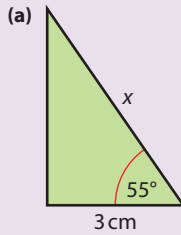
Figure 1.13

**Vector symbols**

To show that a quantity is a vector we can write it in a special way. In textbooks this is often in bold (**A**) but when you write you can put an arrow on the top. In physics texts the vector notation is often left out. This is because if we know that the symbol represents a displacement, then we know it is a vector and don't need the vector notation to remind us.

**Exercise**

10 Use your calculator to find  $x$  in the following triangles.

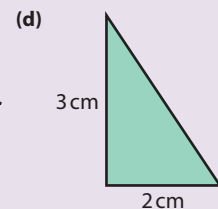
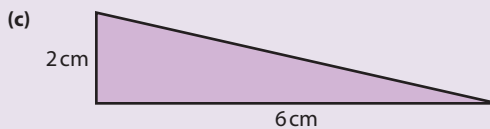
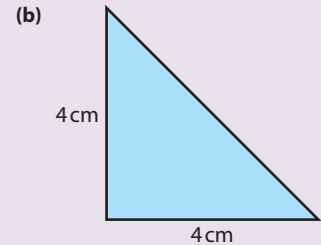
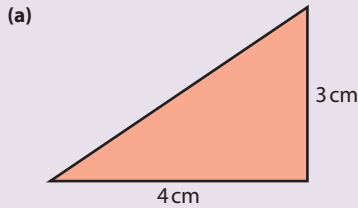
**Pythagoras**

The most useful mathematical relationship for finding the resultant of two perpendicular vectors is Pythagoras' theorem.

$$\text{Hypotenuse}^2 = \text{adjacent}^2 + \text{opposite}^2$$

**Exercise**

11 Use Pythagoras' theorem to find the hypotenuse in the following examples.

**Using trigonometry to solve vector problems**

Once the vectors have been arranged point to tail it is a simple matter of applying the trigonometrical relationships to the triangles that you get.

**Exercises**

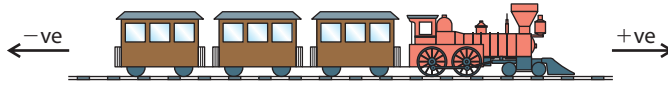
Draw the vectors and solve the following problems using Pythagoras' theorem.

12 A boat travels 4 km west followed by 8 km north. What is the resultant displacement?

13 A plane flies 100 km north then changes course to fly 50 km east. What is the resultant displacement?

## Vectors in one dimension

In this course we will often consider the simplest examples where the motion is restricted to one dimension, for example a train travelling along a straight track. In examples like this there are only two possible directions – forwards and backwards. To distinguish between the two directions, we give them different signs (forward + and backwards –). Adding vectors is now simply a matter of adding the magnitudes, with no need for complicated triangles.

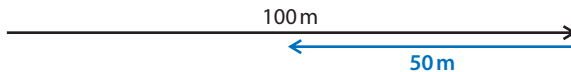


### Worked example

If a train moves 100 m forwards along a straight track then 50 m back, what is its final displacement?

#### Solution

Figure 1.15 shows the vector diagram.



The resultant is clearly 50 m forwards.

## Subtracting vectors

Now we know that a negative vector is simply the opposite direction to a positive vector, we can subtract vector **B** from vector **A** by changing the direction of vector **B** and adding it to **A**.

$$\mathbf{A} - \mathbf{B} = \mathbf{A} + (-\mathbf{B})$$

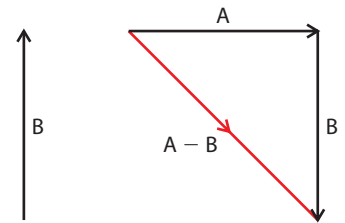
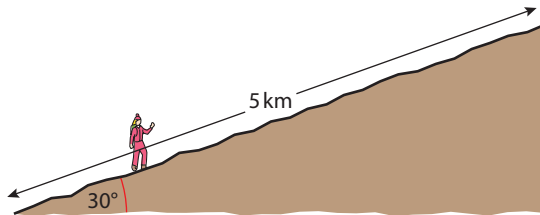


Figure 1.16 Subtracting vectors.

## Taking components of a vector

Consider someone walking up the hill in Figure 1.17. They walk 5 km up the slope but want to know how high they have climbed rather than how far they have walked. To calculate this they can use trigonometry.



$$\text{Height} = 5 \times \sin 30^\circ$$

The height is called the vertical component of the displacement.

The horizontal displacement can also be calculated.

$$\text{Horizontal displacement} = 5 \times \cos 30^\circ$$

This process is called ‘taking components of a vector’ and is often used in solving physics problems.



Which direction is +?

You can decide for yourself which direction you want to be positive but generally we follow the convention:

Right +    Left –  
North +    South –  
Up +        Down –

Figure 1.14 The train can only move forwards or backwards.

**Examiner's hint:** There isn't really any need to draw vector diagrams when doing one-dimensional problems. However, you must never forget that the sign gives the direction.

Figure 1.15 Adding vectors in one dimension.

Figure 1.17 5 km up the hill but how high?

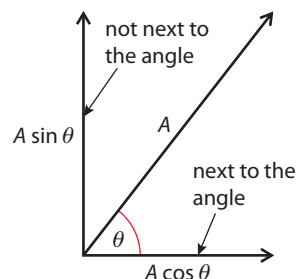


Figure 1.18 An easy way to remember which is cos is to say that it's ‘becos it's next to the angle’.

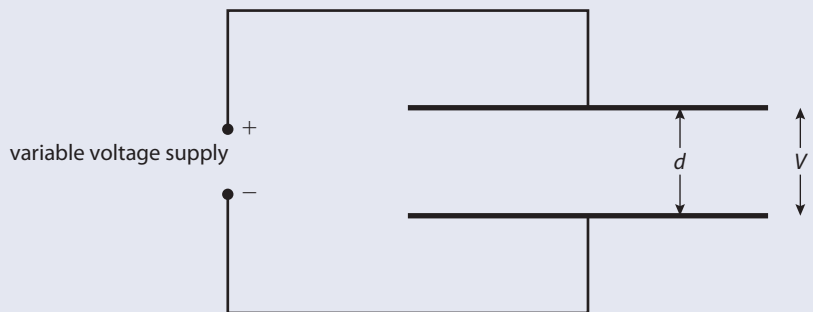
## Exercises

- 14** If a boat travels 10 km in a direction  $30^\circ$  to the east of north, how far north has it travelled?
- 15** On his way to the South Pole, Amundsen travelled 8 km in a direction that was  $20^\circ$  west of south. What was his displacement south?
- 16** A mountaineer climbs 500 m up a slope that is inclined at an angle of  $60^\circ$  to the horizontal. How high has he climbed?

● **Examiner's hint:** Question 1 is about analysing data. It is a typical Paper 2 question. You don't have to know anything about permittivity to answer it.

## Practice questions

- 1** This question is about measuring the permittivity of free space  $\epsilon_0$ . The diagram below shows two parallel conducting plates connected to a variable voltage supply. The plates are of equal areas and are a distance  $d$  apart.



The charge  $Q$  on one of the plates is measured for different values of the potential difference  $V$  applied between the plates. The values obtained are shown in the table below. The uncertainty in the value of  $V$  is not significant but the uncertainty in  $Q$  is  $\pm 10\%$ .

$V/V$	$Q/nC \pm 10\%$
10.0	30
20.0	80
30.0	100
40.0	160
50.0	180

- (a) Plot the data points opposite on a graph of  $V$  ( $x$ -axis) against  $Q$  ( $y$ -axis). (4)
- (b) By calculating the relevant uncertainty in  $Q$ , add error bars to the data points (10.0, 30) and (50.0, 180). (3)
- (c) On your graph, draw the line that best fits the data points and has the maximum permissible gradient. Determine the gradient of the line that you have drawn. (3)
- (d) The gradient of the graph is a property of the two plates and is known as *capacitance*. Deduce the units of capacitance. (1)

The relationship between  $Q$  and  $V$  for this arrangement is given by the expression

$$Q = \frac{\epsilon_0 A}{d} V$$

where  $A$  is the area of one of the plates.

In this particular experiment  $A = 0.20 \pm 0.05 \text{ m}^2$  and  $d = 0.50 \pm 0.01 \text{ mm}$ .

- (e) Use your answer to (c) to determine the maximum value of  $\epsilon_0$  that this experiment yields. (4)

(Total 15 marks)

© International Baccalaureate Organisation

- 2 A student measures a distance several times. The readings lie between 49.8 cm and 50.2 cm. This measurement is best recorded as

- A  $49.8 \pm 0.2 \text{ cm}$ .
- B  $49.8 \pm 0.4 \text{ cm}$ .
- C  $50.0 \pm 0.2 \text{ cm}$ .
- D  $50.0 \pm 0.4 \text{ cm}$ . (1)

© International Baccalaureate Organisation

- 3 The time period  $T$  of oscillation of a mass  $m$  suspended from a vertical spring is given by the expression

$$T = 2\pi\sqrt{\frac{m}{k}}$$

where  $k$  is a constant.

Which **one** of the following plots will give rise to a straight-line graph?

- A  $T^2$  against  $m$
- B  $\sqrt{T}$  against  $\sqrt{m}$
- C  $T$  against  $m$
- D  $\sqrt{T}$  against  $m$  (1)

© International Baccalaureate Organisation

- 4 The power dissipated in a resistor of resistance  $R$  carrying a current  $I$  is equal to  $I^2 R$ . The value of  $I$  has an uncertainty of  $\pm 2\%$  and the value of  $R$  has an uncertainty of  $\pm 10\%$ . The value of the uncertainty in the calculated power dissipation is

- A  $\pm 8\%$ .
- B  $\pm 12\%$ .
- C  $\pm 14\%$ .
- D  $\pm 20\%$ . (1)

© International Baccalaureate Organisation

- 5 An ammeter has a zero offset error. This fault will affect

- A neither the precision nor the accuracy of the readings.
- B only the precision of the readings.
- C only the accuracy of the readings.
- D both the precision and the accuracy of the readings. (1)

© International Baccalaureate Organisation

- 6 When a force  $F$  of  $(10.0 \pm 0.2)$  N is applied to a mass  $m$  of  $(2.0 \pm 0.1)$  kg, the percentage uncertainty attached to the value of the calculated acceleration  $\frac{F}{m}$  is
- A 2%.  
 B 5%.  
 C 7%.  
 D 10%.

(1)

© International Baccalaureate Organisation

- 7 Which of the following is the best estimate, to one significant digit, of the quantity shown below?

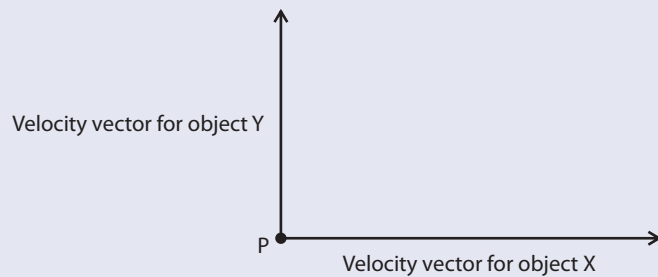
$$\frac{\pi \times 8.1}{\sqrt{(15.9)}}$$

- A 1.5  
 B 2.0  
 C 5.8  
 D 6.0

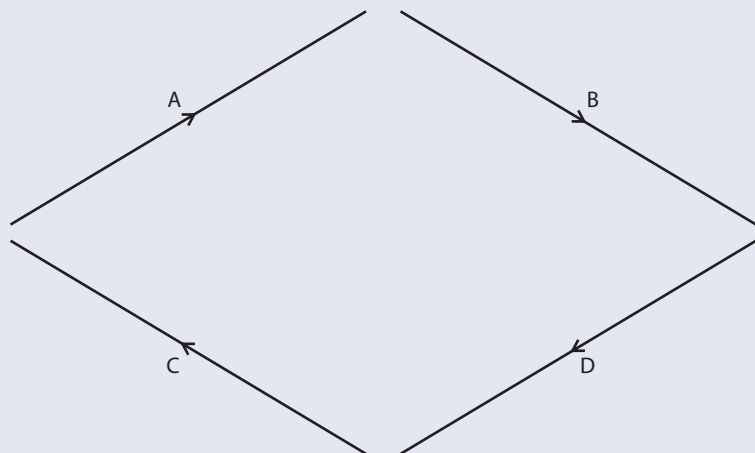
(1)

© International Baccalaureate Organisation

- 8 Two objects X and Y are moving away from the point P. The diagram below shows the velocity vectors of the two objects.



Which of the following velocity vectors best represents the velocity of object X relative to object Y?



(1)

© International Baccalaureate Organisation

- 9 The order of magnitude of the weight of an apple is
- A  $10^{-4}$  N.  
 B  $10^{-2}$  N.  
 C 1 N.  
 D  $10^2$  N.

(1)

© International Baccalaureate Organisation