SCHOLAR Study Guide

# Higher Physics
# Unit 5: Units, Prefixes and Uncertainties


**Authored by:**

Ian Holton (previously Marr College)

**Reviewed by:**

Grant McAllister (Bell Baxter High School)

**Previously authored by:**

Douglas Gavin

John McCabe

Andrew Tookey

Campbell White



**Heriot-Watt University**

Edinburgh EH14 4AS, United Kingdom.

First published 2014 by Heriot-Watt University.

This edition published in 2017 by Heriot-Watt University SCHOLAR.



Distributed by the SCHOLAR Forum.

SCHOLAR Study Guide Higher Physics: Unit 5

Higher Physics Course Code: C757 76

ISBN 978-1-909633-43-8

Print Production and Fulfilment in UK by Print Trail www.printtrail.com

## Acknowledgements

Thanks are due to the members of Heriot-Watt University's SCHOLAR team who planned and created these materials, and to the many colleagues who reviewed the content.

We would like to acknowledge the assistance of the education authorities, colleges, teachers and students who contributed to the SCHOLAR programme and who evaluated these materials.

Grateful acknowledgement is made for permission to use the following material in the SCHOLAR programme:

The Scottish Qualifications Authority for permission to use Past Papers assessments.

The Scottish Government for financial support.

The content of this Study Guide is aligned to the Scottish Qualifications Authority (SQA) curriculum.

# Contents

# Topic 1

# Units, prefixes and scientific notation

Contents



**Learning objective**

By the end of this topic you should be able to:

- understand all the units and prefixes needed for CfE Higher Physics;
- understand how to correctly use scientific notation and significant figures at this level.

## 1.1 Physical quantities, symbols and units

The following sections will cover physical quantities, symbols and units used in:

- Unit 1: Our dynamic universe
- Unit 2: Particles and waves
- Unit 3: Electricity

### 1.1.1 Symbols and units used in Unit 1: Our dynamic universe

| Physics Quantity | Symbol | Unit | Unit Abbreviation |
|---|---|---|---|
| distance | $d$ | metre | m |
| displacement | $s$ | metre | m |
| speed, velocity | $v$ | metre per second | m $s^{-1}$ |
| average velocity | $\bar{v}$ | metre per second | m $s^{-1}$ |
| change in velocity | $\Delta v$ | metre per second | m $s^{-1}$ |
| initial velocity | $u$ | metre per second | m $s^{-1}$ |
| final velocity | $v$ | metre per second | m $s^{-1}$ |
| acceleration | $a$ | metre per second square | m $s^{-2}$ |
| time | $t$ | second | s |
| mass | $m$ | kilogram | kg |
| weight | $W$ | newton | N |
| force | $F$ | newton | N |
| energy | $E$ | joule | J |
| work done | $E_w$ | joule | J |
| potential energy | $E_p$ | joule | J |
| acceleration due to gravity | $g$ | metre per second square | m $s^{-2}$ |

| Physics Quantity | Symbol | Unit | Unit Abbreviation |
|---|---|---|---|
| acceleration due to gravity | $g$ | metre per second square | m $s^{-2}$ |
| gravitational field strength | $g$ | newton per kilogram | N $kg^{-1}$ |
| height | $h$ | metre | m |
| kinetic energy | $E_k$ | joule | J |
| power | $P$ | watt | W |
| momentum | $p$ | kilogram metre per second | kg m $s^{-1}$ |
| impulse | — | newton second | N s |
| universal constant of gravitation | $G$ | metre cube per ( kilogram second square) | $m^3$ $kg^{-1}$ $s^{-2}$ |
| distance between two point masses | $r$ | metre | m |
| speed of light in a vacuum | $c$ | metre per second | m $s^{-1}$ |
| observed time (stationary observer) | $t'$ | second | s |
| observed time (moving observer) | $t$ | second | s |
| observed length (stationary observer) | $l'$ | metre | m |
| observed length (moving observer) | $l$ | metre | m |
| observed frequency (stationary observer) | $f_o$ | hertz | Hz |
| source frequency (moving source) | $f_s$ | hertz | Hz |
| velocity of moving source | $v_s$ | metre per second | m $s^{-1}$ |
| wavelength measured (source stationary) | $\lambda_{rest}$ | metre | m |

| **Physics Quantity** | **Symbol** | **Unit** | **Unit Abbreviation** |
|---|---|---|---|
| wavelength measured (source moving) | $\lambda_{observed}$ | metre | m |
| red shift | $z$ | - - - | - - - |
| Hubble constant | $H_O$ | per second | $s^{-1}$ |

### 1.1.2 Symbols and units used in Unit 2: Particles and waves

| Physics Quantity | Symbol | Unit | Unit Abbreviation |
|---|---|---|---|
| electric charge | $Q$ | coulomb | C |
| voltage, potential difference | $V$ | volt | V |
| Planck's constant | $h$ | joule second | J S |
| frequency | $f$ | hertz | Hz |
| threshold frequency | $f_o$ | hertz | Hz |
| energy level | $E_1$ or $E_2$ | joule | J |
| wavelength | $\lambda$ | metre | m |
| period | $T$ | second | s |
| angle | $\theta$ | degree | $\circ$ |
| order of interference, number of complete wavelengths in a path difference | $m$ | — | — |
| refractive index | $n$ | — | — |
| critical angle | $\theta_c$ | degree | $\circ$ |
| irradiance | $I$ | watt per metre square | W $m^{-2}$ |
| area | $A$ | metre square | $m^2$ |

### 1.1.3 Symbols and units used in Unit 3: Electricity

| **Physics Quantity** | **Symbol** | **Unit** | **Unit Abbreviation** |
|---|---|---|---|
| electric current | $I$ | ampere | A |
| peak voltage | $V_p$ | volt | V |
| root mean square voltage | $V_{rms}$ | volt | V |
| peak current | $I_p$ | ampere | A |
| root mean square current | $I_{rms}$ | ampere | A |
| resistance | $R$ | ohm | $\Omega$ |
| total resistance | $R_T$ | ohm | $\Omega$ |
| electromotive force | $E$ or $\varepsilon$ | volt | V |
| internal resistance | $r$ | ohm | $\Omega$ |
| capacitance | $C$ | farad | F |

## 1.2 Significant figures

It is important when calculating numerical values that the final answer is quoted to an appropriate number of significant figures.
As a general rule, the final numerical answer that you quote should be to the same number of significant figures as the data given in the question.

The above rule is the key point but you might like to note the following points:

1. The answer to a calculation cannot increase the number of significant figures that you can quote.
2. If the data is not all given to the same number of significant figures, identify the least number of significant figures quoted in the data. This least number is the number of significant figures that your answer should be quoted to.
3. When carrying out sequential calculations carry many significant figures as you work through the calculations. At the end of the calculation, round the answer to an appropriate number of significant figures.
4. In the Higher Physics course quoting an answer to three significant figures will usually be acceptable.

**Examples**

**1.** The current in a circuit is 6.7 A and the voltage across the circuit is 21 V. Calculate the resistance of the circuit.

Note: Both of these pieces of data are given to two sig. figs. so your answer must also be given to two sig figs.

I = 6.7 A
V = 21 V
R = ?

$$V = I\ R$$
$$21 = 6.7 \times R$$
$$R = 3.1343$$
$$R = 3.1\ \Omega$$

round to 2 sig figs

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**2.** A 5.7 kg mass accelerates at 4.36 m $s^{-2}$.
Calculate the unbalanced force acting on the mass.

Note: The mass is quoted to two sig. figs and the acceleration is quoted to three sig. figs. so the answer should be quoted to two sig figs.

m = 5.7kg
a = 4.36 m $s^{-2}$
F = ?

$$F = m\ a$$
$$F = 5.7 \times 4.36$$
$$F = 24.852$$
$$F = 25\ N$$

round to 2 sig figs

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**3.** A car accelerates from 0.5037 m $s^{-1}$ to 1.274 m $s^{-1}$ in a time of 4.25 s.
The mass of the car is 0.2607 kg.
Calculate the unbalanced force acting on the car.

Note: The time has the least number of sig figs, three, so the answer should be quoted to three sig figs.

u = 0.5037 m $s^{-1}$
v = 1.274 m $s^{-1}$
t = 4.25 s
m = 0.2607 kg

Step 1: calculate a

$$a = \frac{v - u}{t}$$
$$a = \frac{1.274 - 0.5037}{4.25}$$
$$a = 0.181247\ m\ s^{-2}$$

Step 2: calculate F

$$F = m\ a$$
$$F = 0.2607 \times 0.18147$$
$$F = 0.0472511$$
$$F = 0.0473\ N$$

round to 3 sig figs

**Quiz questions** Go online

**Q1:** A car travels a distance of 12 m in a time of 9.0 s.
The average speed of the car is:

a) 1.3333
b) 1.33
c) 1.3
d) 1.4
e) 1

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**Q2:** A mass of 2.26 kg is lifted a height of 1.75 m. The acceleration due to gravity is 9.8 m $s^{-2}$.
The potential energy gained by the mass is:

a) 38.759 J
b) 38.76 J
c) 38.8 J
d) 39 J
e) 40 J

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**Q3:** A trolley of 5.034 kg is moving at a velocity of 4.03 m $s^{-1}$.
The kinetic energy of the trolley is:

a) 40.878 J
b) 40.88 J
c) 40.9 J
d) 41 J
e) 40 J

## 1.3 Scientific notation

When carrying out calculations, you should be able to use scientific notation. This type of notation has been used throughout the topics where necessary, so you will already be familiar with it

Remember scientific notation is used when writing very large or very small numbers. When a number is written in scientific notation there is usually one, nonzero number, before the decimal point.

**Examples**

**1.** The speed of light is often written as 3 x 108 m $s^{-1}$.

This can be converted into a number in ordinary form by moving the decimal point 8 places to the right, giving 300 000 000 m $s^{-1}$.

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**2.** The capacitance of a capacitor may be 0.000 022 F.

This very small number would often be written as 2.2 x $10^{-5}$ F. The x $10^{-5}$ means move the decimal point 5 places to the left.

Make sure you know how to enter numbers written in scientific notation into your calculator.

### 1.3.1 Prefixes

There are some prefixes that you must know. These are listed in the following table:

| Prefix | Symbol | Symbol |
|---|---|---|
| pico | $p$ | $\times 10^{-12}$ |
| nano | $n$ | $\times 10^{-9}$ |
| micro | $\mu$ | $\times 10^{-6}$ |
| milli | $m$ | $\times 10^{-3}$ |
| kilo | $k$ | $\times 10^{3}$ |
| mega | $M$ | $\times 10^{6}$ |
| giga | $G$ | $\times 10^{9}$ |

In Higher Physics you are expected to know and remember the meaning of all of these prefixes.

# Topic 2

# Uncertainties

Contents

## 2.1 Random, scale and systematic uncertainties

Whenever a physical quantity is measured, there is always an uncertainty in the measurement - no measurement is ever exact. Uncertainties can never be eliminated but must be reduced as far as possible if experimental results are to be valid.

If an experiment 'does not work' - i.e. the expected result is not obtained - this usually means that the uncertainties in the experimental measurements are very high - so high that the anticipated result may be only obtained by chance. Uncertainties can be reduced by careful experimental design and by experimenters exercising care in the way in which they carry out the experiment and take the measurements. Uncertainties must be taken into account when stating the results of experimental investigation.

Quoting a numerical result of an experiment as (value $\pm$ uncertainty) allows us to check the validity of our experimental method. In addition it enables comparison of the numerical result of one experiment with that of another.

If the result of an experiment to measure a physical quantity of known value (e.g. the speed of light *in vacuo*) leads to a range of values that does not include the accepted value then either the experiment is not valid or, more commonly, the uncertainties have been underestimated. An experiment that leads to a smaller range of uncertainties is more valid than an experiment that has a wider range.

When undertaking experiments you should be prepared to discard or to repeat any measurement that is obviously 'wrong' - i.e. not consistent with the other measurements that you have taken.

There are several causes of uncertainty in experimental measurements and these may be random, scale-reading or systematic.

### 2.1.1 Random uncertainties

The effects of random uncertainties are not predictable. For example, when an experimental measurement is repeated several times, the result may not be the same each time. It is likely that some of the readings will be slightly higher than the true value and some will be slightly lower than the true value. Examples could include measurements of time using a stop-watch, measuring an angle using a protractor, measuring length using a measuring tape or ruler.

Random uncertainties are due to factors that cannot be completely eliminated by an experimenter. For example, when taking a measurement of length using a metre stick there may be small variations in the exact positioning of the metre stick from one reading to the next; similarly when reading an analogue meter there may be slight variations in the positions of the experimenter's eyes as readings are taken.

The effects of random uncertainties can be reduced by repeating measurements and finding the mean. The mean value of a number of measurements is the best estimate of the true value of the quantity being measured.

Where a quantity Q is measured n times, the measured value is usually quoted as the mean Qmean of the measurements taken $\pm$ the approximate random uncertainty in the mean. Qmean is the best estimate of the true value and is given by:

$$Q_{mean} = \frac{\Sigma Q_i}{n}$$

The approximate random uncertainty in the mean is given by:

$$\text{approximate random uncertainty} = \frac{Q\ \text{maximum}\ -\ Q\ \text{minimum}}{n}$$

Notes:

1. A random uncertainty can only be calculated from measured data that you would expect to be the same value.
2. A random uncertainty must not be found in calculated values.
3. The above relationship is an approximation; it is not statistically rigorous, but it is sufficiently accurate at this level when at least 5 readings have been taken.

**Example** A student uses a computer program to measure their reaction time. The following values are obtained for the reaction time of the student.

| Attempt number | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Reaction time /s | 0.273 | 0.253 | 0.268 | 0.273 | 0.238 |

a) Calculate the mean reaction time of the student.

b) Calculate the approximate random uncertainty in the mean.

a)

$$mean = \frac{total\ of\ values}{number\ of\ values}$$
$$mean = \frac{(0.273 + 0.253 + 0.268 + 0.273 + 0.238)}{5}$$
$$mean = \frac{1.305}{5}$$
$$mean = 0.261\ s$$

b)

$$\text{random uncertainty} = \frac{(\max value - \min value)}{numbers\ of\ values}$$
$$\text{random uncertainty} = \frac{(0.273 - 0.238)}{5}$$
$$\text{random uncertainty} = 0.007\ s$$

**Interpretation of these calculations**

These are often written as:

best estimate = mean value ± uncertainty

best estimate of reaction time = 0.261 s ± 0.007 s

This means that if the reaction time was measured again it is likely, not guaranteed, that the value would be with the range of 0.261 s plus or minus 0.007 s.

⇒ Likely that measured value of time would lie between 0.254 s and 0.268 s.

**Increasing the reliability**

In order to increase the reliability of a measurement, increase the number of times that the quantity is measured. It is likely that the random uncertainty will decrease.
In the above example this would mean that instead of finding the mean reaction time based on 5 attempts, repeat the measurement so that the calculation is based on 10 attempts.

If you repeat a measurement 5 times and you measure exactly the same value on each occasion then the random uncertainty will be zero. Making further repeated measurements is unnecessary as this will not reduce the random uncertainty so it will not increase the reliability.

## 2.1.2 Scale-reading uncertainties

A scale reading uncertainty is a measure of how well an instrument scale can be read. This type of uncertainty is generally random and is due to the finite divisions on the scales of measuring instruments. For example, the probable uncertainty in a measurement of length, using a metre stick graduated in 1 mm divisions, is 0.5 mm. If more precision is needed then a different measuring instrument (e.g. a metal ruler or a micrometer) or a different technique must be used.

For instruments with analogue scales, the scale-reading uncertainty is usually taken as ± half of the smallest scale division. In some cases, it may be possible to make reliable estimates of smaller fractions of scale divisions.

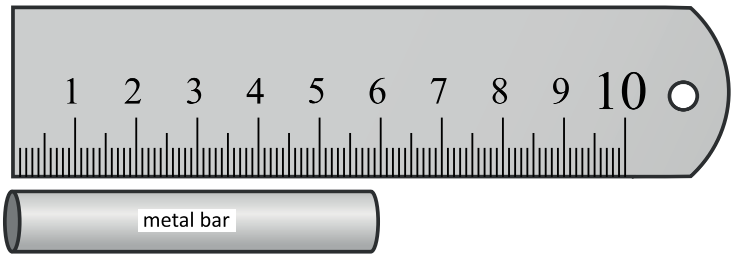
For instruments with digital scales the reading uncertainty is 1 in the last (least significant) digit.

**Examples**

**1. Example 1: Analogue scale**

This approach is used for rulers, metre sticks, liquid in glass thermometer and meters which have a pointer.

The length of metal is measured with the ruler shown below.




Length 6 cm
Scale reading uncertainty = half of one scale division = 0.5 mm

Often expressed as 6.0 cm $\pm$ 0.5 mm

This means that the best estimate of the length is 6.0 cm and it would be expected that the "true" length would be between 5.95 cm and 6.05 cm.

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**2. Example 2: Digital display**

This approach is used whenever a seven segment digital display is present.

The image below shows a digital ammeter.


Current = 12.9 A
Scale reading uncertainty = one in smallest scale division = 0.1 A

Often expressed as 12.9 A $\pm$ 0.1 A

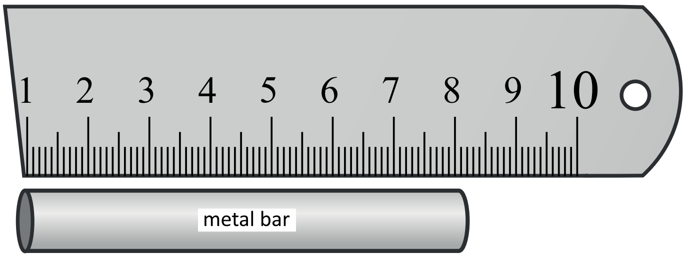
This means that the best estimate of the current is 12.9 A and it would be expected that the "true" current would be between 12.8 A and 13.0 A

### 2.1.3 Systematic uncertainties

Systematic uncertainties have consistent effects on the quantities being measured.

Systematic uncertainties often arise due to experimental design or issues with the equipment.

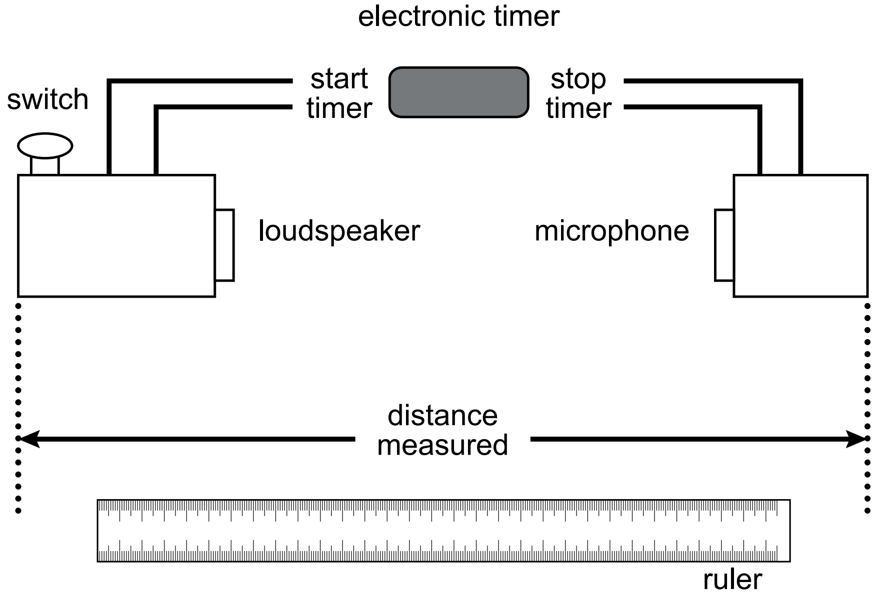
The following example shows a ruler being used to measure the length of a metal bar.




At first sight the length of the metal bar is 8 cm.
However, on closer inspection the actual length is only 7 cm as the ruler starts at 1 cm rather than 0 cm.
This ruler could easily cause all measured values to be too long by 1 cm. This would be a systematic uncertainty.

This systematic uncertainty could have been noticed by the experimenter and corrected but often the presence of a systematic uncertainty is not detected until data is analysed.

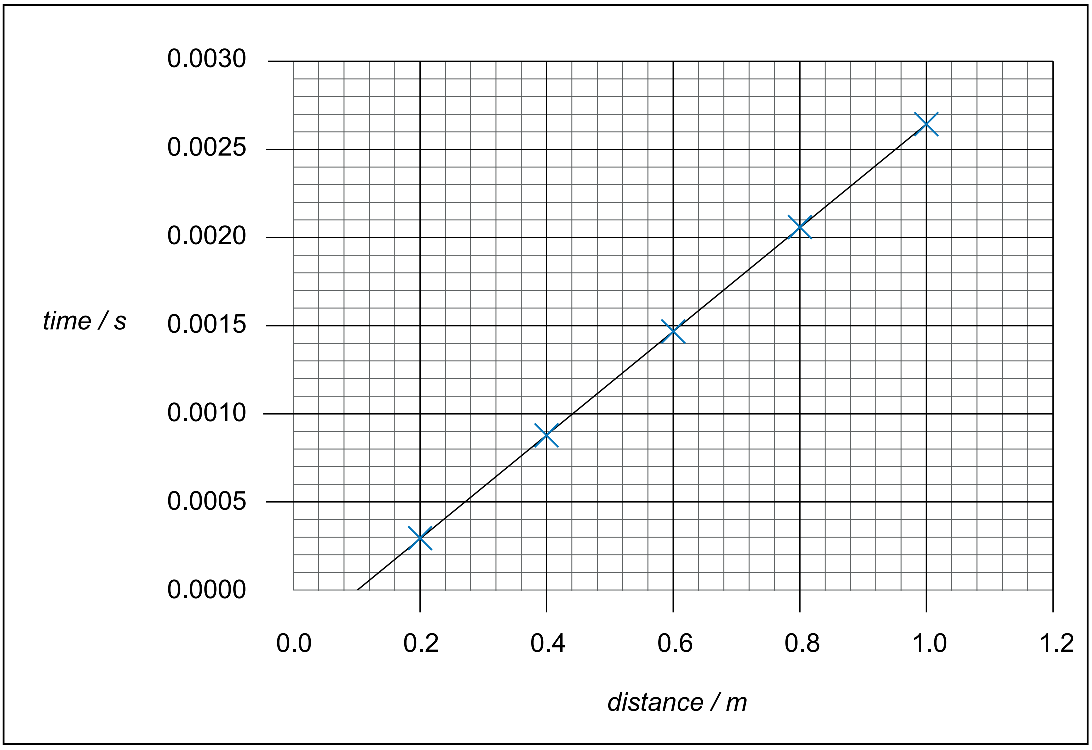
**Example** A student is investigating how the distance between a loudspeaker and microphone affects the time it takes a pulse of sound to travel from the loudspeaker to the microphone. The equipment used is shown below.




When the switch is pressed the loudspeaker produces a sound and the timer starts. When the sound reaches the microphone the timer is stopped.

The distance shown is measured with a ruler. The distance is altered by moving the microphone to a greater distance from the loudspeaker and further measurements are taken.

The results obtained are displayed on the following graph.



The expected graph is a straight line through the origin.
Here a straight line is obtained but it does not go through the origin.
This shows that there is a systematic uncertainty in the investigation.

The line is too far to the right so **all** of the distance measurements are too big by the same value. There is a systematic uncertainty of 0.1 m. This value is found by finding the intercept on the distance axis.

What has caused this systematic uncertainty?

Look at the labelled diagram and notice that the distance is between the extreme edges of the loudspeaker and the microphone.
The sound will be made inside the loudspeaker box and the microphone will be inside the microphone box. This means that the sound does not have to travel this distance and all the distances measured are too big by 0.1 m.

**Further thoughts on this investigation**

1. The gradient of this graph can lead to an estimate of the speed of sound.

$$gradient = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{rise}{run}$$
$$gradient = \frac{\Delta \text{time}}{\Delta \text{distance}}$$
$$gradient = \frac{(0.0015 - 0)}{(0.6 - 0.1)}$$
$$gradient = 3 \times 10^{-3}$$

since

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

and here

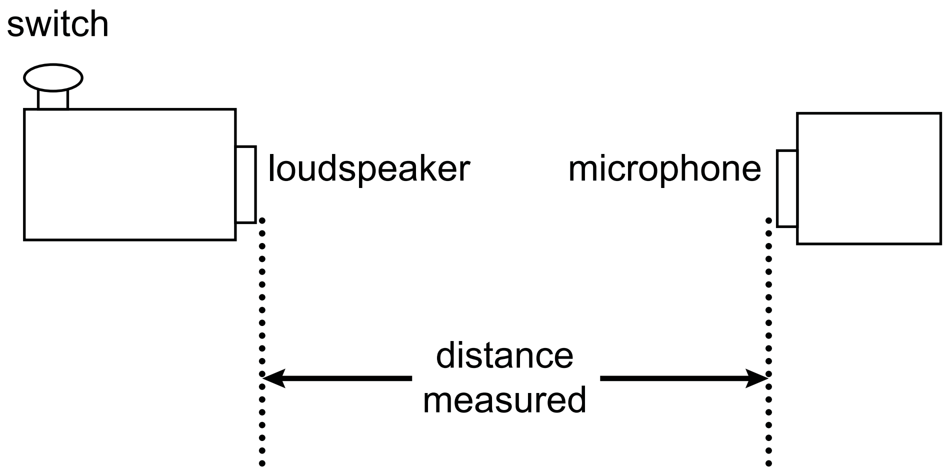
$$gradient = \frac{\Delta \text{time}}{\Delta \text{distance}}$$

hence

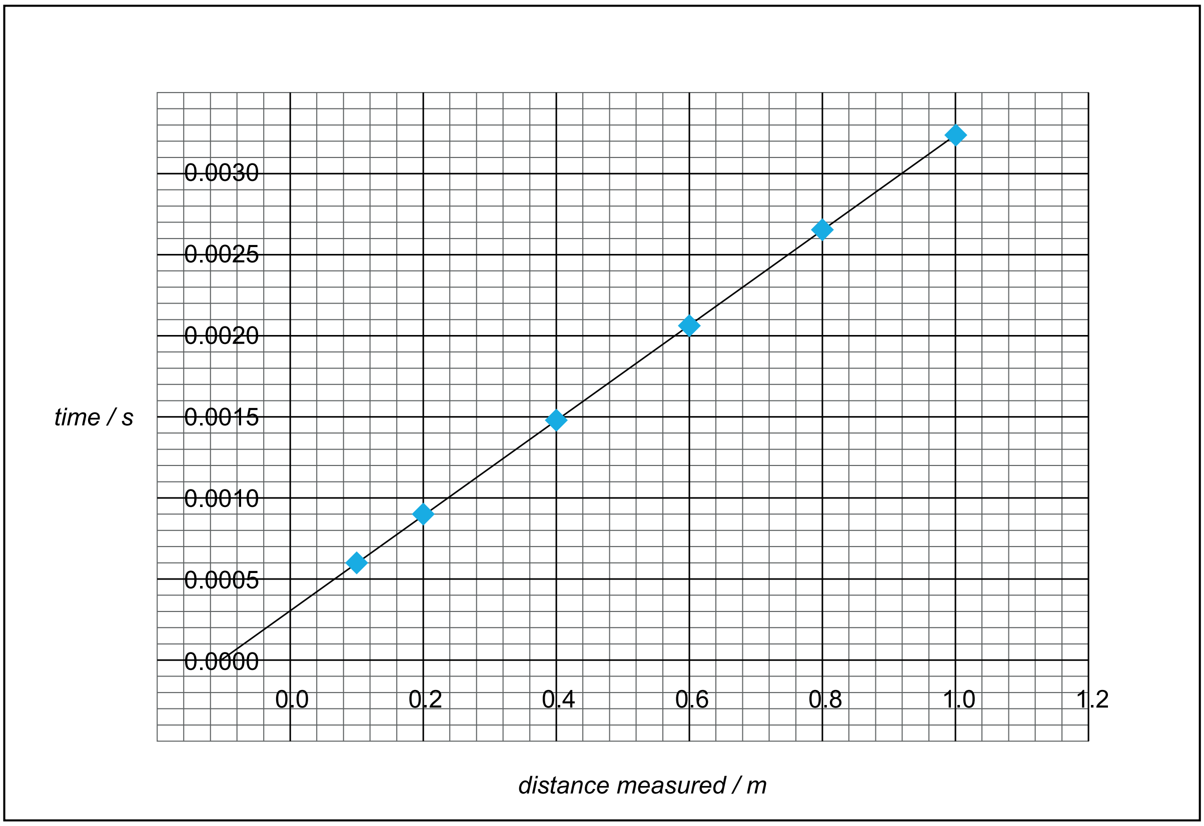
$$speed = \frac{1}{gradient}$$
$$speed = \frac{1}{3 \times 10^{-3}}$$

Speed of sound = 333 m s$^{-1}$

2. It may be suggested that the systematic uncertainty could be removed by measuring the distance between the inside edges of the loudspeaker and microphone as shown in the following diagram.




This would result in the following graph.




Using this approach, a straight line is obtained but again does not pass through the origin indicating the presence of a systematic uncertainty. The line is too far to the left.
The distance measured is too short and the underestimate is always 0.1 m. This value is found from the intercept on the distance axis. This means that all the distance measurements are too small by 0.1 m.

It is impossible to remove the systematic uncertainty unless the actual positions of where the sound is produced and where the sound is detected are known. This cannot be done if the components are mounted inside "boxes".

The gradient of this graph would again give an estimate of the speed of sound.

Identifying systematic effects is often an important part of the evaluation of an experiment.

### 2.1.4 Calibration uncertainties

Calibration uncertainties are associated with the measuring instruments used, and are usually systematic. Calibration uncertainties may be predictable or unpredictable. For example the drift of the time base of an oscilloscope due to temperature changes may not be predictable but it is likely to have a consistent effect on experimental results. Other examples of calibration uncertainties are a clock running consistently fast or consistently slow, an ammeter reading 5% higher than the true reading and a balanced incorrectly zeroed at the start of an experiment reading consistently too high or too low.

### 2.1.5 Calculating and stating uncertainties

**Single measurements** may be quoted as $\pm$ measurement absolute uncertainty, for example 53.20 $\pm$ 0.05 cm. When measured quantities are combined (e.g. when the quantities are multiplied, divided or raised to a power) to obtain the final result of an experiment it is often more useful to quote measurement $\pm$ percentage uncertainty, where

$$\text{percentage uncertainty} = \frac{\text{actual uncertainty}}{\text{measurement}} \times 100$$

In an experiment where more than one physical quantity has been measured, the largest percentage uncertainty in any individual quantity is often a good estimate of the percentage uncertainty in the final numerical result of the experiment.

When comparing the uncertainty in two or more measured values it is necessary to compare percentage uncertainties not absolute uncertainties.

In an investigation the distance travelled and the time taken are measured and the results are expressed in the form.

Best estimate $\pm$ absolute uncertainty

| | | |
|---|---|---|
| distance,d | = | 125 mm $\pm$ 0.5 mm (metre stick, analogue device) |
| time, t | = | 5. 2 s $\pm$ 0.1 s (stop watch, digital device) |

$$\begin{aligned}
\%uncertind &= \frac{absoluteuncertind}{measurmentofd} \times 100 \\
\%uncertind &= \frac{0.5}{125} \times 100 \\
\%uncertind &= 0.4\% \\
\%uncertint &= \frac{absoluteuncertint}{measurmentoft} \times 100 \\
\%uncertint &= \frac{0.1}{5.2} \times 100 \\
\%uncertint &= 2\%
\end{aligned}$$

In order to compare the precision of these two measurements the percentage uncertainty in each measurement must be calculated.

Comparing these two percentage uncertainties it can be seen that the percentage uncertainty in time is much greater than the percentage uncertainty in the distance.

**Finding the uncertainty in a calculated value**

The uncertainty in a calculated value can be estimated by comparing the percentage uncertainties in the measured values. At Higher level normally one percentage uncertainty will be three or more times larger than all the other and as a result this largest percentage uncertainty will be a good estimate of the uncertainty in the calculated value.

**Evaluating an experimental method**

In order to improve the precision of an experiment it is necessary to find the measurement with the largest percentage uncertainty and consider how this percentage uncertainty could be reduced. Using the figures given above for distance and time the percentage uncertainty in time is greatest therefore an improvement method of measuring the time is required. Using two light gates connected to an electronic timer would enable the time to be measured with a smaller scale reading uncertainty. This would improve the precision in the measurement of time and hence in average speed.

**Example** Using the measured values of distance and time given, calculate the average speed of the moving object. In order to carry this out the percentage uncertainties in distance and time must be know.

distance,d = 125 mm $\pm$ 0.4%

time, t = 5. 2 s $\pm$ 2%

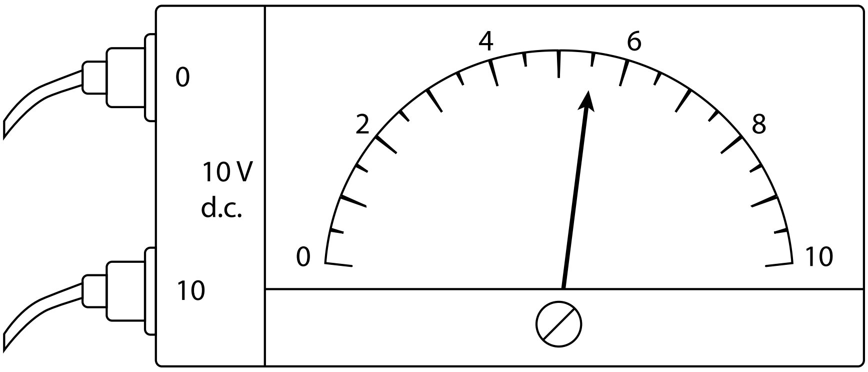
$$averagespeed = \frac{distance\ gone}{time\ taken}$$
$$averagespeed = \frac{125}{5.2}$$
$$averagespeed = 24mms^{-1}$$

The percentage uncertainty in the average speed will be 2%. The percentage uncertainty in t is more than three time the percentage uncertainty in d.

$$averagespeed = 24mms^{-1} \pm 2\%$$

**Quiz** Go online

**Q1:** State the scale reading uncertainty in the following voltmeter reading.



a) ± 0.25 V
b) ± 0.5 V
c) ± 1.0 V
d) ± 2.0 V
e) ± 5.5 V

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**Q2:** A student carries out an investigation to measure the time taken for ten complete swings of a pendulum.
The following values are obtained for the time for ten complete swings.

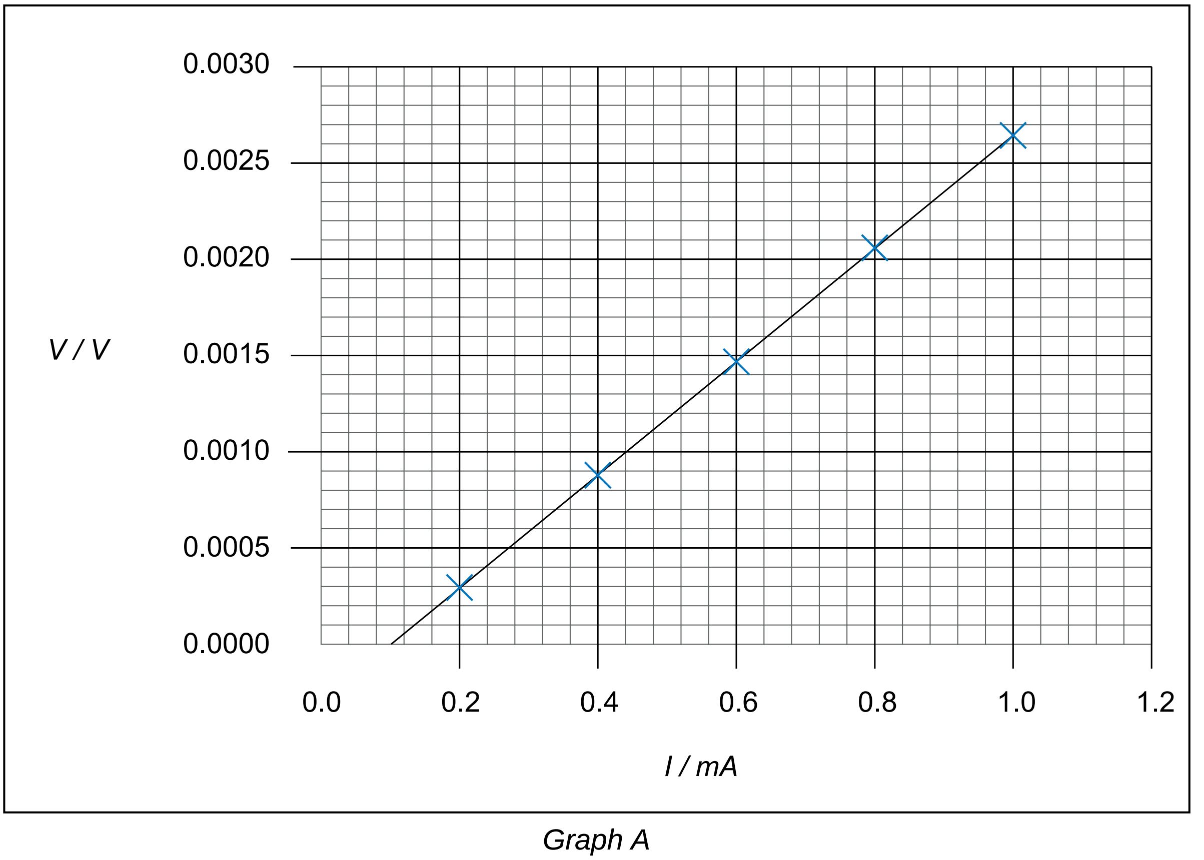
| | | | | |
|---|---|---|---|---|
| 3.1 s | 3.8 s | 3.3 s | 4.1 s | 3.4 s |

What is the random uncertainty in the time for ten complete swings?

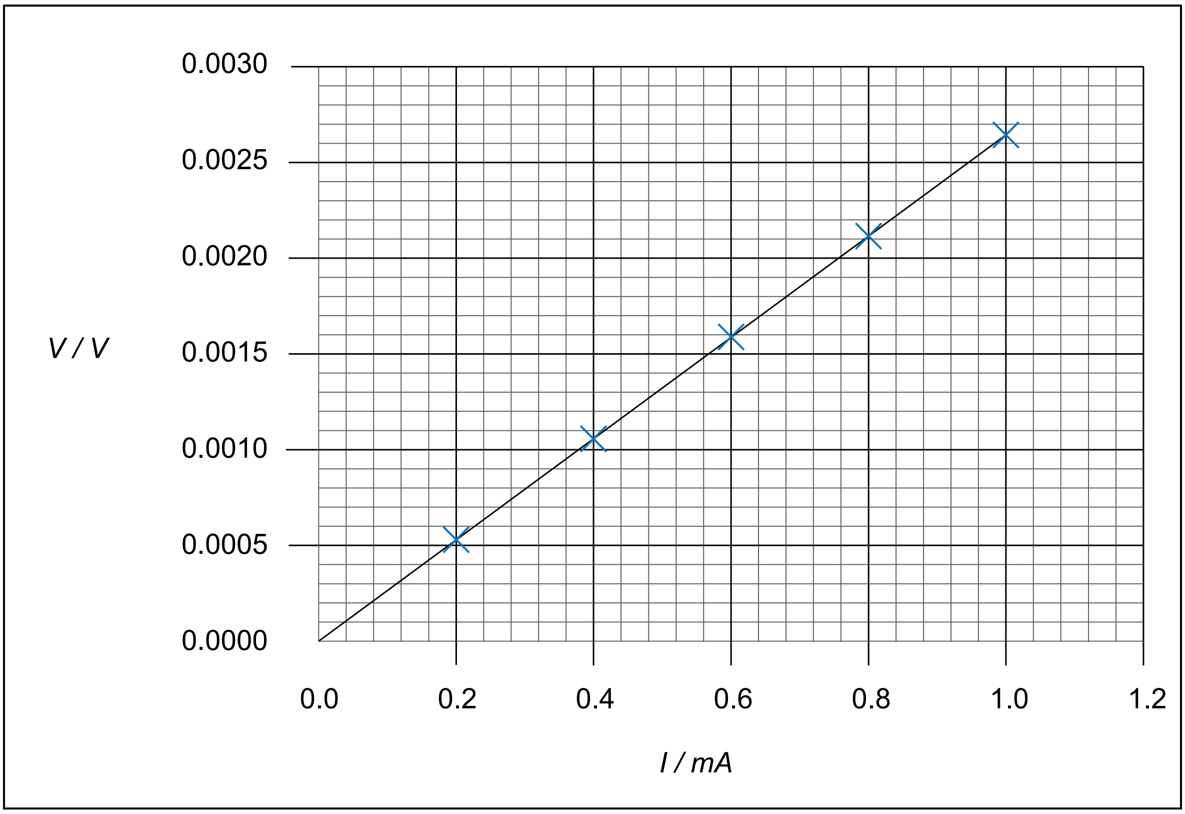
a) ± 0.01 s
b) ± 0.02 s
c) ± 0.1 s
d) ± 0.2 s
e) ± 1.0 s

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

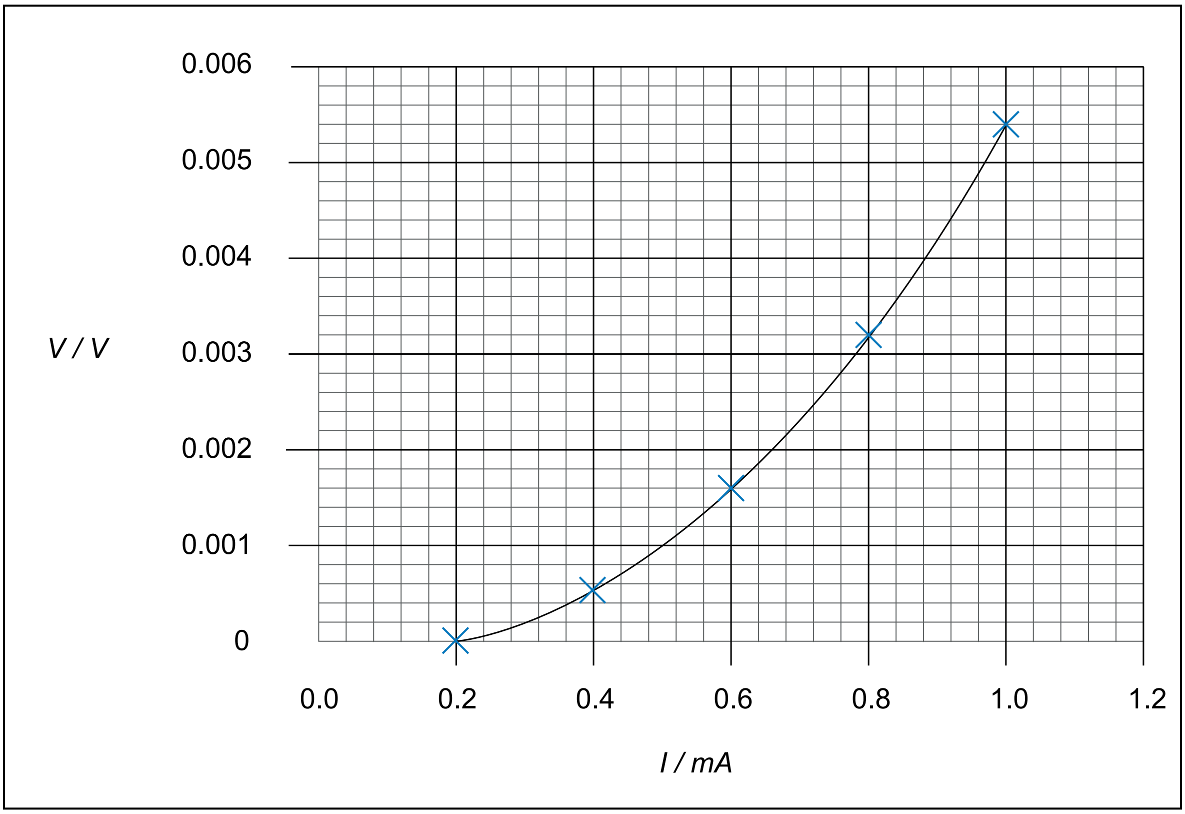
**Q3:** A student carries out three investigations into the variation of voltage and current. The results obtained are shown in the Graphs A, B and C.




*Graph A*




*Graph B*




*Graph C*

Which of the following statements is/are true?

- I Graph A shows a systematic uncertainty
- II Graph B shows a proportional relationship
- III Graph C shows a systematic uncertainty

a) I only
b) II only
c) I and II only
d) I and III only
e) I, II and III

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**Q4:** In an experiment the following measurements and uncertainties are recorded.

| | | |
|---|---|---|
| Temperature rise | = | $10° C \pm 1°C$ |
| Heater current | = | $5.0$ A $\pm$ $0.2$ A |
| Heater voltage | = | $12.0$ V $\pm$ $0.5$ V |
| Time | = | $100$ s $\pm$ $2$ s |
| Mass of liquid | = | $1.000$ kg $\pm$ $0.005$ kg |

The measurement which has the largest percentage uncertainty is the:

a) Temperature rise
b) Heater current
c) Heater voltage
d) Time
e) Mass of liquid

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**Q5:** In an investigation the acceleration of a trolley down a slope is found to be $2.5$ m $s^{-2}$ $\pm$ 4%.
The absolute uncertainty in this value of acceleration is:

a) $\pm$ 0.04 m $s^{-2}$
b) $\pm$ 0.1 m $s^{-2}$
c) $\pm$ 0.4 m $s^{-2}$
d) $\pm$ 1.0 m $s^{-2}$
e) $\pm$ 4.0 m $s^{-2}$

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**Q6:** In an investigation the voltage across a resistor is measured as 20 V $\pm$ 2 V and the current through it is 5.0 A $\pm$ 0.1 A.
The percentage uncertainty in the power is:

a) 0.1%
b) 2%
c) 3%
d) 10%
e) 12%

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**Q7:** Specific heat capacity can be found from the experimental results given below.
Which one of the following measurements creates most uncertainty in the calculated value of the specific heat capacity?

a) Power = 2000 $\pm$ 10 W
b) Time = 300 $\pm$ 1 s
c) Mass = 5.0 $\pm$ 0.2 kg
d) Final temperature = 50 $\pm$ 0.5°C
e) Change in temperature = 30 $\pm$ 1°C

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**Q8:** The light coming from a spectral lamp is investigated and the following data is obtained.

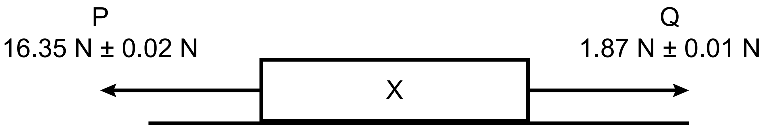
$$\lambda = 450 \text{ nm} \pm 10\%$$
$$\text{f} = 6.7 \times 10^{14}\text{Hz} \pm 2\%$$

This data is used to estimate the speed of light. The absolute uncertainty in this estimate of the speed of light is:

a) $\pm$ 2.0 m $s^{-1}$
b) $\pm$ 10 m $s^{-1}$
c) $\pm$ 6.0 x 106 m $s^{-1}$
d) $\pm$ 3.0 x $10^7$ m $s^{-1}$
e) $\pm$ 3.6 x $10^7$ m $s^{-1}$

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**Q9:** Two forces P and Q act on an object X as shown.




The value of the unbalanced force acting on the object X and the percentage uncertainty in this value, expressed in the form value $\pm$ absolute uncertainty is:

a) 14.48 N $\pm$ 0.03N
b) 14.48 N $\pm$ 0.08N

c) 14.48 N $\pm$ 0.5N
d) 18.22 N $\pm$ 0.03 N
e) 18.22 N $\pm$ 0.08N

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**Q10:** A student measures their reaction time using the digital stop watch on a computer. The following measurements of their reaction time are displayed on the computer's digital stop watch.

| | | | | |
|---|---|---|---|---|
| 0.29 s | 0.25 s | 0.22 s | 0.26 s | 0.24 s |

When evaluating this set of measurements the student makes the following statements.

- I Increasing the number of attempts from 5 to10 would make the mean value more reliable.
- II The scale reading uncertainty in this set of measurements is $\pm$ 0.01 s.
- III You can tell by reviewing the measurements that there is no systematic uncertainty present.

Which of the above statements is/are correct?

a) I only
b) II only
c) III only
d) I and II only
e) I, II and III

## 2.2 Uncertainties and data analysis

In the following topics we will be evaluating experimental results and comparing accuracy and precision.

### 2.2.1 Evaluating experimental results: accuracy and precision

These two words are often used when evaluating experimental results. It is important that they are used correctly.

**Accuracy**

The word accuracy is used when considering how close a measured value is to the true or expected result.

**Example** A student measures the acceleration due to gravity by two different methods. The values obtained are shown below.

Method 1 = 9.4 m $s^{-2}$

Method 2 = 10.1 m $s^{-2}$
Method 2 is closer to the accepted value of 9.8 m $s^{-2}$.
This means that method 2 gives the more accurate result.

**Precision**

The word precision is used when considering how reproducible or repeatable a measurement is. It is often related to the percentage uncertainty in a measurement. (Remember "p" for precision and "p" for percentage uncertainty.)

**Example** Which of the following two voltage measurements is most precise?

$$V_1 = 0.55 \pm 0.01\ V$$
$$V_2 = 6.4 \pm 0.1\ V$$

In order to compare these two measurements the percentage uncertainty in each measurement of voltage must be found.

$$V_1 = 0.55\ V \pm 1.8\%$$
$$V_2 = 6.4\ V \pm 1.6\%$$

The percentage uncertainty in $V_2$ is less than the percentage uncertainty in $V_1$.

This means that V2 is the more precise measurement.

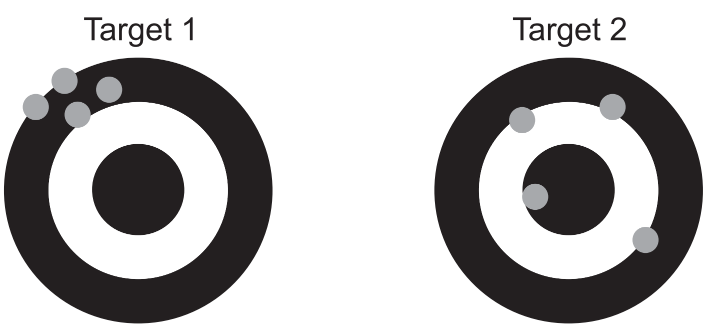
### 2.2.2 Comparing accuracy and precision

In order to help you develop your understanding of accuracy and precision the spread of bullet marks on a target can be considered.

Four bullet marks are shown on each target.

**Accuracy**

Which target shows the more accurate set of shots?




Target 2 is shows the more accurate set of shots because the bullet marks are nearer the middle of the target.

**Precision**

Look again at Target 1 and Target 2. Which target shows the more precise set of shots?

Target 1 is shows the more precise set of shots because the spread of the bullet marks is less.

It is worth noting that since Target 1 shows a set of precise shots, but not accurate shots, it suggests there may be a systematic uncertainty. For example the sights on the gun may be misaligned or there may a wind blowing in a constant direction.

### 2.2.3 Evaluating experimental results in terms of accuracy and precision

A student uses two methods to measure the wavelength of a helium-neon laser. The accepted wavelength for this type of laser is 633 nm.

The results obtained by the student are shown in the table below.

| Method | Wavelength / nm | Uncertainty in wavelength / nm |
|---|---|---|
| 1 | 640 | 25 |
| 2 | 630 | 40 |

**Evaluation**

Accuracy:
Method 2 is more accurate because the value obtained is closer to the accepted value. Method 2 is only 3 nm away from the accepted value while method 1 is 7 nm away from the accepted value.

Precision:
In order to compare the precision of the two methods the percentage uncertainty in each method must be calculated.

Method 1:

$$\%\text{uncert in } \lambda = \frac{uncert\ in\ \lambda \times 100}{\lambda}$$
$$\%\text{uncert in } \lambda = \frac{25 \times 100}{640}$$
$$\%\text{uncert in } \lambda = 3.9\%$$

Method 2:

$$\%\text{uncert in } \lambda = \frac{uncert\ in\ \lambda \times 100}{\lambda}$$
$$\%\text{uncert in } \lambda = \frac{40 \times 100}{630}$$
$$\%\text{uncert in } \lambda = 6.3\%$$

Method 1 has the lower percentage uncertainty in the wavelength therefore it is the more precise method of measurement.

Overall:
Since method 1 is more precise but less accurate, it suggests there is a systematic uncertainty in method 1.
This systematic uncertainty is making all the results too large. The experimental set up should be reviewed in an attempt to identify the source of the systematic uncertainty. If a grating was being used in this method then it may be that the number of lines per millimetre is not correct. The experiment could be repeated using another grating.

Since method 2 is less precise the results should be reviewed to identify the measurement that is contributing the most significant uncertainty. If a random uncertainty was the most significant uncertainty then the first suggestion would be to increase the number of repetitions. This may reduce the percentage uncertainty in the calculated value of the wavelength and improve the precision of the value obtained.

# Hints for activities

## Topic 1: Units, prefixes and scientific notation

### Quiz questions

**Hint 1:** Data is quoted to 2 sig figs so answer must be quoted to 2 sig figs.

**Hint 2:** The acceleration due to gravity is quoted to only 2 sig figs so the answer must be given to 2 sig figs.

**Hint 3:** The mass of the trolley is given to 4 sig figs and the velocity is given to 3 sig figs.

# Answers to questions and activities

## Topic 1: Units, prefixes and scientific notation

### Quiz questions (page 10)

**Q1:** c) 1.3

**Q2:** d) 39 J

**Q3:** c) 40.9 J

## Topic 2: Uncertainties

### Quiz (page 22)

**Q1:** a) $\pm$ 0.25 V

**Q2:** d) $\pm$ 0.2 s

**Q3:** c) I and II only

**Q4:** a) Temperature rise

**Q5:** b) $\pm$ 0.1 m $s^{-2}$

**Q6:** d) 10%

**Q7:** c) Mass = 5.0 $\pm$ 0.2 kg

**Q8:** d) $\pm$ 3.0 x $10^7$ m $s^{-1}$

**Q9:** b) 14.48 N $\pm$ 0.08N

**Q10:** d) I and II only