SCHOLAR Study Guide

Higher Physics
Unit 4: Researching Physics

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Contents

Topic 1

Web-based research

Contents

Prerequisites

You should already:

- have carried out a variety of practical experiments throughout the course (Higher Physics);
- be familiar with researching a physics issue and collating this information into a short presentation (National 5, Outcome 2.2 & 2.3);
- be familiar with the following from your National 5 Assignment:
    - applying knowledge of physics to new situations and interpreting information;
    - selecting and presenting information appropriately in a variety of forms;
    - processing the information/data collected (using calculations and units, where appropriate);
    - drawing valid conclusions and giving explanations supported by evidence/justification;
    - communicating findings/information (National 5, Assignment);
- be familiar with applying your knowledge of experimental techniques to unfamiliar situations (National 5, Outcome 2.4).

Learning objective

By the end of this topic, you should have:

- developed the key skills necessary to undertake research in physics;
- demonstrated the relevance of physics theory to everyday life by exploring the physics behind a topical issue;
- investigated the underlying physics of an issue or story featured in broadcast and publishing media;
- experienced carrying out literature based research. In particular, candidates carrying out web-based research should be familiar with issues of reliability and they should be able to clearly state the source of the information they find;
- developed the skills to allow you to reference websites to allow another person to find the same information;
- the ability to carry out research in order to answer an individual focus question set by your teacher.

1.1 Test your prior knowledge

Q1: Data should be recorded in a table with

a) appropriate significant figures.
b) units.
c) headings.
d) All of the above

. . . .

Q2: When conducting an experiment the variable which you are altering is called the

a) independent variable.
b) dependent variable.
c) constant.
d) hypothesis.

. . . .

Q3: Which of the following could be the correct way to write up an experiment?

a) Aim, Results, Evaluation, Conclusion
b) Aim, Method, Results, Evaluation
c) Aim, Method, Results, Conclusion, Evaluation
d) Aim, Method, Conclusion, Evaluation, Results

1.2 Physics research

The aim of the Researching Physics unit of the course is to help you to develop the key skills necessary to undertake research in physics.

The first step in any research activity involves finding out about a particular topic by carrying out a literature search.

You will be provided with a focus question on a topical issue (this will be given to you by your teacher) and will be expected to research the underlying physics associated with this issue.

The brief you might be given can contain a number of focus questions related to the topic. You will be expected to provide a clear and accurate answer to **one** focus question.

In order to do this, you will have to carry out a number of tasks including:

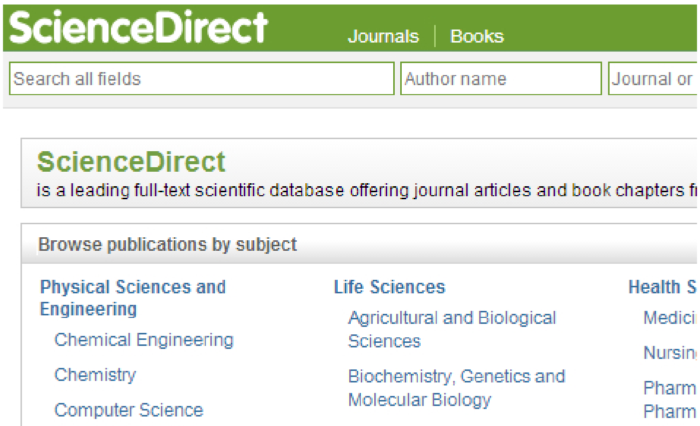
- obtaining and recording information from suitable sources relating to a focus question;
- recording the sources of information selected.

To avoid wasting time and resources it is essential that scientists check the literature to find out what is already known about their area of research.

Scientists use different methods to communicate their findings. These include:

- writing books;
- presenting at conferences - this can be a talk or a conference poster;
- publishing articles in scientific journals and magazines;
- appearing on TV programmes;
- publishing their findings on the internet.

You may be able to use books, scientific journals, videos, TV programmes, etcetera, to access the information you need. However, as the internet can provide information within hours of the completion of an experiment or report, websites offer some of the most up-to-date information on new areas of science. The internet also offers free access to a far greater volume of information than is likely to be found in school or college libraries.



http://www.sciencedirect.com, one of the largest scientific databases

1.3 Carrying out web-based research

The aim of this topic is to help you undertake **effective** web-based research. It is easy to simply look up a single fact on the internet, but harder to know whether or not the information found is accurate and reliable.

When you are carrying out your research:

1. keep your focus question in mind and try not to get side-tracked;
2. don't write as you go along. Instead, bookmark the sites that are of interest to you and return to them when you have finished surfing. You will probably decide later that some of the sites are of no real use;
3. answer your focus question **after** you have gathered all the information that you think you require.

A few simple checks will always allow you to evaluate web-based resources to decide how trustworthy they are.

1.4 Evaluating websites

The internet allows you to access a huge amount of information. However, as this is not controlled, and anyone can publish almost anything on it, you have to decide if the information that you retrieve is reliable.

This activity involves three tasks which address reliability, level and bias of websites.

1.4.1 Reliability

How do we know that information that appears on a web page is reliable and accurate?

Well, the simple answer is that we don't.

However, we can use some key questions to evaluate the accuracy of the sites we find.

The key questions you should ask yourself are:

1. Who wrote the site? Check the address, particularly the domain.
    - .ac and .edu domains are educational sites
    - .gov domains are government sites
    - .co and .com domains are commercial sites
    - .org domains are used by non-profit organisations
2. What is the purpose of the site?
    - Is it to sell something? To inform? To persuade? The domain name should help you to determine this.
3. How current is the site?
    - Check the most recent update. Was it updated in the last week? Month? 6 months? Year?

Reliability: Questions (15 min) Go online

You have been asked to investigate greenhouse gases. Your task is to find out which the main gases are that are thought to contribute to global warming.

Go online and look up the following sites on a web browser:

- http://en.wikipedia.org/wiki/Greenhouse_gas
- http://www.gov.scot/Publications/2016/06/2307/329342

Within these two sites, you will find lists of the principal greenhouse gases, but the lists differ.

Q4: Which source do you think should be the most reliable?

....

Q5: Which list do you think is accurate?

To resolve this particular problem, continue your search to find other listings of greenhouse gases.

Q6: Is either of the original listings inaccurate?

1.4.2 Assessing level

As you carry out research from the web, you will find that sites vary in their complexity.

Always bear in mind that you are studying for Higher Physics - you need to ensure that the information you use is at the right level.

As a rule, try to source information that is at an appropriate level. Having said this, it is usually better to use more straightforward information than complex data that you don't understand yourself.

Assessing level: Questions (15 min) Go online

To illustrate this, suppose you are researching cosmology and want to find out more about black holes.

Go online and visit the following three sites:

- http://www.damtp.cam.ac.uk/research/gr/public/bh_intro.html
- http://www.astrosociety.org/education/publications/tnl/24/24.html
- http://arxiv.org/pdf/0711.2279v2.pdf

The three sites each describe black holes.

Q7: Which of the three is too complex for your level?

. . . .

Q8: Which site gives an easily understood definition of black holes at an appropriate level for a Higher Physics candidate?

1.4.3 Assessing bias

Websites are written for a number of different reasons. The information that is presented on the site will depend on the purpose of the site.

Assessing bias: Questions (15 min) Go online

The three sites below contain information about nuclear power. Go to the sites and consider the purpose of each one.

In this task you will notice that the appearance of sites can vary considerably, but don't let this affect your opinion too much!

- http://www.niauk.org
- http://greenpeace.org.uk/nuclear
- http://www.benefitsofnuclearpower.com/

Q9: Is there a bias to the sites?

. . . .

Q10: Which site(s) would you consider to be the most scientifically accurate?

. . . .

Q11: Which type of website would you use to obtain an unbiased report about nuclear power?

1.5 Referencing

In addition to finding and recording reliable information, you must be able to record your sources in a way that will allow another person to find the same information.

Make sure that your answer includes a clear indication of where you have sourced your data. When you reference a website, ensure that you have included the entire URL (address).

It is good practice to type it into your web browser to check it works, as well as recording the date the website was viewed as some sites are updated more often than others.

Referencing: Questions (15 min) Go online

Suppose you were researching the impact of the Leidenfrost effect and used the following website:

- http://www.wiley.com/college/phy/halliday320005/pdf/leidenfrost_essay.pdf

This URL contains a .pdf that should be copied. Try to open the link below:

- http://www.wiley.com/college/phy/halliday320005/pdf/leidenfrost_essay

In this case, you are redirected to the correct page. This will not be the case if you have made a spelling or other mistake. For example, try and open the link below:

- http://www.wiley.com/college/phy/halliday32005/pdf/leidenfrost_essay.pdf

One small typing error means that you cannot access the page.

1.6 Practice research

Choose one of the following focus questions to generate some web-based research for yourself:

A) What caused the hole in the ozone layer?

B) How do you design an efficient wind turbine?

C) What was the physicist Richard Feynman most well-known for?

For the one(s) you have chosen, ensure you do the following:

1. Present your information in a clean and coherent manner.
2. Find three relevant pieces of information about the topic.
3. Reference your sources.
4. If possible, allow another person to read your research and check your references and give you feedback on the research you have carried out.

1.7 Summary

Summary

The following is a checklist for evaluating web pages, use it when you are answering your focus question.

1. Author (source)
    a) Can you find out the name of the author?
    b) Is there information about the author provided?
    c) Is it clear that an institution or university or organisation sponsored the website (check the domain)?
2. Currency (date)
    a) Is the date the website was put on the internet present?
    b) Is an update or revision date present?
3. Level
    a) Is the website intended for a general or a scientific audience?
    b) Is the topic explored at a suitable level for Higher Physics?
4. Purpose
    a) Is the purpose of the site stated (to persuade, inform, explain, sell)?
5. Bias
    a) Is the information given and / or the views expressed biased?
6. Accuracy
    a) Are the sources of the information listed in a bibliography?

Conclusion

Using the above information, is this an appropriate source for your research? Justify your opinion.

1.8 Resources

Texts

- **Higher Physics for CfE with Answers**, *P Chambers, M Ramsay and I Moore*, Hodder Gibson, ISBN 978-1444168570

Practical work

- Learners should have access to a computer with internet connection to put their knowledge of web based research to the test.

1.9 Assessment

End of topic 1 test (10 min) Go online

Q12: Where might physicists look up information if they were to research a topic?

a) Books
b) Websites
c) Journals
d) All of the above

. . . .

Q13: The first step in any research activity involves finding out about a particular topic by carrying out

a) a literature search.
b) an internet search.
c) an experiment.
d) a peer review.

. . . .

Q14: When carrying out research it is important to assess the level of the information you use to

a) ensure you understand the information.
b) ensure the information contain physics.
c) ensure the information is not too basic.
d) All of the above

. . . .

Q15: Which of the following is the **least** reliable domain?

a) .edu
b) .gov
c) .com
d) .org

. . . .

Q16: Websites with which of the following purposes would be suitable to use in your research?

a) To persuade
b) To inform or explain
c) Blogs
d) To sell

. . . .

Q17: What is the **main** purpose of including references in your research?

a) To fill up space in a word count
b) To allow another person to find the same information
c) To give credit to other authors
d) To show that you researched the topic

Topic 2

Planning an investigation

Contents

Prerequisites

You should already:

- have carried out a variety of practical experiments throughout the course (Higher);
- be familiar with researching a physics issue and collating this information into a short presentation (National 5, Outcome 2.2 & 2.3);
- be familiar with the following from your National 5 Assignment:
  - applying knowledge of physics to new situations and interpreting information;
  - selecting and presenting information appropriately in a variety of forms;
  - processing the information/data collected (using calculations and units, where appropriate);
  - drawing valid conclusions and giving explanations supported by evidence/justification;
  - communicating findings/information (National 5, Assignment);
- be familiar with applying your knowledge of experimental techniques to unfamiliar situations (National 5, Outcome 2.4).

Learning objective

Planning is an essential skill for life, learning and work. Effective planning enables priorities to be dealt with in a controlled manner instead of simply reacting to things as they come along. During your Researching Physics investigation, planning ahead will allow you to be better organised and will save you time, effort and resources. By the end of this topic, you should have the ability to:

- think of an investigation in terms of a number of key stages;
- identify the key stages in planning and carrying out a scientific investigation;
- identify the independent, dependent and controlled variables in an investigation and think of a hypothesis to an investigation;
- recognise that there are always significant safety risks when carrying out scientific procedures that must be taken into account in the planning stages;
- appreciate the importance of planning before starting the experiment.

2.1 Test your prior knowledge

Test your prior knowledge (5 min) Go online

Q1: Which of the following would be the best piece of apparatus to use to measure the current flowing in a wire?

a) Voltmeter
b) Ammeter
c) Ohmmeter
d) Coulombmeter

. . . .

Q2: Which of the following would be the best piece of apparatus to measure the instantaneous speed of a trolley?

a) Stopwatch
b) Ticker timer
c) Light gate
d) Metre stick

. . . .

Q3: Which of the following statement questions allows you to identify the independent variable?

a) What do I change?
b) What do I observe?
c) What do I keep the same?
d) What do I think will happen?

2.2 Planning an investigation

The ability to plan effectively will be crucial when undertaking your scientific investigation during the Researching Physics unit. Indeed, in order to achieve Outcome 2 of this unit you must show that you can 'effectively plan and carry out investigative practical work relating to a topical issue in physics'.

Planning a scientific investigation can be a daunting prospect, however this topic will help you to develop the skills of effectively planning a scientific investigation at Higher Physics level.

Where should you start? What are the planning priorities? Which technique should you use? What apparatus will be required? How can you ensure the safety of yourself and others during the practical aspects of the investigation?

2.3 Variables

Before beginning it is important you have a good understanding of variables and the type of variables which will feature in your investigation.

The independent variable - its values are controlled/selected by the person conducting the experiment to determine the relationship to the observed phenomenon, the dependent variable. The independent variable can be changed as required, the changes do not need to be explained. The independent variable can be found by simply asking the question: What do I need to change?

The dependent variable - it cannot usually be directly controlled and occurs as a consequence of changing the independent variable. The dependent variable can be found by simply asking the question: What do I observe?

The controlled variable(s) - It is also important to identify controlled variables in an investigation. They are variables that are kept constant to prevent them having an effect on the independent and dependent variables. Every experiment will have a controlled variable and it is important it does not change or the results of the experiment will not be valid. It is important to remember that sometimes you may refer to something being constant within the boundaries of your experiment e.g. room temperature or acceleration due to gravity, but these are actually variables.

Also, you must decide which variables are relevant to your investigation. Although some variables may be present they may not be relevant to your investigation and so should be omitted. An example of this is measuring the speeds of an object travelling horizontally. Here the acceleration due to gravity - g - is a constant but it does not affect what you are measuring and so it not relevant to the investigation. The controlled variable can be found by simply asking the question: What do I keep the same?

A list of physical constants can be found at http://physics.nist.gov/cuu/Constants/index.html

2.4 Hypotheses

A good hypothesis will help focus the investigation. As an investigation progresses more and more information comes out and a hypothesis will ensure that the investigation stays on course.

A hypothesis is a statement that proposes a possible explanation of what is happening in the investigation. A useful hypothesis is a testable statement which usually includes a prediction. That prediction then goes on to be tested by altering one variable in a controlled manner. In scientific research it is important that a condition is described and a conclusion postulated e.g. if skin cancer is related to ultraviolet light, then people with a high exposure to ultraviolet light will have a higher incidence of skin cancer.

Hypotheses can sometimes predict unrelated variables, for example, "if the period of a pendulum is related to its mass, then decreasing the mass will decrease the period." As a student would discover when testing this hypothesis, the mass has no effect at all. It is easy to make the mistake of assuming there must be a relationship since you are investigating a topic. The hypothesis made is still valid.

It is important to remember that a hypothesis is still valid even when the results of the experiment are in contradiction to the statement because it will still shed light on the true nature of the relationship being tested. For example, "if the period of a pendulum is related to its length, then the longer the pendulum the shorter the period." Although the results show the opposite to be true, this is still a valid hypothesis as it has allowed the investigation to remain focussed.

2.5 Identifying the key stages

What are the key stages involved in effectively planning and carrying out a scientific investigation? Let's try to work them out by first identifying the key stages in a more familiar procedure - making a cup of coffee!

Identifying the key stages: Exercise (15 min) Go online

Q4: You can probably make a cup of coffee without really thinking about the stages involved. However, imagine you need to write a list of instructions for someone who has never made a cup of coffee before.

Write down a list of the key stages involved in making a cup of coffee. You have 1 minute to complete this task!

Think about these questions:

- Have you all written the same steps?
- Have any important steps been missed?
- Are some steps not always required?
- What does this tell you about the importance of planning ahead?

Note: There may be more than one way to sensibly carry out this procedure! Some stages may not always be required (for example, not everyone takes milk or sugar in their coffee).

There can be some flexibility in the order in which some of the stages are carried out (for example, some people may prefer to add the sugar after the milk, others before the milk).

The order of collection of equipment may be dependent on its location within the kitchen.

However, in general, planning ahead ensures that all the appropriate ingredients and equipment are available, that no key steps are missed out and that the procedure is carried out smoothly and quickly.

An everyday procedure such as making a cup of coffee can be summarised as a series of stages. The more complicated process of planning and carrying out a scientific investigation can also be broken down into a similar series of stages.

Identifying the key stages: Question (10 min) Go online

The stages involved in making a cup of coffee could be grouped into the broad categories listed below.

Complete the table by matching the stages of coffeemaking to the equivalent stages involved when planning and carrying out of a scientific investigation. Choose from:

- Collect and set up apparatus
- Collect results
- Decide on topic for investigation
- Put away apparatus
- Carry out the procedure

Making a cup of coffee	Scientific investigation
Decide to have a cup of coffee	
Collect kitchen equipment and ingredients	
Make coffee	
Drink coffee	
Tidy up	

2.6 Risk assessment

A crucially important part of the planning process for any everyday procedure involves assessing how to safely carry out the procedures involved.

For example, when making a cup of coffee it is important to take precautions to ensure that water and electricity are kept apart, and to avoid spilling boiling water on your skin. The same care and considerations needs to be taken when planning and carrying out an investigation.

Once the hazards associated with a particular experiment have been identified, a risk assessment must be carried out.

The risk assessment allows appropriate precautions to be put in place to allow the equipment to be handled safely. It is worth considering how likely is the risk and how hazardous would it be, this will help give you an indication of the level of precaution needed.

Risk assessment: Question (10 min) Go online

Fill in the blanks to show the precautions you would take to minimise risk in each of the following situations.

Note: The safety precautions required for each experiment and investigation will be different. If you are in any doubt whatsoever about the safety procedures required for your investigation, make sure you speak to your teacher before you start practical work!

Choose from:

- Move anything that could be in the way of the flame i.e. hair, tie etc. Have somewhere to put the heated substance.
- Ensure wires do not overheat - rough calculation of current may be required.
- Discharge the capacitor before breaking up circuit.
- Clear path of projectile before launching.
- Ensure feet are out of the way in case it breaks. Check load limit of spring.

Laboratory situation	Precautions(s) required
Disconnecting a capacitor in a circuit	
Hanging mass on a spring	
Heating a substance over a bunsen	
Creating electromagnets	
Monkey and hunter experiment, firing projectiles	

2.7 Practical techniques and apparatus

A crucial stage in planning a scientific investigation is to identify the most appropriate practical technique to allow you to safely carry out your experiment.

Having identified the most appropriate technique for a particular scientific investigation, apparatus must then be selected to allow that technique to be carried out effectively and safely.

You may wish to consult with your teacher or technician at this point.

2.8 Planning ahead

Planning ahead is essential for safe and effective practical experimentation in physics. For example, some of the stages required to successfully carry out an experimental procedure may be implied, rather than explicitly written in the text.

Consider the following procedure for measuring the final speed of a trolley down a ramp at different angles:

The final speed of a trolley down a ramp was tested by releasing a trolley down a ramp from rest and allowing it to pass through a light gate at the end of the ramp. The result for each release of the trolley at a different angle of ramp was recorded.

This procedure could be broken down into simpler stages to assist with planning. For example:

1. Place the ramp against a stable surface.
2. Measure the angle the ramp makes with the floor using a protractor.
3. Set up a light gate and timer at the bottom of the ramp so the trolley can pass through the light gate.
4. Release the trolley from rest from the top of the ramp (or marked position).
5. Record the final speed of the trolley as it passes through the gate.
6. Repeat steps 3 to 5 for each of the remaining angles of the ramp.

Planning ahead: Questions (5 min) Go online

Q5: Which of the stages in the list of instructions above were not specifically mentioned in the original experimental procedure?

A) Place the ramp against a stable surface.
B) Measure the angle the ramp makes with the floor using a protractor.
C) Set up a light gate and timer at the bottom of the ramp so the trolley can pass through the light gate.
D) Release the trolley from rest from the top of the ramp (or marked position).
E) Record the final speed of the trolley as it passes through the gate.
F) Repeat steps 3 to 5 for each of the remaining angles of the ramp.

. . . .

Q6: What types of issues could arise during practical work if proper planning has not been carried out in advance?

a) Not having the required apparatus to hand at the appropriate time.
b) Working unsafely because inappropriate apparatus has been selected.
c) Running out of time to complete practical work.
d) All of the above

2.9 Summary

Summary

The checklist below will help you to successfully plan and carry out the practical aspects of your Researching Physics investigation.

Checklist	√
Choose a topic (Your teacher may give you one)	
Identify the most appropriate technique(s) you might use	
Identify the variables and form an hypothesis	
Assess risks and plan to safely overcome these risks*	
Identify and collect the required apparatus	
Carry out the experimental procedure to produce and collect results	
Clean up	

*Safety considerations must be revisited throughout all planning and practical stages.

Good luck with planning and carrying out your Researching Physics investigation!

2.10 Resources

Texts

- **Higher Physics for CfE with Answers**, *P Chambers, M Ramsay and I Moore*, Hodder Gibson, ISBN 978-1444168570

Practical work

- Pupils could have access to a variety of apparatus so they can become familiar with them.

2.11 Assessment

End of topic 2 test (10 min) Go online

Q7: Which of the following questions allows you to identify the dependent variable?

a) What do I change?
b) What do I observe?
c) What do I keep the same?
d) What do I think will happen?

. . . .

Q8: Which one of the following is not a constant?

a) Speed of light in a vacuum
b) Electronic charge
c) Mass added to a trolley
d) Planck's constant

. . . .

Q9: The purpose of a risk assessment is to:

a) prevent harming yourself.
b) prevent harming someone else.
c) avoid damaging equipment.
d) All of the above

. . . .

Q10: Decide on topic for investigation
Collect and set up apparatus

What is the next stage in carrying out an investigation?

a) Write up experiment
b) Carry out the procedure
c) Put away apparatus
d) Analyse results

Topic 3

Carrying out an investigation

Contents

Prerequisites

You should already:

- have carried out a variety of practical experiments throughout the course (Higher);
- be familiar with researching a physics issue and collating this information into a short presentation. (National 5, Outcome 2.2 & 2.3);
- be familiar with the following from your National 5 Assignment:
  - applying knowledge of physics to new situations and interpreting information;
  - selecting and presenting information appropriately in a variety of forms;
  - processing the information/data collected (using calculations and units, where appropriate);
  - drawing valid conclusions and giving explanations supported by evidence/justification;
  - communicating findings/information (National 5, Assignment);
- be familiar with applying your knowledge of experimental techniques to unfamiliar situations (National 5, Assignment);
- have the ability to:

Prerequisites continued

- identify the independent, dependent and controlled variables in an investigation and create a hypothesis to an investigation;
- recognise that there are always significant safety risks when carrying out scientific procedures that must be taken into account in the planning stage;

Learning objective

Before starting any experiment you should have devoted some time to planning.
Breaking an experiment down into key stages involves looking at areas such as apparatus required, procedures to be carried out and risks. Effective planning will help you to save time in the long term and will ensure you are fully prepared before you start your investigation.
In addition, your investigation may require you to order apparatus not normally found in the lab so it is helpful to identify these so they can be requested before you wish to start.
These steps should ensure that when you come to carry out your investigation, it will run more smoothly. By the end of this topic, you should have the ability to:

- think of an investigation in terms of a number of key stages;
- identify the key stages in planning and carrying out a scientific investigation;
- appreciate the importance of planning before starting the experiment.

3.1 Test your prior knowledge

Test your prior knowledge (5 min) Go online

Q1: What would be the best piece of apparatus to measure the temperature of a water being heating over a Bunsen burner?

a) Clinical thermometer
b) Liquid crystal thermometer
c) Laboratory thermometer
d) Any of the above

. . . .

Q2: Which of the following would be the best piece of apparatus to use to measure the potential difference between two points in a circuit?

a) Voltmeter
b) Ammeter
c) Ohmmeter
d) Coulombmeter

. . . .

Q3: What is the least appropriate piece of apparatus to use to measure the length of the playground?

a) Trundle wheel
b) Metre stick
c) Vernier calipers
d) 30 cm ruler

3.2 Carrying out an investigation

This topic will help you to develop the skills of effectively carrying out a scientific investigation at Higher Physics level.

It will focus on identifying key stages in an experimental procedure.

3.3 Identifying the key stages

What are the key stages involved in effectively carrying out your investigation?

It is good practice to work these out before you start your investigation in order to save time later.

You may find that some stage must be carried out before others as they require products from one experiment are reactants in another. Or, you may find that some techniques may take so long that you need to set them up as soon as you arrive in the lab.

Identifying the key stages: Exercise (10 min) Go online

Consider the following procedure for measuring internal resistance of a cell.

A voltmeter was connected across the cell to measure the terminal potential difference. An ammeter was placed in series with the cell and readings taken. Bulbs were added in parallel and readings of potential difference and current measured. A graph of the results were plotted and the internal resistance found.

Q4: Break the procedure down into a logical and detailed series of stages. In order to do this, you will have to plan ahead.

You may in particular wish to consider which apparatus you will need to collect, and at what point in the procedure it would be most appropriate to collect and assemble them.

Note: There may be more than one way to sensibly carry out this procedure! There can be some flexibility in the order in which some of the stages are carried out. However, in general, planning ahead ensures that all the appropriate apparatus is available, that no key steps are missed out and that the procedure is carried out smoothly and quickly.

3.4 Practical techniques

Throughout the Higher Physics course, you will have become familiar with a variety of techniques and have developed the skills to carry these out safely in the lab.

Whether measuring a distance, speed, force, time, current, potential difference, etc. it is important that you are using the most suitable equipment for the experiment. For example, a thermometer tells you the exact temperature of a substance but it is good practice to check that your thermometer is of the correct range before you begin. A thermometer with range 0°C to 100°C would not be used if the boiling points of your substances are over 100°C!

3.4.1 Safe methods for heating

If your experiment involves heating a substance, you should carefully consider your heating method. Bunsen burners can reach high temperatures quickly but can be hard to control the heating and should never be used if flammable liquids are involved.

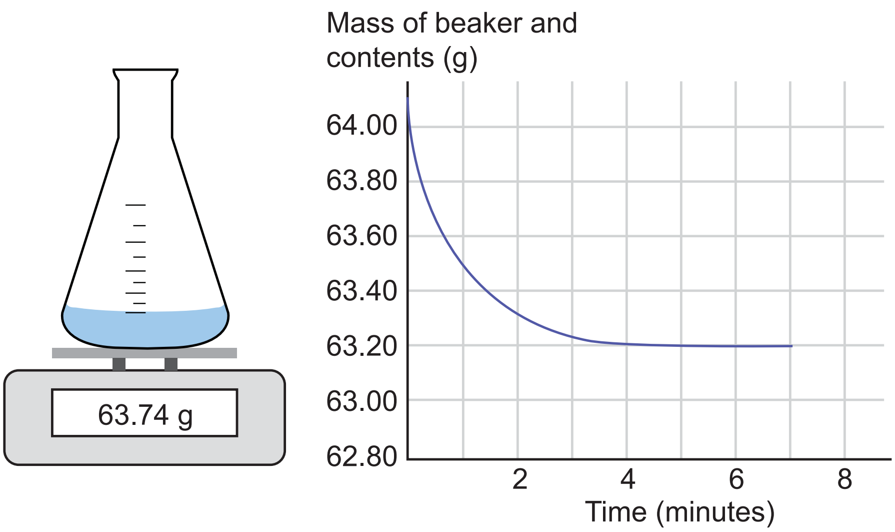
Water baths are safe to use but are very slow to heat, cannot heat anything above 100 ºC (the boiling point of water) and have poor temperature control. You may decide to use a heat lamp or immersion heater but care must be taken as these can become very hot to handle and can take a long period to cool down. Also, they may not provide uniform heating to the substance being heated.

3.4.2 Use of a balance

There are many different methods for using a balance to measure a mass accurately. One is given as follows.

Steps to using a balance:

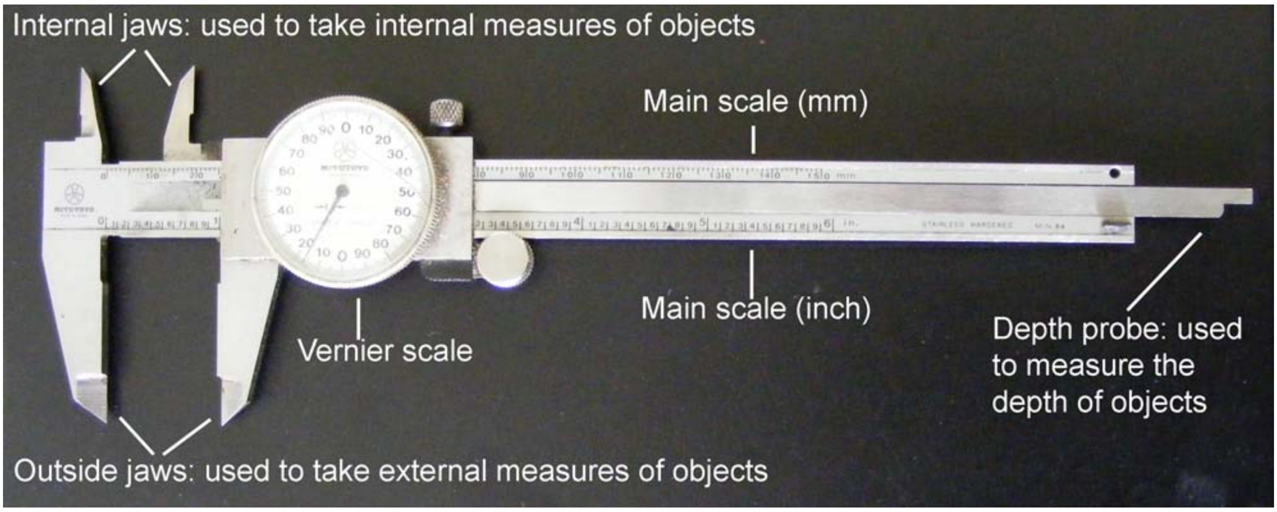
1. Turn on the balance.
2. When the balance reads 0.00 g place the container on the balance.
3. "Tare" or "zero" the balance (may be marked as T).
4. When the balance reads 0.00 g again it is ready to be used for that container.
5. Place substance into container.
6. Place the container onto the balance (depending on the mass being measured a container may not be needed).
7. Record the reading with correct units for mass (g/mg).



3.4.3 Vernier calipers

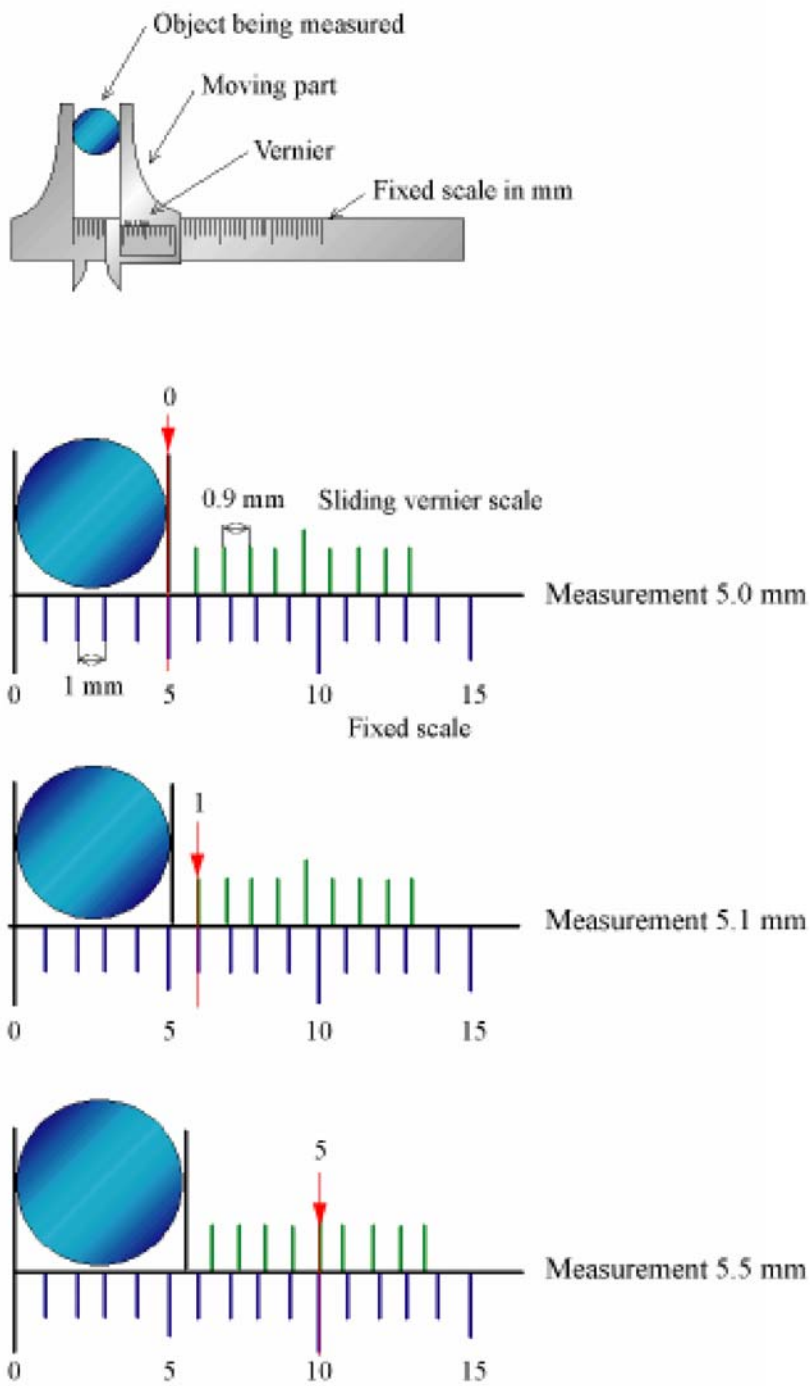
Throughout the Higher Physics course you will have made a number of measurements of length and distance. Occasionally in physics you may have to measure very small lengths and Vernier calipers are often the best piece of equipment to use.

1. Place the calipers around the object using either the internal or outside jaws (see diagram).
2. Use the left end of the sliding scale to give the basic main scales value. You should always go for the lower value.
3. Use the Vernier scale to give the final digit.



Vernier calipers: Using Vernier calipers (10 min) Go online

It can take a little bit of practice to become familiar and confident in the use of Vernier calipers. Using the diagram below, try to get the same final measurement as the ones stated.



3.5 Summary

Summary

You should now have the ability to:

- think of an investigation in terms of a number of key stages;
- identify the key stages in planning and carrying out a scientific investigation;
- appreciate the importance of planning before starting the experiment.

You should be able to describe each of the following practical techniques and be aware of when to use them.

1. Safe methods for heating
2. Use of a balance
3. Use of Vernier calipers

3.6 Resources

Texts

- **Higher Physics for CfE with Answers**, *P Chambers, M Ramsay and I Moore*, Hodder Gibson, ISBN 978-1444168570

Practical work

- Pupils could have access to apparatus for the experimental work so they can become familiar with it.
- Pupils should already have covered a wide range of practical techniques as part of the Higher Physics course.

3.7 Assessment

End of topic 3 test (10 min) Go online

Q5: Planning ahead ensures that:

a) all the appropriate apparatus is available.
b) no key steps are missed out.
c) the procedure is carried out smoothly and quickly
d) All of the above.

. . . .

Q6: Match up each piece of equipment in the table below to its most appropriate use. Choose from:

1. Measuring temperature of a substance from 0°C to 100°C	2. Measuring a very small length or distance accurately
3. Measuring length or distance	4. Measuring the potential difference **across** a component
5. Heating a solid block	6. Heating a substance to 100°C quickly
7. Timing an event where reacting time is negligible	8. Measuring mass
9. Measuring the current **through** a component	

Technique	Use
Immersion heater	
Ammeter	
Voltmeter	
Metre stick	
Use of balance	
Heating using a Bunsen burner	
Stopwatch	
Thermometer	
Vernier calipers	

Topic 4

Processing & analysing results

Contents

Prerequisites

You should already:

- have carried out a variety of practical experiments throughout the course (Higher);
- be familiar with researching a chemical issue and collating this information into a short presentation (National 5, Outcome 2.2 & 2.3);
- be familiar with the following from your National 5 Assignment:
  - applying knowledge of physics to new situations and interpreting information;
  - selecting and presenting information appropriately in a variety of forms;
  - processing the information/data collected (using calculations and units, where appropriate);
  - drawing valid conclusions and giving explanations supported by evidence/justification;
  - communicating findings/information (National 5, Assignment);
- be familiar with applying your knowledge of experimental techniques to unfamiliar situations (National 5, Assignment);

Prerequisites continued

- have the ability to:
  - select the appropriate practical technique(s) and apparatus for a particular procedure;
  - recognise that there are always significant safety risks when carrying out scientific procedures that must be taken into account in the planning stage.

Learning objective

The ability to process data correctly and make decisions about the quality of the data is an essential skill for a practising physicist. Outcome 3 of the Researching Physics unit of Higher Physics states that the student has the ability to present and analyse information in an appropriate format, draw valid conclusions and make a valid evaluation of procedures. The aim of this topic is to help you to obtain a qualitative understanding of the approaches used to estimate the reliability of data obtained from experiments.
By the end of this topic, you should have the ability to:

- represent experimental data using a scatter graph;
- sketch lines and/or curves of best fit;
- carry out calculations of averages (means) for experimental data;
- identify and eliminate 'rogue' points from results;
- qualitatively appreciate the reproducibility of repeated measurements from variability of data values;
- qualitatively understand the uncertainty associated with a measurement.

4.1 Test your prior knowledge

Test your prior knowledge (5 min) Go online

Q1: Vernier calipers are a piece of equipment that allow you to measure:

a) Length
b) Time
c) Mass
d) Temperature

. . . .

Q2: When representing experimental data in physics you will most commonly plot a:

a) Pie chart
b) Bar graph
c) Box plot
d) Scatter graph

. . . .

Q3: When plotting a graph of your experimental results, which information should be presented on the (horizontal) x-axis?

a) Dependent variable
b) Independent variable
c) Constant variable
d) The variable that you measure

4.2 Representing experimental data using a scatter graph

Scatter graphs are similar to line graphs in that they use horizontal and vertical axes to plot data points. However, they have a very specific purpose. Scatter plots show how much one variable is affected by another. The relationship between two variables is called their correlation.

When you carry out an experiment, you normally change one variable and measure another. For example, you might investigate the effect of changing the angle of a ramp on final speed of a trolley - changing the angle and measuring the final speed of the trolley.

Best-fit lines can also be called trend lines or linear regressions. Plotting data as a scatter graph suggests that you are investigating the relationship between the two variables.

4.2.1 Guidelines for plotting a scatter graph

1. Draw axes at right angles to each other:
   - The horizontal is the x-axis - the independent variable (the one that you change) is plotted here.
   - The vertical is the y-axis - the dependent variable (the one you measure) is plotted here.
2. Label the axes with the variables and their units. The variable that you change will go on the x-axis and the variable that you measure will go on the y-axis.
3. Put the correct scale on each axis. The correct scale is decided from the range of points you have to plot but must always be uniform. So if you have a range of points, 0.5, 1.3, 1.9, 3.4, 4.8, then the scale will be from 0-5, evenly spread.
4. Plot the points.

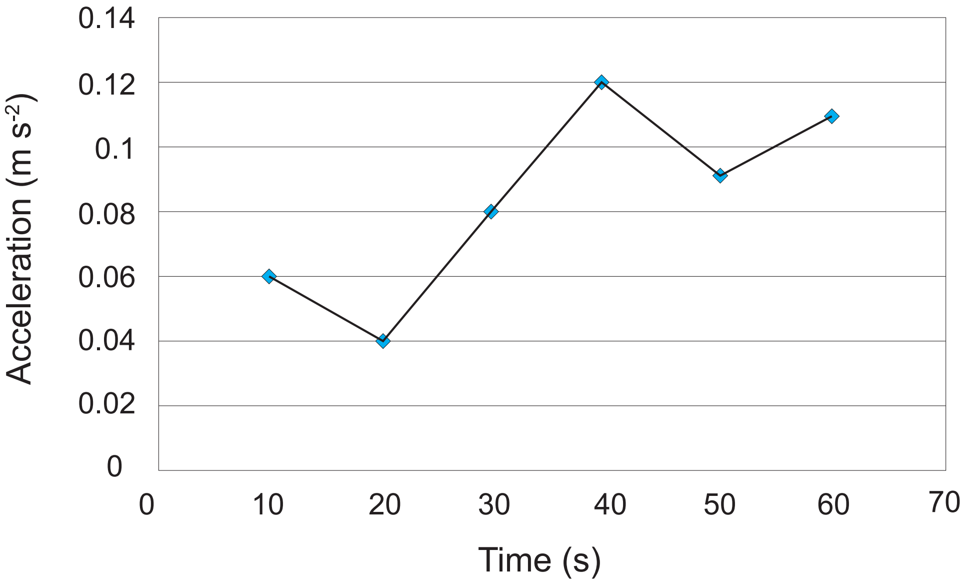
4.2.2 Drawing the line - the best fit

When you have plotted the points, you have to join them up with some sort of line. The usual graph shapes are a straight line or a smooth curve.

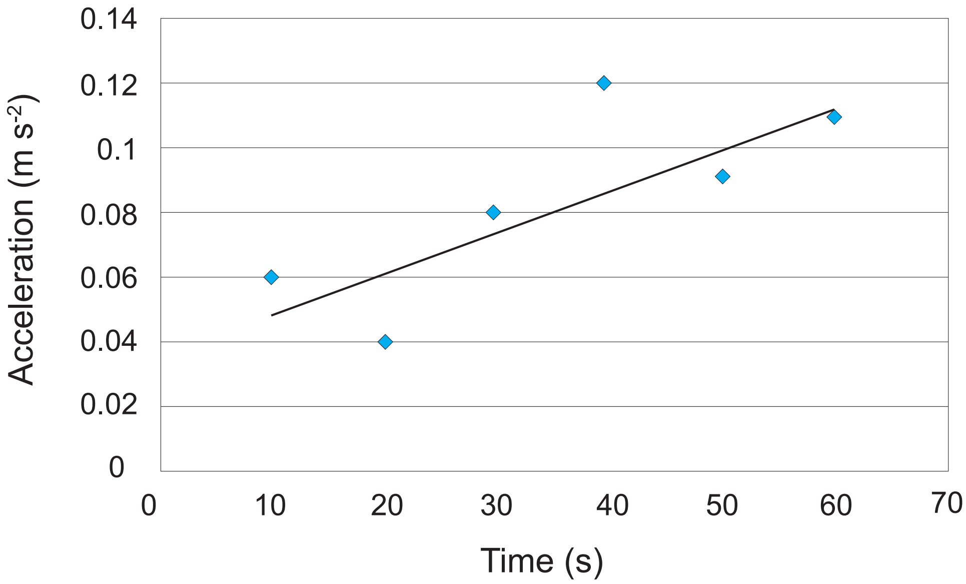
If the graph is a straight line, use a ruler to draw it. Ideally, the line would go through all the points, but this rarely happens and so you draw the line which goes as near as possible to as many points as possible. This is called the line of best fit.

Do not draw a line from one dot to the next. This will give a 'join the dots' look to the graph and can prevent you from seeing the trend to the graph.

An example of a graph where a line has been drawn by 'joining the dots' is shown below.



It would be difficult to draw a conclusion about the trend of this graph the way it has been drawn. However, when a line of best fit is drawn, a trend can be seen, as follows.



When drawing a straight line of best fit, try to draw the line through the middle of the points. You might not hit any of the points directly but you should aim to have the same number of points above and below your line.

If the graph is not a line but a curve, then the line joining the points has to be drawn freehand, but it should still be drawn as a smooth curve which fits as many points as well as possible.

Drawing the line - the best fit: Question (20 min) Go online

Q4: On graph paper, plot the following data as a scatter plot and draw the line of best fit.

Length of string (m)	Period of swing (s)
0.1	0.68
0.2	0.74
0.3	0.96
0.4	1.06
0.5	1.14
0.6	1.52
0.7	1.70

4.3 Replicate measurements

Repeat experiments should always be performed. The number of replicate experiments carried out will depend on the particular experiment, but a minimum of three times is recommended.

The purpose of repeat measurements is to assess the variability and prevent a mistake affecting the conclusion of an experiment. The closer together the values from repeated experiments are, the better the reproducibility. Generally, an experiment can be considered to be reliable if the results are reproducible.

Replicate measurements: Question (5 min) Go online

Q5: Sample results from two experiments to find the acceleration due to gravity (in m s^{-2}) are given as follows. Which experiment provides the most reproducible results?

Experiment A	Experiment B
9.8	9.9
10.1	9.8
9.5	9.9
9.8	10.0
10.0	9.8
9.6	9.8
9.3	10.0

Acceleration due to gravity (m s^{-2})

4.4 Calculating the mean value for experimental data

The mean is the sum of the measured values divided by the number of measurements.

Example

For example, the mean can be calculated from the set of results below:

0.114, 0.165, 0.210, 0.186, 0.139

Step 1 : Calculate the sum of all the values

- (0.114 + 0.165 + 0.210 + 0.186 + 0.139) = 0.814

Step 2: Divide this by the total number of results added together to calculate the mean:

- (0.814 / 5) = 0.1628 = **0.163**

Calculating the mean value: Questions (5 min) Go online

Q6: Calculate the mean of 0.123, 0.109, 0.128, 0.116, 0.119.

. . . .

Q7: Calculate the mean of 10.2, 11.8, 11.0, 10.8, 11.3.

4.5 Identification and elimination of "rogue" points

Learning objective

An introduction to identifying and eliminating rogue points.

Errors will always be present in any measurement you make. Sometimes it is easy to identify when you have made a mistake.

For example, when timing an event using a stopwatch you may have anticipated the start and end points and so you know that the time displayed on the stopwatch does not match the time for the event to take place.

In most cases, you will have no obvious errors but still obtain a data point that does not seem to match the trend in the rest of your data. As you have already seen in drawing a best-fit line or curve, you do not 'join the dots' in drawing a graph, you draw the line to pass through most of the points. In this case, points far away from the line can be considered to be 'rogue' points, but they do not affect the line that you have drawn.

It is more difficult to identify rogue points when you have repeated the same experiment a number of times and are calculating the average. You cannot ignore a point just because it does not 'look' right, but there are occasions when you can reject a point.

Example

A student is using an ammeter to determine the current flowing through a bulb in a circuit. The student performs 10 replicate measurements using the same equipment each time.

The current through the bulb, in milliamps, found each time is as follows:

- 1.95, 2.12, 1.89, 2.04, 2.68, 1.99, 2.09, 2.01, 1.92, 2.11

From this data, 2.68 mA 'looks' like a rogue point because it seems much higher than the rest of the numbers obtained. In this case, we can check if it can be eliminated because the bulb will have a statement of power and voltage at which it should operate.

Identification and elimination of "rogue" points: Questions (5 min) Go online

Q8: Calculate the average of all 10 data points.

- 1.95, 2.12, 1.89, 2.04, 2.68, 1.99, 2.09, 2.01, 1.92, 2.11

. . . .

Q9: Calculate the average of 9 data points, eliminating 2.68.

- 1.95, 2.12, 1.89, 2.04, 1.99, 2.09, 2.01, 1.92, 2.11

. . . .

Q10: A student is using a top pan balance to measure the mass of a brass pendulum bob. The student performs 10 replicate measurements using the same brass bob each time.

The following results are obtained (Kg):

0.145, 0.162, 0.139, 0.154, 0.218, 0.149, 0.159, 0.151, 0.142, 0.161

Calculate the average of all 10 data points.

. . . .

Q11: The label on the brass bob states that there is 0.15 Kg present, reject the rogue value and calculate the new average.

4.6 Qualitative understanding of uncertainty associated with a measurement

Accuracy means closeness to the true value. On the pieces of apparatus that are used to measure, you will see a number with a plus or minus ($\pm$) then another number. This is a measure of the accuracy of the apparatus for measuring the specified value. The $\pm$ value is called the absolute **uncertainty** of the measurement.

When considering measurements, there will always be error attached to the measurement regardless of how careful you are. All measurements have an uncertainty built into them.

There are many different types of uncertainty that can arise when conducting an experiment; systematic uncertainty, calibration uncertainty and scale reading uncertainty. The one you will use most often is scale reading uncertainty. When making measurements there will always be an uncertainty associated with reading the scale on a piece of equipment.

4.6.1 Scale reading uncertainty - Analogue

The uncertainty of an analogue measurement can be taken as half of the smallest division on the scale. For example, if a thermometer is marked in increments of 1°C then the temperature that is recorded is accurate to 0.5°C.

Scale reading uncertainty - Analogue: Exercise (5 min) Go online

Q12: Consider the different types of measuring equipment in the laboratory. Picture the equipment used for measuring length, force, voltage and temperature.

Match the uncertainty value to the apparatus. Choose from:

- 0.15 V
- 5 N
- 0.05 cm
- 0.05°C

Apparatus	Uncertainty
Newton meter with 10 N divisions	
Voltmeter with 0.3 V divisions	
Thermometer with 0.1°C divisions	
Ruler with 0.1 cm divisions	

4.6.2 Scale reading uncertainty - Digital

The uncertainty of a digital measurement can be taken as one of the smallest divisions on the scale. For example, if a digital top pan balance has a reading for a mass of 2.98 g then the mass that is recorded is accurate to 0.01 g.

Scale reading uncertainty - Digital: Exercise (5 min) Go online

Q13: Consider the different types of measuring equipment in the laboratory. Picture the equipment used for measuring current, voltage, and mass.

Match the uncertainty value to the apparatus. Choose from:

- 0.001 mA
- 0.1 V
- 0.1 V
- 1 g

Apparatus	Uncertainty
Voltage reading of 12.3 V	
Voltage reading of 3.6 V	
Current reading of 0.128 mA	
Balance reading of 1309 g	

4.7 Summary

Summary

You should feel confident in:

- representing experimental data using a scatter graph;
- sketching lines and/or curves of best fit;
- calculating averages (means) for experimental data;
- identifying and eliminating of 'rogue' points from results;
- describing how the reproducibility of repeated measurements from variability of data values;
- describing the uncertainty associated with a measurement.

Make sure that you do not add your own errors when making measurements by being as careful as you can when reading scales, setting up equipment and copying down numbers!

4.8 Resources

Texts

- **Higher Physics for CfE with Answers**, *P Chambers, M Ramsay and I Moore*, Hodder Gibson, ISBN 978-1444168570

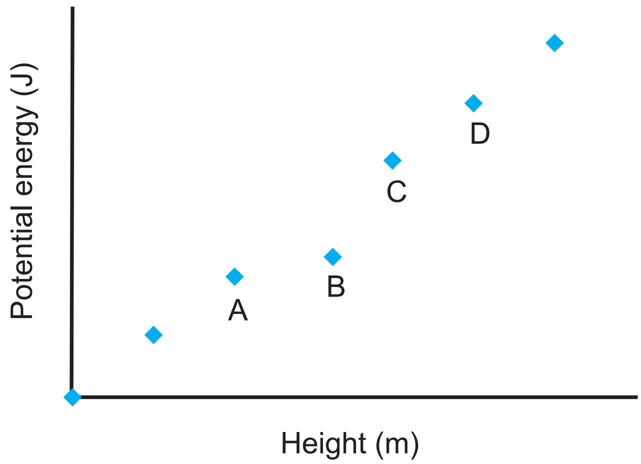
Practical work

- Pupils could have access to apparatus to check their uncertainties.

4.9 Assessment

End of topic 4 test Go online

Q14: A student carried out an experiment to investigate how the potential energy of a ball (J) varies with height (m). Which of the following should be discarded as a "rogue" point?



. . . .

Q15: An experiment was conducted to determine Boyle's law. The experiment was repeated several times and the following results obtained for the volume of the gas:

	1	**2**	**3**	**4**
Initial burette (cm^3)	0.0	20.0	10.0	0.0
Final burette (cm^3)	24.1	43.5	33.6	23.8
Volume of vinegar (cm^3)	24.1	23.5	23.6	23.8

Which of the following shows the correct average change in volume?

a) 23.55 cm^3
b) 23.63 cm^3
c) 23.75 cm^3
d) 23.80 cm^3

. . . .

Q16: A student measures the mass of a projectile on a digital balance that reads to ± 0.01 g. The measured mass was 3.75 g.

a) 3.74 g
b) 3.76 g
c) 3.75 g
d) 3.74 g - 3.76 g

. . . .

Q17: Which of the following are suitable methods for drawing the line on a scatter graph?

1. Line of best fit
2. Curve of best fit
3. Dot-to-dot
4. All of the above

Topic 5

Evaluating & drawing conclusions

Contents

Prerequisites

You should already:

- have carried out a variety of practical experiments throughout the course. (Higher);
- be familiar with researching an issue in physics and collating this information into a short presentation (National 5, Outcome 2.2 & 2.3);
- be familiar with the following from your National 5 Assignment:
  - applying knowledge of physics to new situations and interpreting information;
  - selecting and presenting information appropriately in a variety of forms;
  - processing the information/data collected (using calculations and units, where appropriate);
  - communicating findings/information (National 5, Assignment);
- be familiar with applying your knowledge of experimental techniques to unfamiliar situations (National 5, Outcome 2.4);
- have the ability to:
  - select the appropriate practical technique(s) and apparatus for a particular procedure;
  - recognise that there are always significant safety risks when carrying out scientific procedures that must be taken into account in the planning stage;
- have confidence in:

Prerequisites continued

- representing experimental data using a scatter graph;
- sketching lines and/or curves of best fit;
- calculating averages (means) for experimental data;
- identifying and eliminating of 'rogue' points from results;
- describing the uncertainty associated with a measurement.

Learning objective

By the end of this topic, you should have the ability to:

- evaluate an experimental procedure - assess its effectiveness, plan for future modifications and to judge whether an alternative method might be more suitable;
- evaluate experimental results - spot trends and patterns in the data, to make predictions in similar situations in the future and to assess and explain the relevance of the results obtained.

5.1 Introduction

The aim of this topic is to develop the skills of evaluating and drawing conclusions within the context of an investigation in physics.

We are constantly evaluating situations in our everyday lives and drawing conclusions based on the available evidence to help decide the best way forward. Most of the time we do this without even thinking about it.

For example, imagine baking a cake. We might evaluate how the finished cake looks. If it is too pale, then it probably should have been left in the oven for a bit longer. If it is burnt around the edges, however, then a cooler oven should have been used or perhaps the cake should have been removed from the heat sooner. We will probably also evaluate how the cake tastes. If it is not moist enough, then perhaps some extra liquid ingredients should have been added or maybe less flour should have been used. If the cake is very heavy, it is likely that the ingredients should have been stirred for less time to make it lighter.

The skill of evaluating experimental procedures and data and then drawing relevant, evidence-based conclusions is crucial for carrying out effective investigative research in physics.

The Researching Physics unit of the revised Higher Physics will give you the opportunity to demonstrate these skills whilst writing your report.

Top tip

Evaluate experimental data and procedures as you go along. Don't wait until you are writing up your report - it may be too late to fix any problems at that stage.

Your conclusion(s) should relate back clearly to the aim(s) of the investigation. Make sure you are very clear about what you are setting out to do from the start - it will make life much easier when you are producing your scientific communication.

Make sure your conclusion is both accurate (gives the correct result) and reproducible (could be achieved again if the experiment was repeated).

5.2 Test your previous knowledge

Test your previous knowledge (5 min) Go online

Q1: An experiment was conducted to determine Boyle's law. The experiment was repeated several times and the following results obtained for the volume of the gas:

	1	**2**	**3**	**4**
Initial burette (cm^3)	0.00	20.00	10.00	0.00
Final burette (cm^3)	25.10	44.50	34.60	24.80
Volume of vinegar (cm^3)	25.10	24.50	24.60	24.80

Which of the following shows the correct volume for the average titre?

a) 24.55 cm^3
b) 24.63 cm^3
c) 24.75 cm^3
d) 24.80 cm^3

. . . .

Q2: A student weighs out the mass added to a trolley on a digital balance that reads to $\pm$0.01 g. The measured mass was 45.15 g. What is the true mass of the sample?

a) 45.14 g
b) 45.15 g
c) 45.16 g
d) 45.14 g - 45.16 g

. . . .

Q3: An analogue newtonmeter has divisions of 10 N, what is the scale reading uncertainty of the piece of equipment?

a) 1 N
b) 2 N
c) 5 N
d) 10 N

5.3 Evaluating procedures

Evaluating procedures: Questions (10 min) Go online

This activity will take you through a series of questions, all designed to help you think critically in evaluating experimental procedures.

Q4: Select the piece of apparatus that would be most suitable for carrying out each of the tasks in an investigation.

Choose from:

- 100 cm^3 beaker
- Ohmmeter
- Top pan balance
- Newtonmeter / Newton balance

Task	Apparatus
Accurately measuring the mass to be added to a wire to measure Young's Modulus.	
Measuring about 100 cm^3 of water, to be used in a latent heat experiment.	
The force exerted on a wire due to a mass.	
Accurately measuring the resistance in a length of wire.	

. . . .

Q5: Many different methods are available in a physics laboratory to measure distance. Match up the most appropriate measuring method to each task in the table below.

Choose from:

- Trundle wheel
- Vernier calipers
- Metre stick

Task	Measurement tool
Internal diameter of a metal nut	
Height of lab stool	
Length of classroom	

. . . .

Q6: Why would it be inappropriate to use a Bunsen burner to warm a thermistor when investigating temperature and resistance?

a) Temperature rises too quickly.
b) Extreme temperatures could be harmful to equipment.
c) Thermistors operate at low temperatures.
d) All of the above

. . . .

Q7: What are **two** advantages of conducting an investigating into irradiance from a lamp in a dark room?

A) Results can be replicated.

B) It is quiet.

C) A lightmeter is more reliable in a darker room.

D) Background sources of light have been eliminated.

. . . .

Q8: A student wants to measure the speed of sound in air. She decides to measure the 100 m distance using a trundle wheel and record the time using a stopwatch.

Why is she likely to be unsuccessful in obtaining an accurate measurement using this method?

a) The distance is too long.
b) She should use a metre stick.
c) Her reaction time will be too slow.
d) All of the above

. . . .

Q9: Select a more appropriate method that she could use to measure the speed of sound in air.

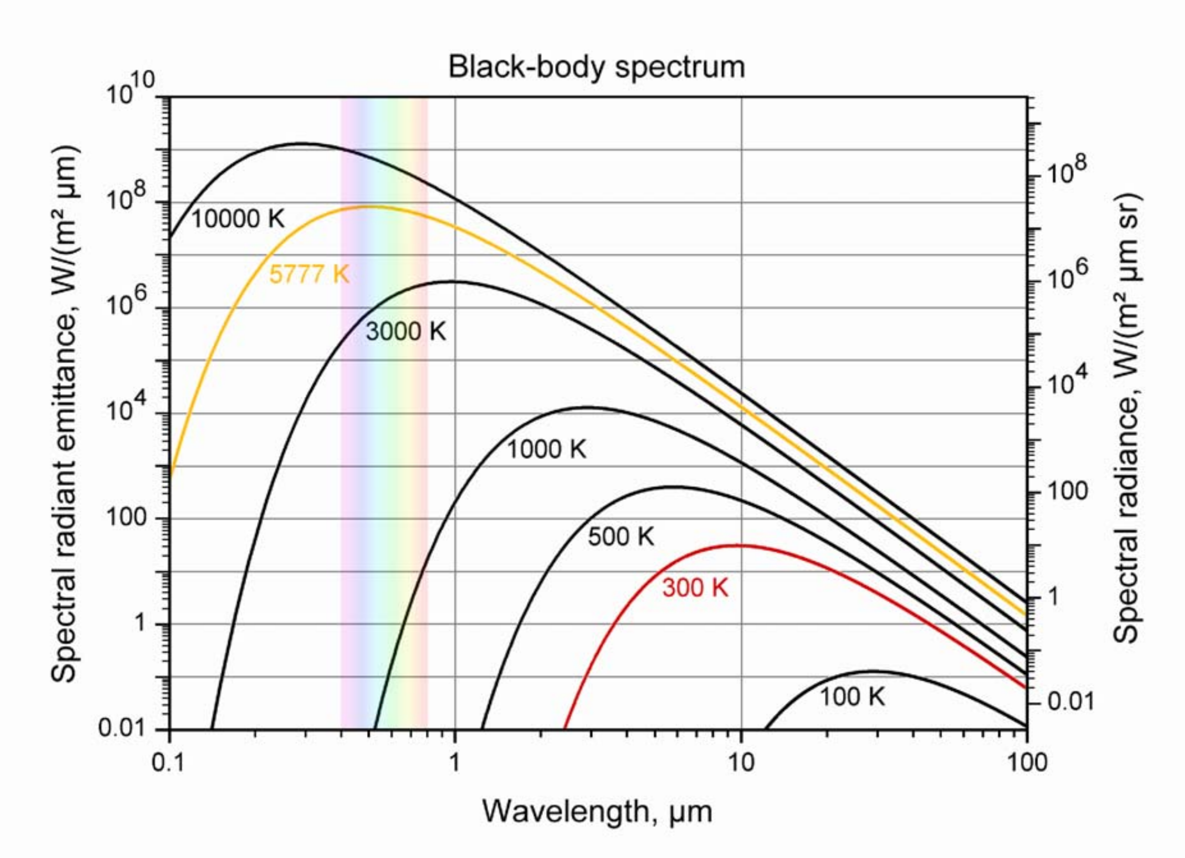
a) Use a metre stick to measure distance.
b) Use an electronic fast timer.
c) Make a louder sound.
d) All of the above

5.4 Evaluating results and drawing conclusions

This activity will take you through a series of questions, all designed to help you evaluate your results and enable you to draw conclusions from them.

Evaluating results and drawing conclusions: Questions (15 min) Go online

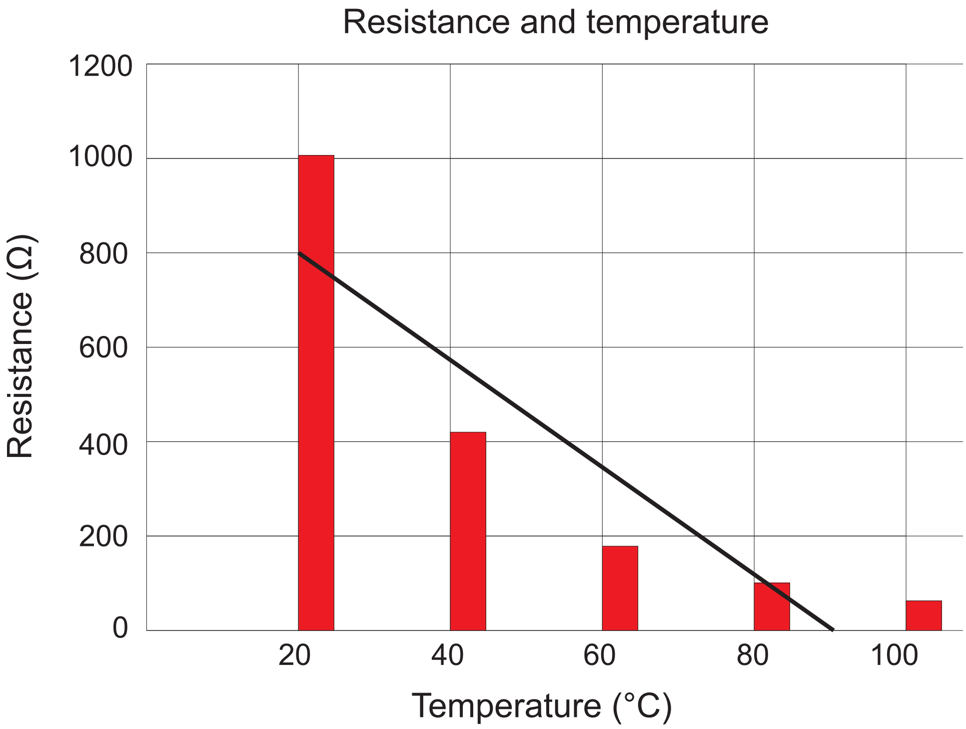
Q10: What general trend can be observed in the following graph?



a) As the temperature increases the peak wavelength decreases.
b) As the temperature increases the peak wavelength increases.
c) As the temperature decreases the peak wavelength decreases.
d) As the temperature increases the peak wavelength shifts to the left.

. . . .

Q11: Why is a bar graph not the correct way to present this information?



a) The information to be graphed is two sets of numbers.
b) The scale does not fit.
c) It does not give a smooth line.
d) The graph is too small.

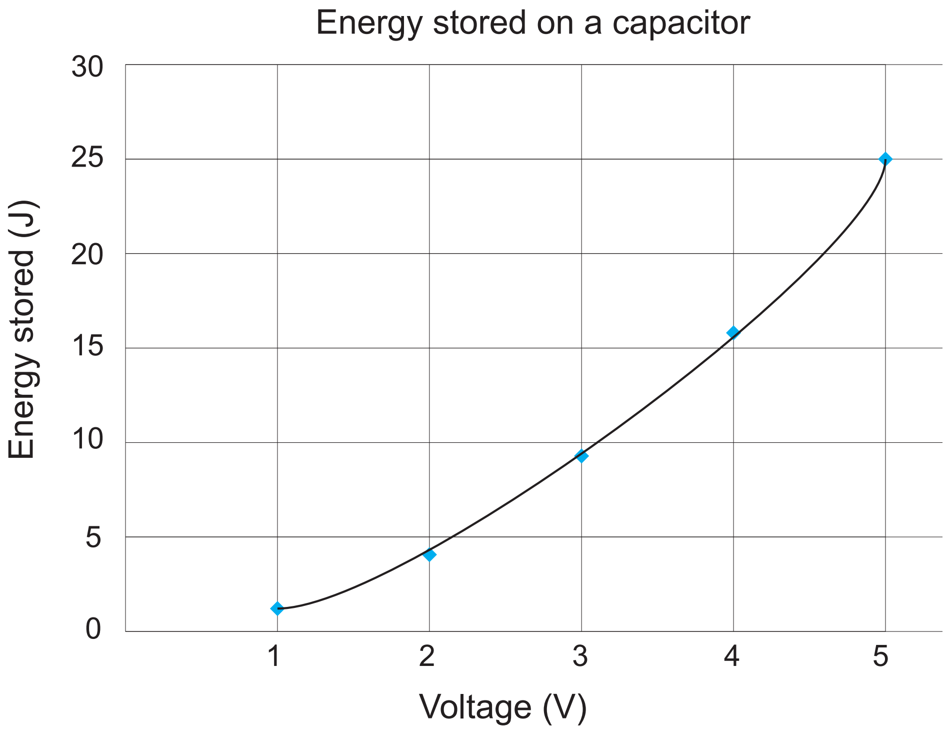
....

Q12: Identify an additional problem with the graph above.

a) The line of best fit should be a curve.
b) The scale is incorrect.
c) The x and y axis are the wrong way around.
d) There are too few points on the graph.

....

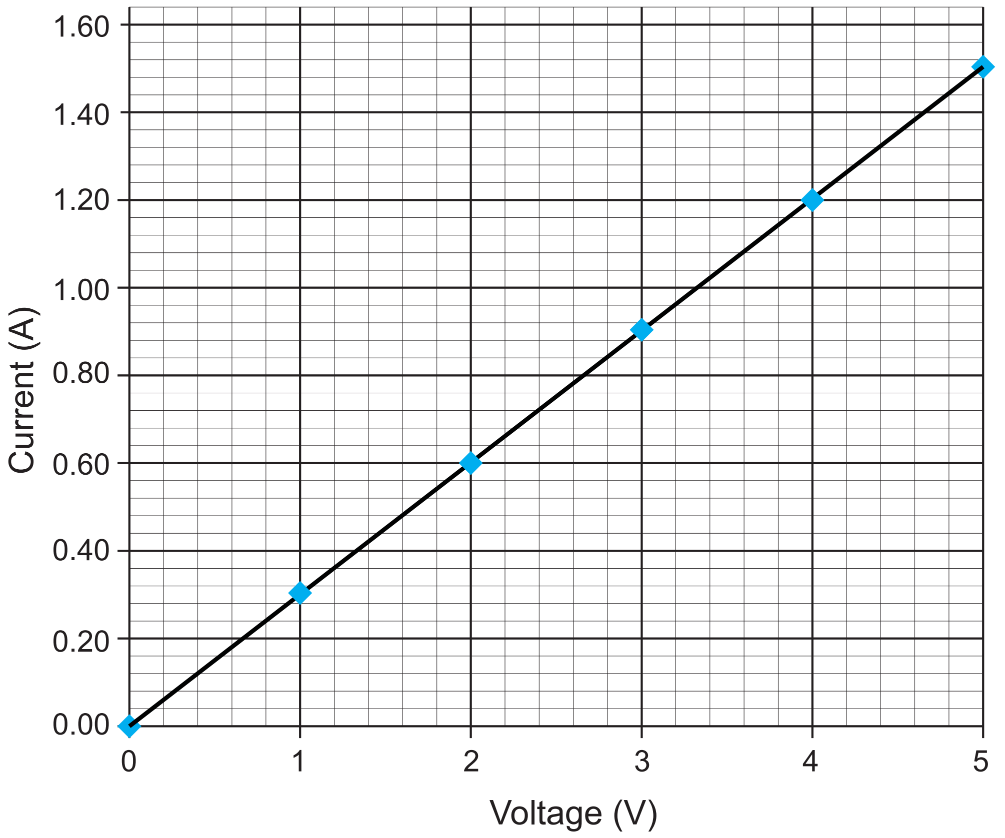
Q13: What trend is shown in the graph below?



a) As voltage increases, energy stored increases.
b) As voltage increases, energy stored decreases.
c) As energy stored increases, voltage increases.
d) As energy stored decreases, voltage increases.

. . . .

Q14: Describe the relationship between the variables in th following graph.



a) As voltage increases, current increases.
b) As voltage increases, current decreases.
c) As current decreases, voltage increases.
d) As current increases, voltage decreases.

. . . .

Q15: From the graph, estimate the current value for a voltage of 2.5 V?

a) 0.25 A
b) 0.75 A
c) 1.00 A
d) 2.50 A

5.5 Summary

Summary

You should now have the ability to:

- evaluate an experimental procedure:
  - assess its effectiveness;
  - plan for future modifications;
  - judge whether an alternative method might be more suitable.
- evaluate experimental results:
  - spot trends and patterns in the data;
  - make predictions in similar situations in the future;
  - assess and explain the relevance of the results obtained.

5.6 Resources

Texts

- **Higher Physics for CfE with Answers**, *P Chambers, M Ramsay and I Moore*, Hodder Gibson, ISBN 978-1444168570

Practical work

- Pupils could carry out some of the reactions demonstrated by the graphs in this topic and record their own results.

5.7 Assessment

There is no end of topic test for this topic as the topic itself is a series of questions.

Topic 6

Scientific communication

Contents

Prerequisites

You should already:

- be familiar with researching a physics issue and collating this information into a short presentation (National 5, Outcome 2.2 & 2.3);
- have carried out a variety of practical experiments throughout the course (Higher);
- be familiar with the following from your National 5 Assignment:
  - applying knowledge of physics to new situations and interpreting information;
  - selecting and presenting information appropriately in a variety of forms;
  - processing the information/data collected (using calculations and units, where appropriate);
  - communicating findings/information (National 5, Assignment);
- be familiar with applying your knowledge of experimental techniques to unfamiliar situations (National 5, Outcome 2.4);
- have the ability to:
  - select the appropriate practical technique(s) and apparatus for a particular procedure;
  - recognise that there are always significant safety risks when carrying out scientific procedures that must be taken into account in the planning stage;

Prerequisites continued

- have confidence in:
    - representing experimental data using a scatter graph;
    - sketching lines and/or curves of best fit;
    - calculating averages (means) for experimental data;
    - identifying and eliminating of 'rogue' points from results;
    - describing the relative accuracy of apparatus used to measure the volume of liquids;
    - describing how the reproducibility of repeated measurements from variability of data values;
    - describing the uncertainty associated with a measurement.

Learning objective

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

- write up a report on your investigation using the skills of scientific communication.

6.1 Introduction

As part of the Researching Physics unit you will be asked to prepare a scientific communication about your investigation. The aim of this topic is to help you to develop the skills required in doing this.

It is very important that scientists effectively communicate their work and results. There's no point in having a great scientific discovery and not telling anyone about it!

The scientific communication can take any of the formats in which the results of scientific research are commonly reported, including:

- PowerPoint presentation;
- Conference poster;
- Video presentation/podcast;
- Web page;
- Scientific paper;
- Traditional lab report, etc.

However, regardless of the format chosen, your scientific communication must contain the following essential features:

- A clear statement of the aim of your work;
- An analysis of your results;
- A valid evaluation of the procedures and results;
- A valid conclusion based on the evidence in your results.

It can also be helpful (although not essential to pass the unit) to set the scene by including a summary of the background physics as part of an introduction (you will have looked up information on this as part of your focus question), and a brief explanation of the procedure(s) used. These additional sections would usually appear between the aim and the results.

6.2 Test your prior knowledge

Test your prior knowledge Go online

Q1: Here are the results of an experiment into measuring the volume of a gas.

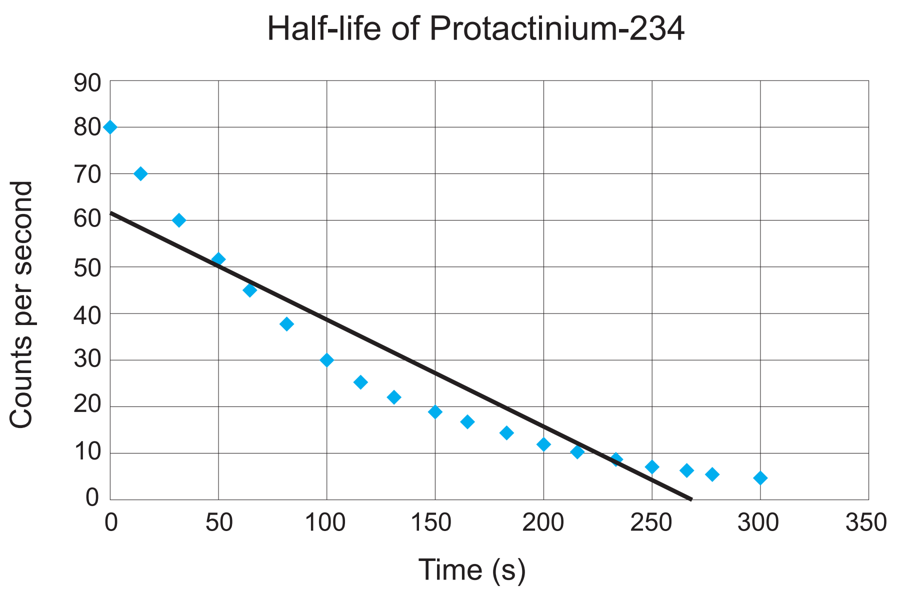
	Volume (cm^3)
1	35.0
2	29.7
3	35.5
4	34.6

Which reading in the table should be discarded before calculating the average volume?

a) 1
b) 2
c) 3
d) 4

. . . .

Q2: Identify the problem with the following graph:



a) The line of best fit should be a curve.
b) The scale is incorrect.
c) The x-axis and y-axis are the wrong way around.
d) The reaction time should be in seconds.

6.3 The passive voice

Good scientific writing includes all the normal conventions of good writing practice. However, there are some additional 'golden rules' that should be observed in scientific writing.

- Write in the past tense and passive voice.

For example, 'Sodium chloride was added to the solution.' is correct whereas 'Add sodium chloride to the solution.' or 'I added the sodium chloride to the solution.' are both incorrect.

The passive voice: Questions (5 min) Go online

Try putting the following sentences into the past tense and passive voice.

Q3: I added a 100 g mass to the end of the pendulum.

. . . .

Q4: Record the time taken to travel 200 m.

. . . .

Q5: We then measured the length of the spring using a metre stick.

6.4 Grammar in physics

The name of a planet should have a capital letter. For example, 'Earth' is correct when discussing a planet, and 'earth' should be used when discussing dirt or soil. The use of a capital letter makes these two very different words.

The name of a technique should **not** have a capital letter, except at the start of a sentence, for example, 'The travelling microscope was set up.'.

Appropriate use of abbreviations.
The expression should be written in full the first time it is used in the text, immediately followed by the abbreviation in brackets. The abbreviation should be used from then onwards, eg European Space Agency (ESA) should thereafter be referred to as ESA.

Use the correct scientific spellings for physics words.
For example reflection and refraction are both principles involving light but are very different to each other and so must be spelled correctly when being used.

If you have to use a chemical symbol they should be written exactly as they appear in the periodic table. For example, use 'Au' and not 'au'.

Grammar in physics: Question (5 min) Go online

Choose the correct version of the word.

Q6:

1. 5.1 N of Force / force was applied to the spring.
2. The chemical symbol for iron is fe / Fe.
3. The equipment used to measure small lengths accurately is called Vernier Calipers / vernier calipers.
4. The angle of refraction was measured using a Protractor / protractor.
5. The current through / across the resistor was measured using an ammeter.

6.5 Formal language

A list of rules you should remember when writing up your report:

- Always use formal language in your investigation report.
- Colloquial (slang) language is never appropriate in scientific writing!
- Scientific writing should be both concise and precise.
- Scientific writing should contain sufficient accurate, detailed information to allow the experiment to be repeated but without using redundant words or information.
- Be consistent with units and names.
- Do not change between different units or names, e.g. use either ml or cm^3. Do not use both in the same report.

Formal language: Questions (5 min) Go online

Think of an appropriate formal phrase to replace the colloquial phrase.

Q7: The current flowed to the buzzer causing it to go off.

. . . .

Q8: Light bounced off the surface of the mirror.

. . . .

Q9: The image was upside-down.

. . . .

Q10: The rest of the stuff needed for the circuit was added.

6.6 Formats of scientific communication

Scientists can use a number of different methods to communicate about their work. The most appropriate method will depend on the target audience and in how much detail the information needs to be shared. Commonly used scientific communication formats include:

1. **Traditional lab report**
    - a formal account of an experiment
    - contains enough detail to be used to repeat the experiment
    - can be used to evaluate the procedure and results of an experiment
    - written using the notes recorded in a lab book
2. **Scientific report**
    - summarises the contents of many lab reports
    - reviews some of the scientific literature in the topic
    - makes recommendations based on both the research results and the literature
    - related lab reports, diagrams and raw data may be attached as appendices
3. **Scientific paper**
    - a scientific report which is submitted to be an article in a scientific journal
    - peer-reviewed by a respected scientist to evaluate the experiments, the results and the writing
    - the more high-quality scientific papers a scientist produces, the more respected the scientist!
4. **Scientific poster**
    - a large poster used to communicate research results at scientific conferences
    - a highly visual method of presentation
    - summarises key points briefly on a single page
5. **PowerPoint presentation**
    - used to share results at meetings and conferences
    - visual, interactive form of communication
    - slides contain minimal information
    - information on slides is expanded upon orally
6. **Video presentation**
    - modern form of scientific communication
    - visual and engaging
    - means of interaction with wide audiences over the internet

7. **Podcasts**
    - short soundbites of information on websites
    - modern form of scientific communication
    - means of interacting with wide audiences over the internet
8. **Blogs**
    - short, regular 'diary'-like posts on a website
    - allow scientists to 'drip-feed' information to a wide audience
    - another modern form of scientific communication

Formats of scientific communication: Exercise Go online

In the past, scientists would almost always have produced a written report to communicate their research findings. Nowadays, they can choose to communicate in any one of a diverse range of communication media.

Examine and compare the four different resources listed below.

Note: It is not necessary to understand all of the physics content in the resources to undertake this activity. These resources can be evaluated with your current level of physics knowledge.

1. A video clip entitled 'Physics with a Bang - Electricity'.
    - http://youtu.be/MWncO6C1-XU
2. A scientific paper 'On Velocities Beyond the Speed of Light c'.
    - http://www.journal.chemistrycentral.com/content/3/1/13

Once you have looked over these resources, answer the following questions:

Q11: Which one was most eye-catching?

A) The video clip
B) The scientific paper
C) The journal article
D) The conference poster

. . . .

Q12: Which one looks like it will be the easiest to read and understand?

A) The video clip
B) The scientific paper
C) The journal article
D) The conference poster

. . . .

Q13: Which one looks most credible and reliable?

A) The video clip
B) The scientific paper
C) The journal article
D) The conference poster

. . . .

Q14: Which one was most interesting?

A) The video clip
B) The scientific paper
C) The journal article
D) The conference poster

. . . .

Q15: Which one gave the most information?

A) The video clip
B) The scientific paper
C) The journal article
D) The conference poster

. . . .

Q16: For which of the following did you need to understand everything in the resource to gain a general understanding of the experiment?

A) The video clip
B) The scientific paper
C) The journal article
D) The conference poster

6.7 Summary

Summary

In a scientific communication, it is important that enough accurate, detailed information to allow the experiment to be repeated is presented. The style of the language used should be both formal and consistent.

You should now have the ability to:

- evaluate an experimental procedure;
  - assess its effectiveness;
  - plan for future modifications;
  - judge whether an alternative method might be more suitable;
- evaluate experimental results:
  - spot trends and patterns in the data;
  - make predictions in similar situations in the future;
  - assess and explain the relevance of the results obtained.

6.8 Resources

Texts

- **Higher Physics for CfE with Answers,** *P Chambers, M Ramsay and I Moore*, Hodder Gibson, ISBN 978-1444168570

It would be helpful for students to have access to a variety of physics posters, journals, web pages and scientific reports for reference.

6.9 Assessment

End of topic 6 test (25 min) Go online

Q17: Look at the following sentences taken from a third year student's lab report:

"Face the lightmeter towards the lamp and keep these two objects in the same position (0.5 m apart) for the experiment. Set the power supply for the lamp to 30 V. Now record the reading in lux displayed on the lightmeter screen. Increase the voltage by 5 V, up to 100 V, recording the light level."

Rewrite the student's lab report to bring it up to the standard required for a real scientific report. Check the golden rules of scientific writing to help you!

. . . .

Q18: Change the list of instructions below into scientific report format by converting to the past tense (as the experiment was carried out in the past by the time of writing) and passive voice, and joining the sentences up into a paragraph.

1. Using a protractor adjust the angle of the projectile launcher to 5°.
2. Insert the projectile on to the launcher.
3. Launch the projectile.
4. Using a marker, mark the spot where the projectile lands.
5. Measure the distance from the launcher to the marker using a trundle wheel.
6. Increase the angle of launch by 5° and launch the projectile with an equal force.
7. Again measure the distance travelled.
8. Repeat steps continually increasing the angle.

. . . .

Q19: The format chosen for a scientific communication will depend largely on the target audience.

Choose the most appropriate form of scientific communication for each of the situations listed in the following table. Choose from:

- Blog
- Lab report
- PowerPoint presentation
- Scientific paper
- Scientific poster
- Scientific report
- Video (on website)

Situation	Type of communication
You are a scientist working in the quality assurance lab of a radar manufacturing company. You are undertaking an experiment to analyse the transmission of the signals and need to record the details so you don't forget what you did.	
You are a university professor who has just completed some highly significant, ground-breaking research that needs to be communicated to other experts in the scientific community.	
You are a scientific journalist working for a popular science magazine and want to provide your wide readership with short, regular news updates on the latest hot scientific topics.	
You are a scientist who is giving a one-off schools lecture entitled 'What is in comets?' You think that students who are not able to be in the live audience would also benefit from seeing these exciting experiments.	
You are a young researcher who needs an eye-catching visual method of communicating a summary of your results at an international conference.	
You are a scientist advising the government on nuclear power. You have reviewed a large number of articles on the subject and now need to collate and communicate your findings.	
You are a product development scientist working for a large consumer goods company. You have been asked to present the results of your recent research work to the company director. You know he will want to ask lots of questions.	

Topic 7

End of unit test

Contents

7.1 Key learning points

Key point

Web based research

The following is a checklist for evaluating web pages; you should be familiar with this and have used it to help you answer your focus question.

Author (source)

- Can you find out the name of the author?
- Is there information about the author provided?
- Is it clear that an institution or university or organisation sponsored the website (check the domain)?

Currency (date)

- Is the date the website was put on the internet present?
- Is an update or revision date present?

Level

- Is the website intended for a general or a scientific audience?
- Is the topic explored at a suitable level for Higher Physics?

Purpose

- Is the purpose of the site stated (to persuade, inform, explain, sell)?

Bias

- Is the information given and / or the views expressed biased?

Accuracy

- Are the sources of the information listed in a bibliography?

Conclusion

- Using the above information, is this an appropriate source for your research? Justify your opinion.

Key point

Planning an investigation

When planning an investigation you need to consider what is to be measured.

- The independent variable - What do I need to change?
- The dependent variable - What do I observe?
- The controlled variable(s) - What do I keep the same?

A hypothesis is a statement that proposes a possible explanation of what is happening in the investigation.

The checklist below will help you to successfully plan and carry out the practical aspects of your Researching Physics investigation.

Checklist	$\surd$
Choose a topic (Your teacher may give you one)	
Identify the most appropriate technique(s) you might use	
Plan the stages of the experiment	
Assess risks and plan to safely overcome these risks*	
Identify and collect the required apparatus	
Carry out the experimental procedure to produce and collect results	
Clean up	

*Safety considerations must be revisited throughout all planning and practical stages.

Key point

Carrying out an investigation

You should now have the ability to:

- think of an investigation in terms of a number of key stages;
- identify the key stages in planning and carrying out a scientific investigation;
- appreciate the importance of planning before starting the experiment.

You should be able to describe each of the following practical techniques and be aware of when to use them.

- Use of a balance
- Safe methods of heating
- Use of vernier calipers

Key point

Processing and analysing results

You should feel confident in:

- representing experimental data using a scatter graph;
- sketching lines and/or curves of best fit;
- calculating averages (means) for experimental data;
- identifying and eliminating of 'rogue' points from results;
- describing how the reproducibility of repeated measurements from variability of data values;
- describing the uncertainty associated with a measurement.

Make sure that you do not add your own errors when making measurements by being as careful as you can when reading scales, transferring solids and liquids and copying down numbers.

Key point

Evaluating and drawing conclusions

You should now have the ability to:

- evaluate an experimental procedure:
    - assess its effectiveness;
    - plan for future modifications;
    - judge whether an alternative method might be more suitable.
- evaluate experimental results:
    - spot trends and patterns in the data;
    - make predictions in similar situations in the future;
    - assess and explain the relevance of the results obtained.

Key point

Scientific communication

In a scientific communication, it is important that enough accurate, detailed information to allow the experiment to be repeated is presented. The style of the language used should be both formal and consistent.

7.2 End of unit assessment

End of unit 4 test (15 min) Go online

Q1: Where might physicists look up information if they were to research a topic?

a) Books
b) Websites
c) Journals
d) All of the above

. . . .

Q2: The first step in any research activity involves finding out about a particular topic by carrying out

a) a literature search.
b) an internet search.
c) an experiment.
d) a peer review.

. . . .

Q3: Which of the following should you check when assessing if a website is reliable?

a) Which country it is from?
b) When was it last updated?
c) Does it look nice?
d) Are there any photos?

. . . .

Q4: Which of the following is the least reliable domain?

a) .edu
b) .gov
c) .com
d) .org

. . . .

Q5: Websites with which of the following purposes of would be suitable to use in your research?

a) To persuade
b) To inform
c) Blogs
d) To sell

. . . .

Q6: What is the **main** purpose of including references in your research?

a) To fill up space in a word count
b) To allow another person to find the same information
c) To give credit to other authors
d) All of the above

....

Q7: Calculate the mean of the following set of data.

0.123, 0.109, 0.128, 0.116, 0.119

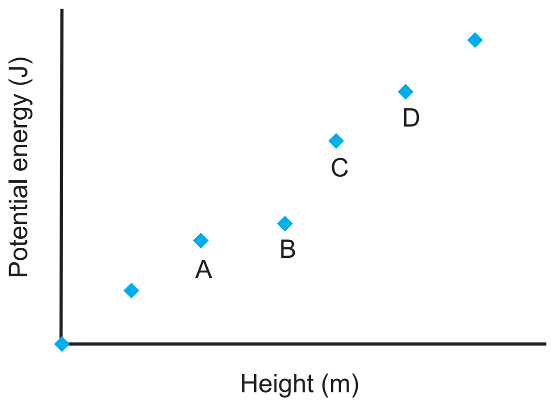
....

Q8: Calculate the mean of the following set of data.

10.2, 11.8, 11.0, 10.8, 11.3

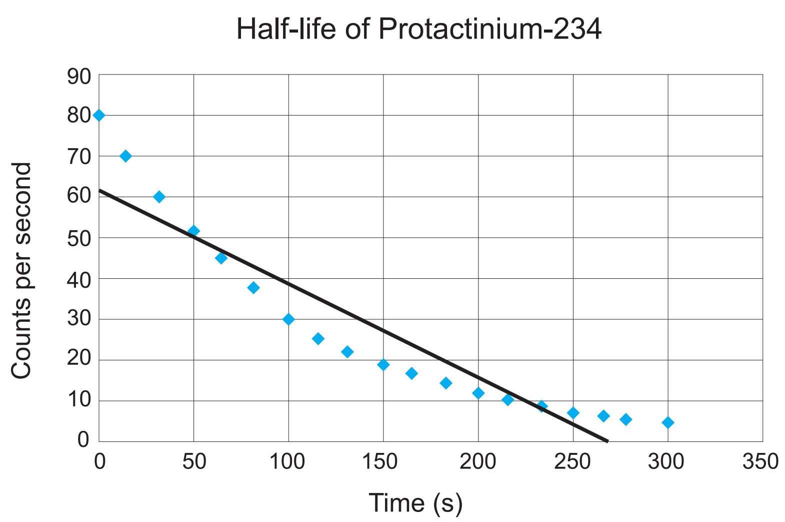
....

Q9: A student carried out an experiment to investigate how the potential energy of a ball (J) varies with height (m). Which point should be discarded as a "rogue" point?



....

Q10: Identify the problem with the following graph.



a) The line of best fit should be a curve.
b) The scale is incorrect.
c) The x and y axis are the wrong way around.
d) All of the above

. . . .

Q11: Choose the most appropriate form of scientific communication for each of the situations listed in the following table. Choose from:

- Blog
- Lab report
- PowerPoint presentation
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- Scientific poster
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Situation	Type of communication
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You are a scientific journalist working for a popular science magazine and want to provide your wide readership with short, regular news updates on the latest hot scientific topics.	
You are a scientist who is giving a one-off schools lecture entitled 'What is in comets?' You think that students who are not able to be in the live audience would also benefit from seeing these exciting experiments.	
You are a young researcher who needs an eye-catching visual method of communicating a summary of your results at an international conference.	
You are a scientist advising the government on nuclear power. You have reviewed a large number of articles on the subject and now need to collate and communicate your findings.	
You are a product development scientist working for a large consumer goods company. You have been asked to present the results of your recent research work to the company director. You know he will want to ask lots of questions.	

7.3 Resources

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Appendix A

Uncertainties

Contents

A.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.

A.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 $\pm$ uncertainty

best estimate of reaction time = 0.261 s $\pm$ 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.

$\Rightarrow$ 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.

A.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 $\pm$ half of the smallest scale division. In some cases, it may be possible to make reliable estimates of smaller fractions of scale divisions.

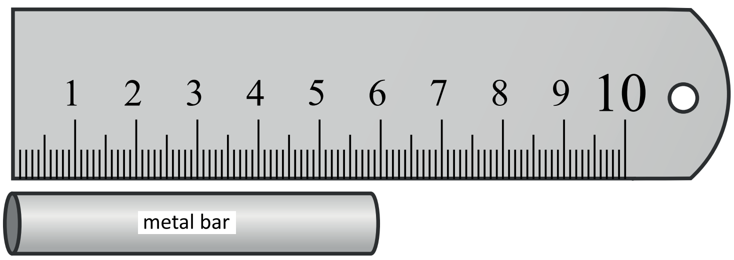
For instruments with digital scales the reading uncertainty is 1 in the last (least significant) digit.

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 ± 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 ± 0.1 A

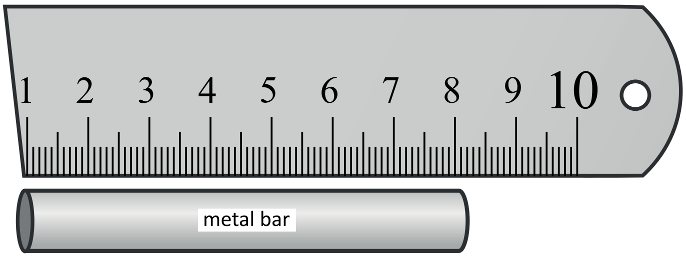
This means that the best estimate of the current is 12.9 A and it would be expected that the "true" current would be between 12.8 A and 13.0 A

A.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.

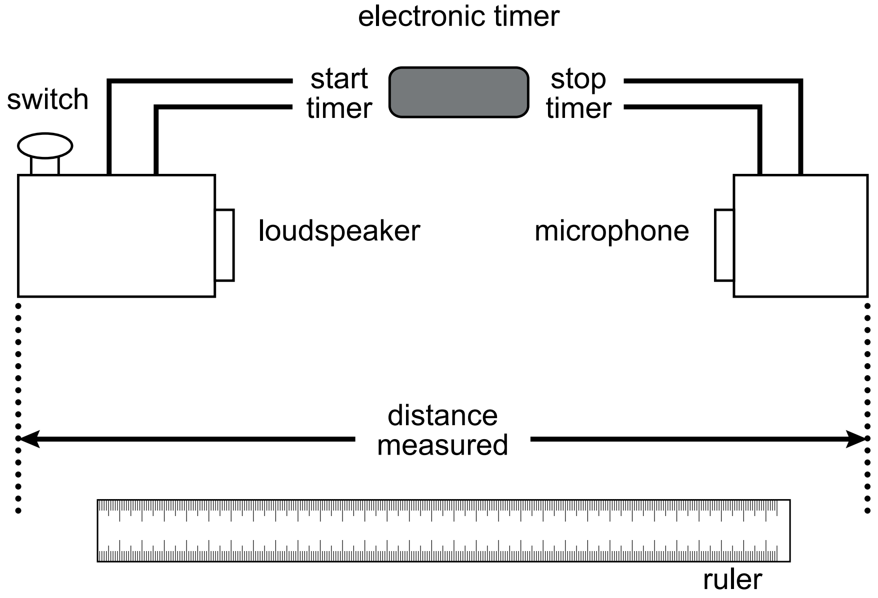
The following example shows a ruler being used to measure the length of a metal bar.



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.

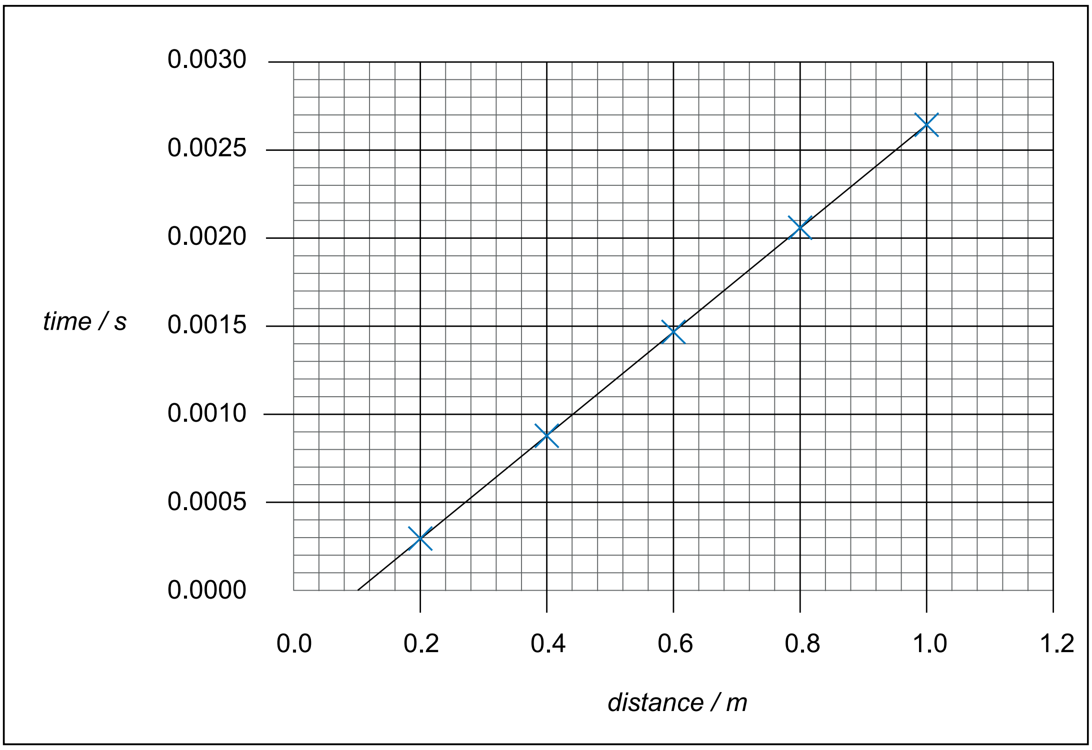
Example A student is investigating how the distance between a loudspeaker and microphone affects the time it takes a pulse of sound to travel from the loudspeaker to the microphone. The equipment used is shown below.



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

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

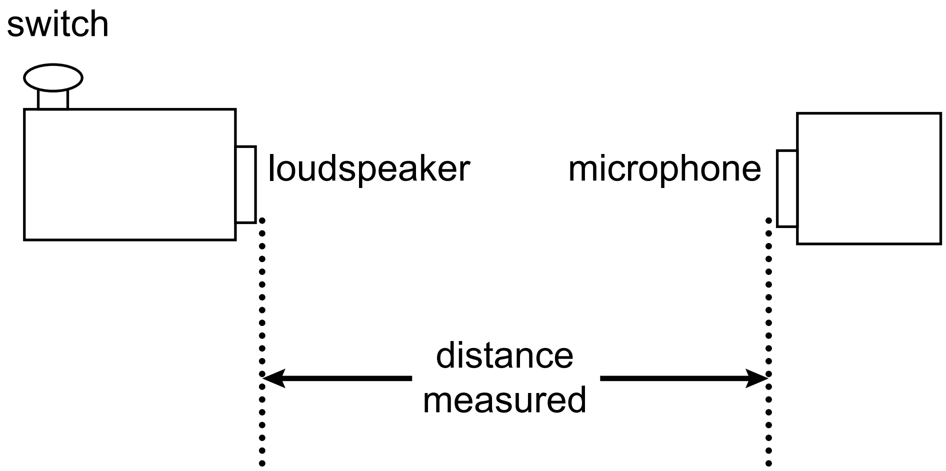
and here

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

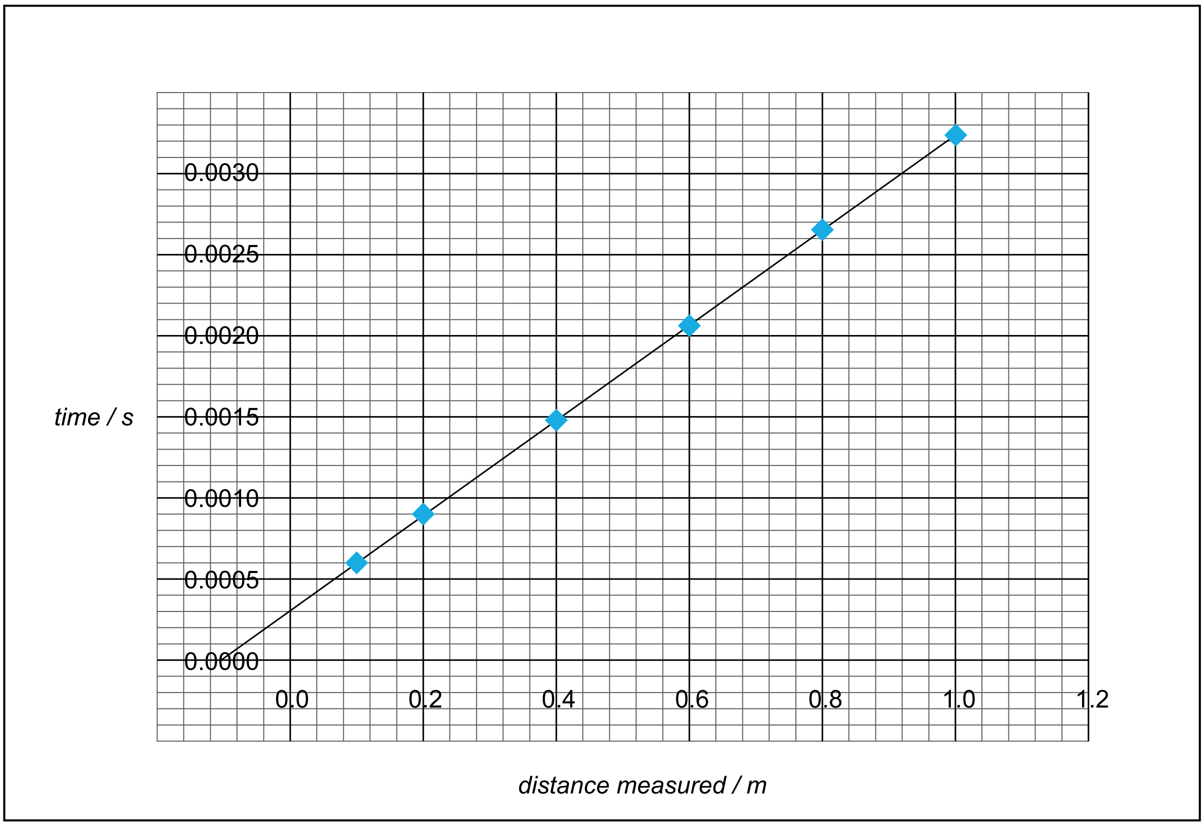
hence

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

A.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.

A.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%

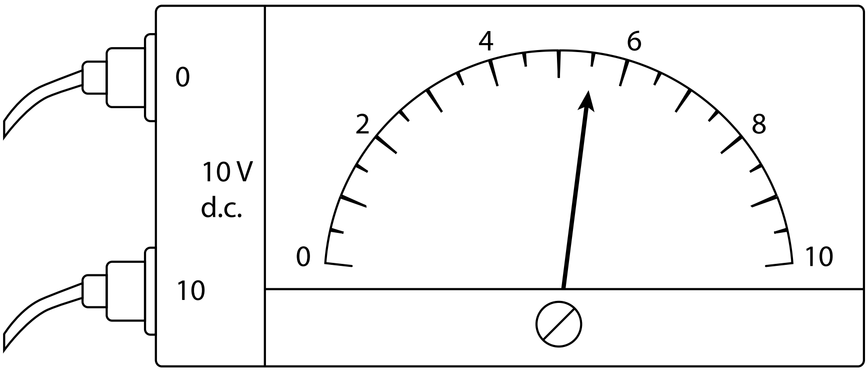
$$averagespeed = \frac{distance\ gone}{time\ taken}$$
$$averagespeed = \frac{125}{5.2}$$
$$averagespeed = 24mms^{-1}$$

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.

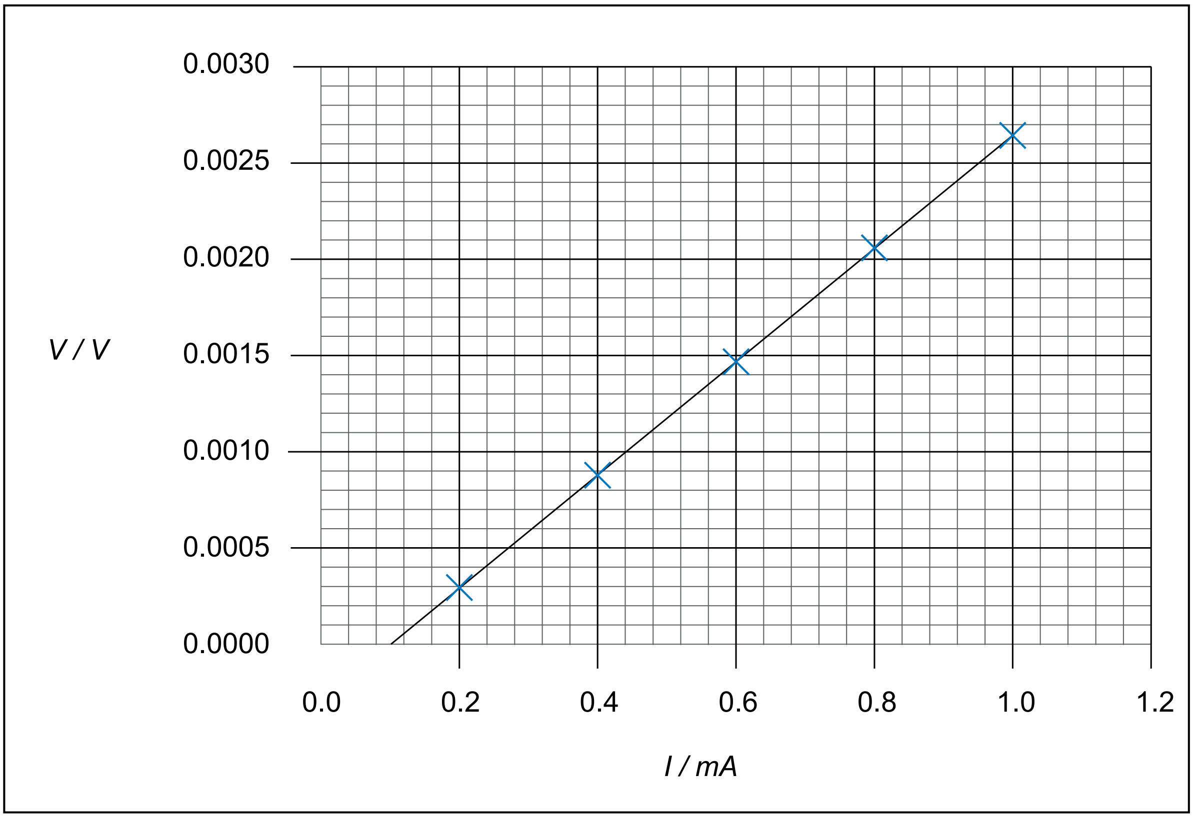
3.1 s	3.8 s	3.3 s	4.1 s	3.4 s

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

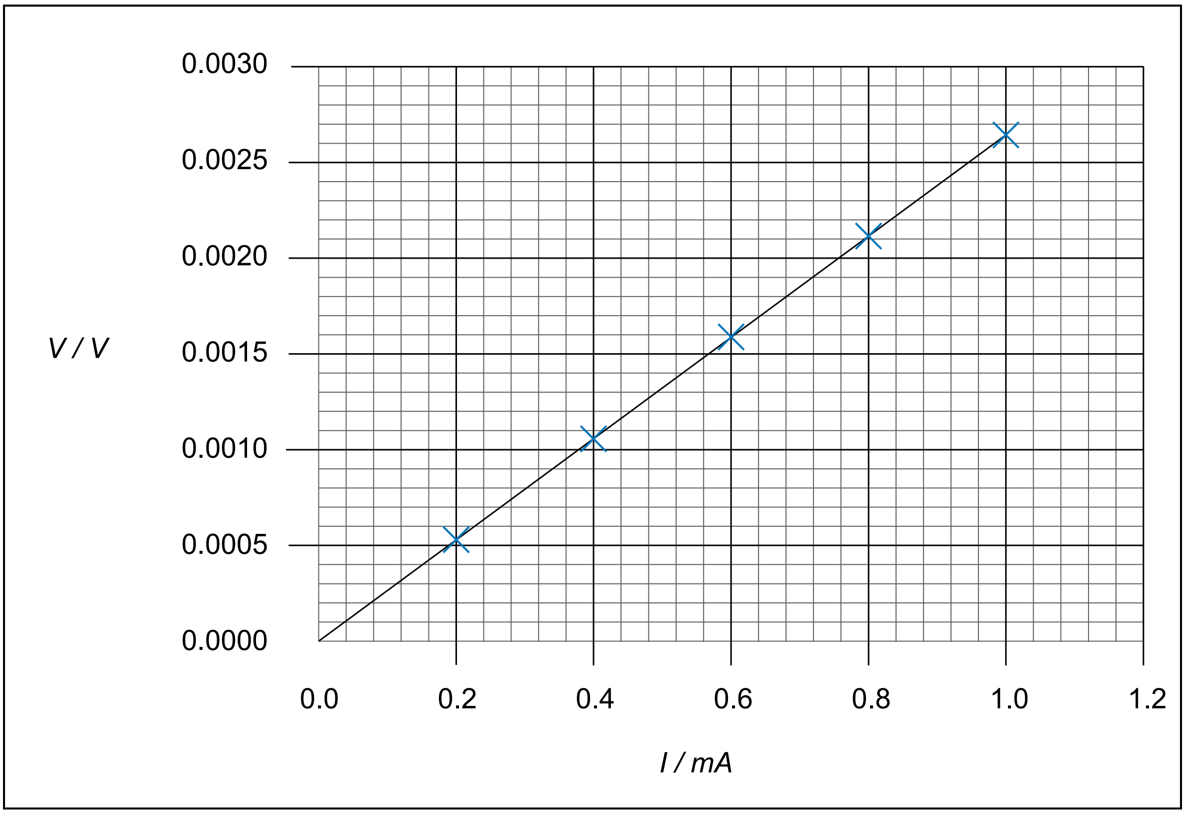
a) ± 0.01 s
b) ± 0.02 s
c) ± 0.1 s
d) ± 0.2 s
e) ± 1.0 s

. . . .

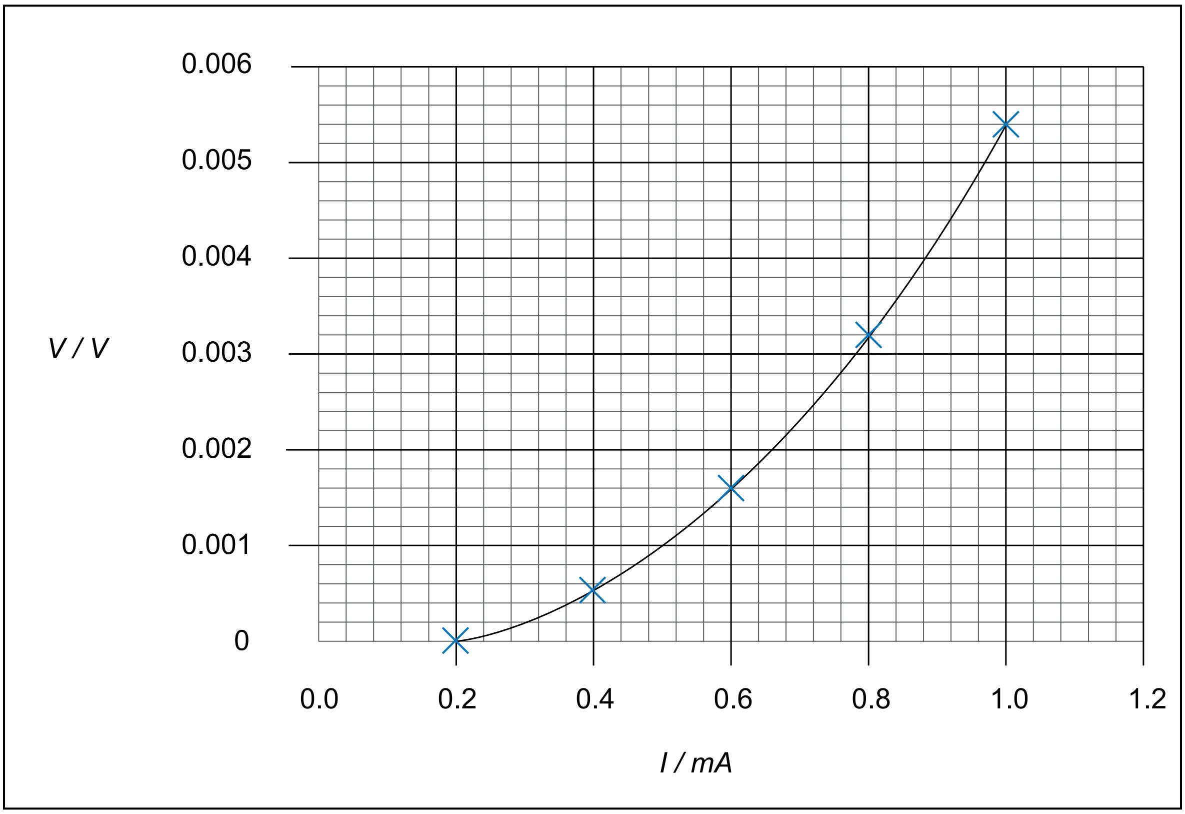
Q3: A student carries out three investigations into the variation of voltage and current. The results obtained are shown in the Graphs A, B and C.



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 ± 1°C
Heater current	=	5.0 A ± 0.2 A
Heater voltage	=	12.0 V ± 0.5 V
Time	=	100 s ± 2 s
Mass of liquid	=	1.000 kg ± 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} ± 4%.
The absolute uncertainty in this value of acceleration is:

a) ± 0.04 m s^{-2}
b) ± 0.1 m s^{-2}
c) ± 0.4 m s^{-2}
d) ± 1.0 m s^{-2}
e) ± 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.

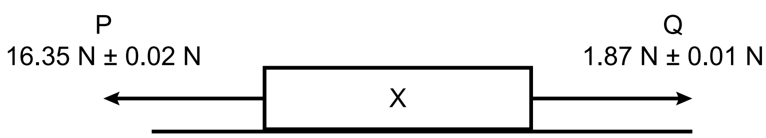
$$\lambda = 450 \text{ nm} \pm 10\%$$
$$f = 6.7 \times 10^{14} \text{Hz} \pm 2\%$$

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

A.2 Uncertainties and data analysis

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

A.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.

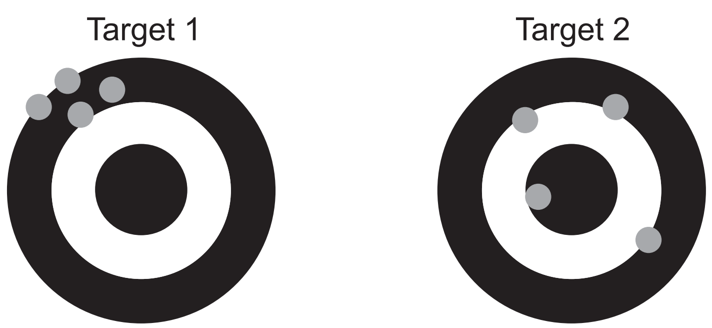
A.2.2 Comparing accuracy and precision

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.

A.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.

Answers to questions and activities

Topic 1: Web-based research

Answers from page 3.

Q1: d) All of the above

Q2: a) independent variable.

Q3: c) Aim, Method, Results, Conclusion, Evaluation

Reliability: Questions (page 5)

Q4:

- The Scottish Government site is much more reliable than the Wikipedia site.
- This is because anybody can add anything to Wikipedia at any time without proving that it is correct.
- The Scottish Government site is a *.gov* site and so will have been fact checked to ensure all information there is correct.
- Both sites have been updated recently.

Q5:

- The Scottish Government site is much more accurate than the Wikipedia site.
- This is because anybody can add anything to Wikipedia at any time without proving that it is correct.
- The Scottish Government site is a *.gov* site and so will have been fact checked to ensure all information there is correct.

Q6:

- In general, both sites are accurate, but, upon closer inspection, some of the information on the Wikipedia site is not correct.

Assessing level: Questions (page 6)

Q7: http://arxiv.org/pdf/0711.2279v2.pdf

Q8: http://www.astrosociety.org/education/publications/tnl/24/24.html

Assessing bias: Questions (page 6)

Q9: Yes, each of these sites has a bias.

Q10: The niauk site is the most scientifically accurate. (It has a .org domain and is written by the industry. It is likely to have the most scientifically accurate information.)

Q11: A site with a .gov domain which had been recently updated. A .gov site should have the least bias in their reporting.

End of topic 1 test (page 10)

Q12: d) All of the above

Q13: a) a literature search.

Q14: d) All of the above

Q15: c) .com

Q16: b) To inform or explain

Q17: b) To allow another person to find the same information

Topic 2: Planning an investigation

Test your prior knowledge (page 15)

Q1: b) Ammeter

Q2: c) Light gate

Q3: a) What do I change?

Identifying the key stages: Exercise (page 17)

Q4: Model answer:

1. Decide to have a cup of coffee
2. Turn on tap
3. Put water in kettle
4. Turn off tap
5. Switch on kettle to boil water
6. Get out the cup
7. Get out the teaspoon
8. Put teaspoon in cup
9. Get out the coffee
10. Put coffee in cup
11. Get out the sugar
12. Add sugar
13. Add boiling water to cup
14. Leave for 1 minutes
15. Get out the milk
16. Add milk
17. Stir with teaspoon
18. Drink coffee
19. Wash dishes
20. Tidy up

Planning ahead: Questions (page 20)

Q5: Options A and B

Q6: d) All of the above

End of topic 2 test (page 22)

Q7: b) What do I observe?

Q8: c) Mass added to a trolley

Q9: d) All of the above

Q10: b) Carry out the procedure

Topic 3: Carrying out an investigation

Test your prior knowledge (page 25)

Q1: c) Laboratory thermometer

Q2: a) Voltmeter

Q3: c) Vernier calipers

Identifying the key stages: Exercise (page 26)

Q4: Model answer:

1. Connect an ammeter to a cell in series.
2. Connect a voltmeter across the cell.
3. Take readings for potential difference and current.
4. Add a bulb to the circuit.
5. Take readings of potential difference and current.
6. Continue to add bulbs in parallel and make readings.
7. Tidy equipment.
8. Plot a graph of potential difference against current.
9. Find the internal resistance of the cell by calculating the gradient of the line of best fit.

End of topic 3 test (page 31)

Q5: d) All of the above.

Q6:

Technique	Use
Immersion heater	Heating a solid block
Ammeter	Measuring the current **through** a component
Voltmeter	Measuring the potential difference **across** a component
Metre stick	Measuring length or distance
Use of balance	Measuring mass
Heating using a Bunsen burner	Heating a substance to 100°C quickly
Stopwatch	Timing an event where reacting time is negligible
Thermometer	Measuring temperature of a substance from 0°C to 100°C
Vernier calipers	Measuring a very small length or distance accurately

Topic 4: Processing & analysing results

Test your prior knowledge (page 35)

Q1: a) Length

Q2: d) Scatter graph

Q3: b) Independent variable

Drawing the line - the best fit: Question (page 37)

Q4: The equation of the line is given as y = 1.6x + 0.32. Calculate the gradient of your graph and compare it to this value of 1.6.

Replicate measurements: Question (page 38)

Q5: Answer: Experiment B as the values are closer together.

Calculating the mean value: Questions (page 39)

Q6: 0.119

Q7: 11.02 = 11.0

Identification and elimination of "rogue" points: Questions (page 40)

Q8: (1.95 + 2.12 + 1.89 + 2.04 + 2.68 + 1.99 + 2.09 + 2.01 + 1.92 + 2.11) / 10 = 20.8 / 10 = 2.08 mA

Q9: (1.95 + 2.12 + 1.89 + 2.04 + 1.99 + 2.09 + 2.01 + 1.92 + 2.11) / 10 = 18.12 / 10 = 2.01 mA

Q10: (0.145, 0.162, 0.139, 0.154, 0.218, 0.149, 0.159, 0.151, 0.142, 0.161) / 10
= 1.58 / 10
= 0.158 Kg

Q11: Eliminate the rogue value - 0.218
(0.145 + 0.162 + 0.139 + 0.154 + 0.149 + 0.159 + 0.151 + 0.142 + 0.161) / 9
= 1.362 / 9
= 0.1513 Kg

Scale reading uncertainty - Analogue: Exercise (page 41)

Q12:

Apparatus	Uncertainty
Newton meter with 10 N divisions	5 N
Voltmeter with 0.3 V divisions	0.15 V
Thermometer with 0.1°C divisions	0.05°C
Ruler with 0.1 cm divisions	0.05 cm

Scale reading uncertainty - Digital: Exercise (page 41)

Q13:

Apparatus	Uncertainty
Voltage reading of 12.3 V	0.1 V
Voltage reading of 3.6 V	0.1 V
Current reading of 0.128 mA	0.001 mA
Balance reading of 1309 g	1 g

End of topic 4 test (page 42)

Q14: B

Q15: a) 23.55 cm^3

Q16: d) 3.74 g - 3.76 g

Q17: A and B

Topic 5: Evaluating & drawing conclusions

Test your previous knowledge (page 48)

Q1: c) 24.75 cm^3

Q2: d) 45.14 g - 45.16 g

Q3: c) 5 N

Evaluating procedures: Questions (page 49)

Q4:

Task	Apparatus
Accurately measuring the mass to be added to a wire to measure Young's Modulus.	Top pan balance
Measuring about 100 cm^3 of water, to be used in a latent heat experiment.	100 cm^3 beaker
The force exerted on a wire due to a mass.	Newtonmeter / Newton balance
Accurately measuring the resistance in a length of wire.	Ohmmeter

Q5:

Task	Measurement tool
Internal diameter of a metal nut	Vernier calipers
Height of lab stool	Metre stick
Length of classroom	Trundle wheel

Q6: b) Extreme temperatures could be harmful to equipment.

Q7: A and D

Q8: c) Her reaction time will be too slow.

Q9: b) Use an electronic fast timer.

Evaluating results and drawing conclusions: Questions (page 51)

Q10: a) As the temperature increases the peak wavelength decreases.

Q11: a) The information to be graphed is two sets of numbers.

Q12: a) The line of best fit should be a curve.

Q13: a) As voltage increases, energy stored increases.

Q14: a) As voltage increases, current increases.

Q15: b) 0.75 A

Topic 6: Scientific communication

Test your prior knowledge (page 60)

Q1: b) 2

Q2: a) The line of best fit should be a curve.

The passive voice: Questions (page 61)

Q3: 100 g was added to the end of the pendulum.

Q4: The time taken to travel 200 m was recorded.

Q5: The length of the spring was measured using a metre stick.

Grammar in physics: Question (page 62)

Q6:

1. 5.1 N of force was applied to the spring.
2. The chemical symbol for iron is Fe.
3. The equipment used to measure small lengths accurately is called vernier calipers.
4. The angle of refraction was measured using a protractor.
5. The current through the resistor was measured using an ammeter.

Formal language: Questions (page 62)

Q7: The current flowed to the buzzer switching it on and causing it to sound.

Q8: The light was reflected off of the incident surface of the mirror.

Q9: The image was inverted.

Q10: The remainder of the components/equipment was added to the circuit.

Formats of scientific communication: Exercise (page 64)

Q11: Any answer is correct.

Q12: Any answer is correct.

Q13: B, C and D are correct.

Q14: Any answer is correct.

Q15: B and C are correct.

Q16: Any answer is correct.

End of topic 6 test (page 67)

Q17: The lightmeter and the lamp were set up 0.5 m apart facing each other. The lamp's power supply was set to 30 V and a reading of the light level was recorded in lux. The voltage was increased in increments of 5 V up to 100 V and the light level was recorded at each voltage.

Q18: Please note that this is not the only correct answer. There will be many other variations that would all be acceptable. This is only provided as a specimen answer.

A protractor was used to adjust the angle of the projectile launcher to 5°. The projectile was inserted into the launcher and the projectile subsequently launched. The marker landed and the position when it landed was marked. The distance from the launcher to the landing position was measured using a trundle wheel. The angle of launch was increased by 5° and the projectile was launched with an equal force as before. This distance was measured as before and the steps were repeated.

Q19:

Situation	Type of communication
You are a scientist working in the quality assurance lab of a radar manufacturing company. You are undertaking an experiment to analyse the transmission of the signals and need to record the details so you don't forget what you did.	Lab report
You are a university professor who has just completed some highly significant, ground-breaking research that needs to be communicated to other experts in the scientific community.	Scientific paper
You are a scientific journalist working for a popular science magazine and want to provide your wide readership with short, regular news updates on the latest hot scientific topics.	Blog
You are a scientist who is giving a one-off schools lecture entitled 'What is in comets?' You think that students who are not able to be in the live audience would also benefit from seeing these exciting experiments.	Video (on website)
You are a young researcher who needs an eye-catching visual method of communicating a summary of your results at an international conference.	Scientific poster
You are a scientist advising the government on nuclear power. You have reviewed a large number of articles on the subject and now need to collate and communicate your findings.	Scientific report
You are a product development scientist working for a large consumer goods company. You have been asked to present the results of your recent research work to the company director. You know he will want to ask lots of questions.	PowerPoint presentation

Topic 7: End of unit test

End of unit 4 test (page 73)

Q1: d) All of the above

Q2: a) a literature search.

Q3: b) When was it last updated?

Q4: c) .com

Q5: b) To inform

Q6: b) To allow another person to find the same information

Q7: 0.119

Q8: 11.02 = 11.0

Q9: B

Q10: a) The line of best fit should be a curve.

Q11:

Situation	Type of communication
You are a scientist working in the quality assurance lab of a radar manufacturing company. You are undertaking an experiment to analyse the transmission of the signals and need to record the details so you don't forget what you did.	Lab report
You are a university professor who has just completed some highly significant, ground-breaking research that needs to be communicated to other experts in the scientific community.	Scientific paper
You are a scientific journalist working for a popular science magazine and want to provide your wide readership with short, regular news updates on the latest hot scientific topics.	Blog
You are a scientist who is giving a one-off schools lecture entitled 'What is in comets?' You think that students who are not able to be in the live audience would also benefit from seeing these exciting experiments.	Video (on website)
You are a young researcher who needs an eye-catching visual method of communicating a summary of your results at an international conference.	Scientific poster
You are a scientist advising the government on nuclear power. You have reviewed a large number of articles on the subject and now need to collate and communicate your findings.	Scientific report
You are a product development scientist working for a large consumer goods company. You have been asked to present the results of your recent research work to the company director. You know he will want to ask lots of questions.	PowerPoint presentation

Appendix A: Uncertainties

Quiz (page 86)

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