CHAPTER

01 Practical investigation

This chapter covers most of the skills needed to successfully plan and conduct a practical investigation.

Section 1.1 is a guide to designing and planning an investigation, including how to write a hypothesis, and how to identify the variables. It explains validity, reliability, precision and accuracy, to assist in planning an investigation appropriately.

Section 1.2 is a guide to conducting investigations. It describes methods for accurately collecting and recording data to uncertainty errors. It explores presenting data using tables and graphs, to aid in selecting the most appropriate format for presenting the results.

Section 1.3 explains how to discuss an investigation and draw evidence-based conclusions that relate to the hypothesis and research question.

Practical Investigation Steps

The size and scope of a practical investigation can be initially quite daunting, but establishing a task list and timeline will help break it down into manageable steps. The entire task is expected to take between 7 and 10 hours.

Here are some steps that will need to be considered in a timeline:

- Determine the topic and type of investigation.
- Research and write down the theory on which the investigation is based.
- Determine an appropriate question to answer, and formulate a hypothesis.
- Identify the independent, dependent and controlled variables.
- Select equipment and resources needed for the investigation.
- Determine an appropriate procedure (methodology), considering validity, reliability and accuracy.
- Assess the risks and ethical issues, and identify measures to address these.
- Conduct the investigation and record all data obtained.
- Analyse and evaluate the data.
- Evaluate your methods. Suggest ways of improving or extending the investigation.
- Write an evidence-based conclusion. Describe the limitations of the study.
- Write the final report. (This should not be the focus of the investigation but rather an opportunity to communicate the investigation process and your conclusions.)

Some of these tasks are larger and will require more time than others. Many will overlap. Plan a realistic approach, consult with teachers to establish school-based time constraints and fix dates for the completion of each task. Allow time for reflection and to review your earlier work.

Science Inquiry Skills

- identify, research and construct questions for investigation; propose hypotheses; and predict possible outcomes
- design investigations, including the procedure to be followed, the materials required, and the type and amount of primary and/or secondary data to be collected; conduct risk assessments; and consider research ethics
- conduct practical work, including the manipulation of devices, safely, competently and methodically for the collection of valid and reliable data
- Represent data in meaningful and useful ways, including using appropriate *Système Internationale* (SI) units and symbols, and significant figures
- organise and analyse data to identify trends, patterns and relationships
- identify sources of random and systematic uncertainty and estimate their effect on measurement results
- state absolute uncertainties in values and calculate percentage uncertainty where appropriate
- combine uncertainties in calculations to determine the overall uncertainty in a measurement (addition, subtraction, multiplication and division)
- identify anomalous data and calculate the percentage difference between the experimental results and a currently accepted value
- select, synthesise and use evidence to make and justify conclusions
- interpret a range of scientific texts and evaluate processes and conclusions by considering the available evidence, and use reasoning to construct scientific arguments
- select, construct and use appropriate representations, including text and graphical representations of empirical and theoretical relationships, to communicate conceptual understanding, solve problems and make predictions
- select, use and interpret appropriate mathematical representations, including linear and non-linear graphs and algebraic relationships representing physical systems, to solve problems and make predictions
- relate gradients and axis intercepts of linear graphs to physical quantities
- apply dimensional analysis to determine the appropriate units for calculated quantities, e.g. a gradient in a graph
- use uncertainty bars to represent the uncertainty in a value on a graph and take into account when sketching a line of best fit
- communicate to specific audiences and for specific purposes using appropriate language and nomenclature

School Curriculum and Standards Authority. (2023). *Physics ATAR course Year 12 Syllabus for teaching from 2025*.

1.1 Designing and planning the investigation

Taking the time to carefully plan and design a practical investigation before you begin will help you to maintain a clear and concise focus throughout. Preparation is essential. Ensure you understand the theory behind the investigation and prepare a detailed plan for the practical components of the investigation. This section is a guide to some of the key steps that should be taken when planning and designing a practical investigation (Figure 1.1.1).

FIGURE 1.1.1 There are many elements to a practical investigation, which may appear overwhelming to begin with. Taking a step-by-step approach will help the process and assist you in completing a worthwhile investigation.

DETERMINING THE TYPE OF INVESTIGATION

In your course, you will be expected to prepare a portfolio of the practical work you have undertaken across the range of physics areas studied. This portfolio will include evidence of a variety of science inquiry skills, including experimental design and the communication and evaluation of scientific data.

Several types of research methods are used in science. Physics investigations typically fall into two methodologies:

- analysing the slope of a linear graph
- determining the relationship between two continuous **variables**.

From your research on the topic you are investigating you may find that there is a mathematical relationship between the variables that you are exploring. It may be possible to use your algebra skills to write the mathematical relationship in the form of a linear equation, $y = mx + c$, where y is the dependent variable and x is the independent variable. A graph of the y and x variables will result in a linear graph with a slope equal to a constant, m, or collection of constants. By equating the value of the slope to these constants some meaningful analysis can be made, such as finding a value for the acceleration due to gravity or the specific heat capacity of a metal.

If, in your research, you find that there is no equation that links your variables, then you can investigate to determine what the relationship might be. By graphing your variables, you may find that the relationship is linear, or it may be inverse, exponential or even inverse squared. An investigation of this kind results in a calibration curve, which can be used to predict values of the dependent variable given particular values of the independent variable.

DEVELOPING RESEARCH QUESTIONS AND AIMS, FORMULATING HYPOTHESES AND IDENTIFYING VARIABLES

The research question, aim and hypothesis are interlinked. It is important to note that each of these can be refined as the planning of the investigation continues.

Formulating a question

A research question is a question that comes from an inquiring mind. When you are actively involved in developing your scientific understanding you will want to know what factors affect a variable, or what is the relationship between two variables. The research question poses the question that the investigation seeks to answer. For example: What is the relationship between voltage and current?

Before formulating a question, it is good practice to conduct a literature review of the topic to be investigated. You should become familiar with the relevant scientific concepts and key terms.

During this review, write down questions, correlations or equations as they arise.

Compile a list of possible ideas. Do not reject ideas that initially might seem impossible. Use these ideas to generate questions that are answerable.

Before constructing a hypothesis, formulate a question that needs an answer. This question will lead to a hypothesis when:

- the question is reduced to measurable variables
- a prediction is made based on knowledge and experience.

Evaluating your question

Once a question has been chosen, stop to evaluate the question before progressing. The question may need further refinement or even further investigation before it is suitable as a basis for an achievable and worthwhile investigation. A major planning point is to attempt something that is possible to complete in the time available or with the resources on hand. It might be a little difficult to create a particularly complicated device with the facilities available in the school laboratory.

To evaluate the question, consider the following:

- Relevance: Is the question related to the appropriate area of study?
- Clarity and measurability: Can the question lead to a clear hypothesis? If the question cannot lead to a specific hypothesis, it will be very difficult to complete the research.
- Time frame: Can the question be answered within a reasonable period of time? Is the question too broad?
- Knowledge and skills: Do you have a level of knowledge and a level of laboratory skills that will allow the question to be explored? Keep the question simple and achievable.
- Practicality: Are resources, such as laboratory equipment and materials, likely to be readily available? Keep things simple. Avoid investigations that require sophisticated or rare equipment. Equipment that is more-readily available includes timing devices, objects that could be used as projectiles, a tape measure and other common laboratory equipment.
- Safety and ethics: Consider the safety and ethical issues associated with the question you will be investigating. If there are issues, can these be addressed?
- Advice: Seek advice from your teacher about the question. Their input may prove very useful. Their experience may lead them to consider aspects of the question that you have not thought about.

Defining the aim of the investigation

An aim is a statement describing in detail what will be investigated to answer the research question. For example: The aim of the experiment is to investigate the relationship between the voltage and current in a circuit with constant resistance. Each aim should directly relate to the variables that will be referred to in the hypothesis. The aims do not need to include the details of the method.

Example

- Aim: The aim of the experiment is to investigate the relationship between mass and acceleration, when a constant force is applied.

Hypothesis

A hypothesis is a definite statement, based on previous knowledge and evidence or observations, that attempts to answer the research question. The hypothesis must relate the independent and dependent variables and describe the relationship between them. For example: Increasing the voltage supplied to a circuit with constant resistance increases the current proportionally.

Here are some further examples of hypotheses:

- For a constant force, if the mass is increased, the acceleration is decreased as an inverse relationship.
- If the value of the resistance of a circuit increases, the current flowing in the circuit will decrease as an inverse relationship.

- Assuming no heat loss to the surroundings, the temperature rise of a fixed mass of water is proportional to the time it is heated by a constant power source.
- As the height from which an object is dropped increases, the final velocity of the object will increase as a squared relationship.

There are no wrong or right hypotheses. You might formulate a hypothesis that a more experienced person will disagree with; however, the purpose of an investigation is to find the answer to a research question. If the answer to the question supports your hypothesis, then that is a positive result, as it will confirm your understanding of the concept. On the other hand, if your investigation does not support your hypothesis, then that is a useful result as well, as you can now say that your original understanding was not correct and you can change your understanding to a more scientific one. Some of you might notice that the following hypothesis will not be supported by the investigation:

- The greater the mass of a marble, the faster it will hit the ground, when dropped from the same height.

This doesn't mean that the hypothesis is wrong, but it may indicate that there was some misconception that you had that was not exposed in your literature review.

Formulating a hypothesis

A good hypothesis should:

- be a definite statement of the relationship
- include an independent and a dependent variable that is continuous and measurable
- be worded so that it can be tested in the experiment.

The hypothesis should also be falsifiable. This means that a negative outcome would disprove it. For example, the hypothesis that all apples are round cannot be proved beyond doubt, but it can be disproved, in other words, it is falsifiable. In fact, only one oval-shaped apple is needed to disprove this hypothesis. Unfalsifiable hypotheses cannot be tested by science. These include hypotheses on ethical, moral and other subjective judgements.

Variables

A good scientific hypothesis can be tested, that is, it can be supported or refuted through investigation. To be a testable hypothesis, it should be possible to measure both the change or treatment and the effect, or what will happen. The factors that can be changed, or are changed as a result of the experiment or investigation, are called the variables. An experiment or investigation determines the relationship between variables.

There are three categories of variables:

- The **independent variable** is the variable that is changed by the researcher. You must test only one independent variable in any investigation, otherwise it cannot be stated that the changes in the dependent variable are the result of changes in the independent variable.
- The **dependent variable** is the variable that may change in response to a change in the independent variable. This is the variable that will be measured or observed. You should measure only one dependent variable in any investigation. If you want to measure another dependent variable then you will need to do another investigation with another hypothesis.
- **Controlled variables** are all the variables that must be kept constant during the investigation otherwise the test cannot be fair.

Read the following example of a hypothesis.

If the cross-sectional area of a resistor is constant, the longer the wire, the greater the resistance as a linear relationship.

Identify the different variables.

- independent variable: length of wire
- dependent variable: resistance of the wire
- controlled variables: potential difference, material of the resistor, temperature of the resistor.

Completing a table like Table 1.1.1 will assist in evaluating the question or questions.

TABLE 1.1.1 Break the question down to determine the variables.

Research question	How does the power of a kettle affect the time taken to boil water?
Independent variable	the power of the kettle
Dependent variable	the time the kettle takes to boil water
Controlled variables	mass of the water, purity of the water, starting temperature of the water and kettle
Potential hypothesis	The greater the power of a kettle, the less time it will take to boil water, as an inverse relationship

Qualitative and quantitative variables

Variables are either qualitative or quantitative, with further subsets in each category.

- **Qualitative variables** can be observed but not measured; for example, describing a light globe as bright or dim. They can only be sorted into groups or categories such as brightness, type of construction material or type of device.
  - Nominal variables are categorical variables in which the order is not important; for example, the type of material or type of device.
  - Ordinal variables are categorical variables in which order is important and groups have an obvious ranking or level; for example, brightness (Figure 1.1.2).
- **Quantitative variables** can be measured. Length, area, weight, temperature and cost are all examples of quantitative data.
  - Discrete variables consist of only integer numerical values, not fractions; for example, the number of pins in a packet, the number of springs connected together, or the energy levels in atoms.
  - Continuous variables allow for any numerical value within a given range; for example, the measurement of temperature, length, mass and frequency.

In physics, you should choose continuous quantitative variables for both the independent and dependent variables. This will allow you to construct a line graph, and therefore determine the slope of the line, or the relationship between the variables.

FIGURE 1.1.2 When recording qualitative data, describe in detail how each variable will be defined. For example, if recording the brightness of light globes, light meters are a quantitative way to gather data.

WRITING THE METHODOLOGY

The methodology, or method, of your investigation is a step-by-step procedure. When detailing the method, ensure it enables you to conduct a valid, reliable and accurate investigation.

Validity

Validity refers to whether an experiment is in fact testing the hypothesis. Is the investigation obtaining data that is relevant to the question, or is it flawed?

To ensure an investigation is valid, it should be designed so that only one variable is changed at a time. The other variables must remain constant, so that meaningful conclusions can be drawn about the effect of the independent variable alone.

To ensure validity, you must carefully determine:

- the independent variable—the variable that will be changed, and how it will change
- the dependent variable—the variable that will be measured
- the controlled variables—the variables that must remain constant.

Reliability

Reliability refers to the idea that the experiment can be repeated many times and will obtain consistent results. You can maintain the investigation's reliability by:

- listing and defining the control variables and how they will be kept constant
- listing the detailed steps that you will take to conduct the experiment, describing what you will do and how you will measure and record data
- ensuring that there are enough changes of the independent variable. Typically, five changes over a wide range of the independent variable are considered sufficient.
- ensuring there are enough trials conducted for each value of the independent variable. Typically, you should conduct at least three trials repeating the experiment, then average the three measurements. This reduces random errors and allows systematic errors to be identified. If a reading differs too much from the rest (known as an outlier), discard it before averaging (Figure 1.1.3).

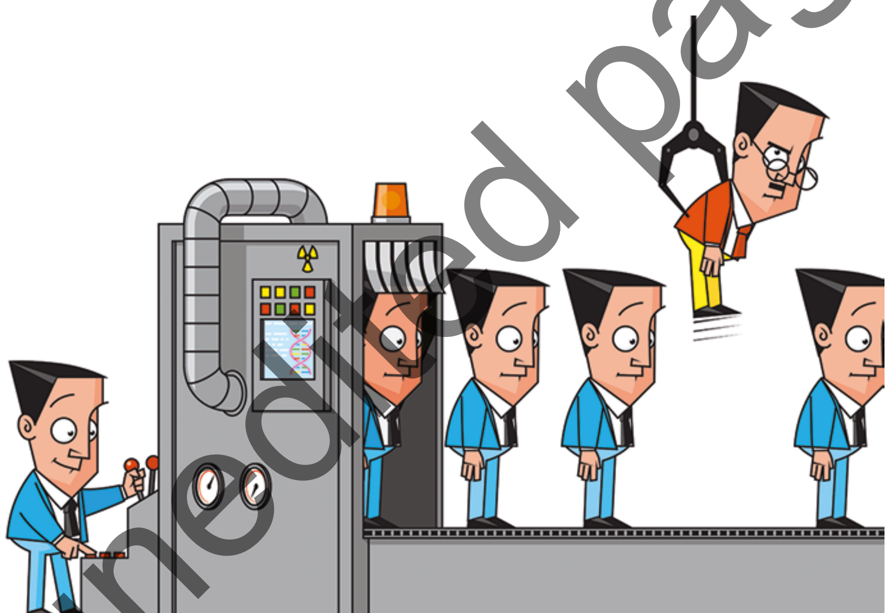

FIGURE 1.1.3 Replication increases the reliability of your investigation. It ensures that if anyone repeats the investigation they will obtain similar data.

Accuracy and precision

Precision refers to the extent to which the instrument can make repeated measures of the dependent variable that are the same for the same value of the independent variable. For example, if each measurement of the current in an electrical circuit is within 0.1 A of the others, then the device is more precise than a device for which there is a difference of 0.5 A. **Accuracy** refers to how close a measurement is to the true or accepted value.

You will need to consider if the instruments to be used are sensitive enough. Build some testing into your investigation to confirm the accuracy and reliability of the equipment and your ability to read the information obtained.

Reasonable steps to ensure the accuracy of the investigation include considering:

- the type of instrument that will be used to measure the independent and dependent variables.
- calibrating the measuring equipment by testing a standard.

Describe the materials and method in appropriate detail in your scientific reports. This should ensure that every measurement can be repeated and the same result obtained within reasonable margins of experimental uncertainty. (A margin of less than 5% is reasonable.)

Data analysis

How you will be analysing the data produced from your investigation must be considered when writing your method. A wide range of analysis tools are available. For example, tables can be used to organise data so that patterns can be established, and graphs can show relationships and comparisons. In fact, preparing an empty table showing the data that needs to be obtained will help in the planning of the investigation. See page 13 for more information on organising a data table.

Sourcing appropriate materials and technology

When designing your investigation, you will need to decide on the materials, technology and instrumentation that will be used to carry out your research. It is important to find the right balance between items that are easily accessible and those that will give you accurate results. As you move on to conducting your investigation, it will be important to take note of the quality of your chosen instruments and how this affects the accuracy and validity of your results.

Modifying the methodology

The methodology may need modifying as the investigation is carried out. The following actions will help to determine any issues in the methodology and how to modify it.

- Record everything.
- Be prepared to make changes to the approach.
- Note any difficulties encountered and the ways they were overcome. What were the failures and successes? Every test carried out can contribute to the understanding of the investigation as a whole, no matter how much of a disaster it may first appear.
- Do not panic. Go over the theory again, and talk to the teacher and other students. A different perspective can lead to a solution.

If the expected data is not obtained, don't worry. As long as it can be critically and objectively evaluated, with the limitations of the investigation identified and further investigations proposed, the work is worthwhile.

COMPLYING WITH ETHICAL AND SAFETY GUIDELINES

Ethical considerations

Some investigations require an ethics approval—consult with the teacher. In fact, when deciding on an investigation, identify all possible ethical considerations and evaluate whether those parts of the investigation are necessary or if there are ways you can reduce or mitigate them.

Occupational health and safety

While planning for an investigation, it is important to consider the potential risks to ensure the safety and yourself and others.

Everything we do has some risk involved. Risk assessments are performed to identify, assess and control hazards. A risk assessment should be performed for any situation, in the laboratory or outside in the field. Always identify the risks and control them to keep everyone safe. For example, carry out voltage–current experiments with low voltages (less than 6.0 V DC or 4 × 1.5 V batteries) coupled to resistors so that the currents in the circuits are of the order of milliamps. *At all times* avoid direct exposure to 240 V AC household voltages (Figure 1.1.4).

To identify risks, think about:

- the activity that will be carried out
- the equipment or chemicals that will be used.

The following hierarchy of risk controls is organised from most to least effective:

1. *Elimination:* Eliminate dangerous equipment, procedures or substances.
2. *Substitution:* Find different equipment, procedures or substances to use that will achieve the same result, but have less risk associated with them.
3. *Isolation:* Ensure there is a barrier between the person and the hazard. Examples include physical barriers such as guards in machines, or fume hoods to work with volatile substances.
4. *Engineering controls:* Modify equipment to reduce risks.
5. *Administrative controls:* Provide guidelines, special procedures, warning signs and information about safe behaviours for any participants.
6. *Personal protective equipment (PPE):* Wear safety glasses, lab coats, gloves and respirators etc. where appropriate. Provide these to other participants as needed.

FIGURE 1.1.4 When planning an investigation, you need to identify, assess and control hazards.

Science outdoors

Sometimes investigations and experiments will be carried out outdoors. Working outdoors has its own set of potential risks and it is equally important to consider ways to eliminate or reduce these risks.

Table 1.1.2 contains examples of risks associated with fieldwork outdoors.

TABLE 1.1.2 Risks associated with fieldwork outdoors.

Risks	Control measures
sunburn	wear sunscreen, a hat and sunglasses
hot or cold weather	wear clothing to protect against heat or cold
projectile launch	create barriers so that people know not to enter the area
trip hazards	minimise the use of cables (electrical, computer) and cover them up with matting be aware of tree roots, rocks etc.

First aid measures

Minimising the risk of injury reduces the chance of requiring first aid assistance. However, it is still important to have someone with first aid training present during practical investigations. Always tell the teacher or laboratory technician if an injury or accident happens.

Personal protective equipment

Everyone who works in a laboratory wears items that help keep them safe. This is called **personal protective equipment (PPE)** and includes:

- safety glasses
- shoes with covered tops
- disposable gloves when handling chemicals
- a disposable apron or a lab coat if there is risk of damage to clothing
- ear protection if there is risk to hearing.

1.1 Review

SUMMARY

- An aim is a statement describing in detail what will be investigated. For example: The aim of the experiment is to investigate the relationship between force, mass and acceleration.
- A hypothesis is a definite statement of the relationship between the independent and dependent variables based on previous knowledge and evidence or observations that attempts to answer the research question. For example: With the force kept constant, the acceleration decreases with increasing mass as an inverse relationship.
- Once a question has been chosen, stop to evaluate the question before progressing. The question may need further refinement or even further investigation before it is suitable as a basis for an achievable and worthwhile investigation. Make sure that it is possible to complete the activity in the time available and with the resources on hand. It might be a little difficult to create a particularly complicated device with the facilities available in the school laboratory.
- There are three categories of variables:
  - The independent variable is the variable that is changed by the researcher.
  - The dependent variable is the variable that may change in response to a change in the independent variable. This is the variable that will be measured or observed.
  - Controlled variables are all the variables that must be kept constant during the investigation so that it is a fair test.
- The methodology of your investigation is a step-by-step procedure. When detailing the methodology, ensure it complies as a valid, reliable and accurate investigation.
- It is also important to determine how many times the independent variable needs to be changed and how many trials need to be run for each change in the independent variable.
- Data analysis should be a consideration in the method. Determine how the data will be presented and analysed. A wide range of analysis tools could be used. For example, tables organise data so that patterns can be established and graphs can show relationships and comparisons.
- In every investigation you need to consider the risks and potentially hazardous situations, and act to minimise those risks.

KEY QUESTIONS

1 In a practical investigation a student changes the potential difference across a circuit by adding or subtracting batteries in series in the circuit.
  - **a** How could the potential difference be a discrete value?
  - **b** How could it be continuous?

2 In another experiment the student uses the following range of values to describe the brightness of a light: dazzling, bright, glowing, dim, off. What type of measurement is the variable 'brightness'?

3 Select the best hypothesis from the three options below. Give reasons for your choice.
  - **A** Hypothesis 1: If you increase the mass of the marble that you drop, the final velocity of the marble will increase linearly.
  - **B** Hypothesis 2: The greater the potential difference across a resistor, the greater the current through it.
  - **C** Hypothesis 3: Different metals will have different resistances.

4 Give the correct term that describes an experiment with each of the following conditions.
  - **a** The experiment addresses the hypothesis and aims.
  - **b** The experiment is repeated and consistent results are obtained.
  - **c** Appropriate, high-quality equipment is chosen and calibrated for the desired measurements.

5 A student wanted to find out how the tension in an elastic band affects the band's initial velocity when launched from their finger. State:
  - **a** the independent variable
  - **b** the dependent variable
  - **c** three controlled variables.

1.2 Conducting investigations, and recording and presenting data

Once the planning and design of a practical investigation is complete, the next step is to undertake the investigation and record the results. As with the planning stages, there are key steps and skills to keep in mind to maintain high standards and minimise potential error throughout the investigation (Figure 1.2.1).

This section will focus on the best methods for conducting a practical investigation, systematically generating, recording and processing data, and then presenting it in a concise and clear manner.

FIGURE 1.2.1 When carrying out your investigation try to maintain high standards to minimise potential errors.

CONDUCTING INVESTIGATIONS TO COLLECT AND RECORD DATA

For an investigation to be scientific, it must be objective and systematic. Ensuring familiarity with the methodology and protocols before beginning will help you to achieve this.

While working, keep asking questions: Is the work biased in any way? If changes are made, how will they affect the study? Will the investigation still be valid for the aim and hypothesis?

It is essential that during the investigation the following are recorded:

- all quantitative data collected
- the methods used to collect the data
- any incident, feature or unexpected event that may have affected the quality or validity of the data.

The data recorded is the **raw data**. Usually this data needs to be processed in some manner before it can be presented. If an error occurs in the processing of the data or you decide to present the data in an alternative format, the recorded raw data will always be available for you to refer back to.

IDENTIFYING ERRORS

All practical investigations have errors associated with them. Errors can occur for a variety of reasons. It is important that potential errors are considered when planning an investigation and that measures are taken to reduce them. This ensures the investigation is as accurate as possible. Any additional errors that occur during the collection of results should also be recorded.

There are two types of errors:

- systematic errors
- random errors.

Systematic errors

A **systematic error** is an error that is consistent and will occur again if the investigation is repeated in the same way.

Systematic errors are usually a result of instruments that are not calibrated correctly or methods that are flawed.

An example of a systematic error would be if a ruler mark indicating 5 cm from 0 cm was actually only 4.9 cm from 0 cm due to a manufacturing error or shrinkage of the wood. Another example would be if the researcher repeatedly used a piece of equipment incorrectly throughout the entire investigation. Figure 1.2.2 shows how traffic police reduce systematic errors in their data collection.

FIGURE 1.2.2 To avoid a systematic error, make sure that you are using measuring equipment correctly. Laser speed guns, for example, need to be placed on a stationary support so the aim point is held on a single target point for the duration of the read.

Random errors

Random errors occur in an unpredictable manner and are generally small. Random errors are typically caused by minor, unpredictable changes in experimental conditions that lead to fluctuations around the true value. An example of a random error could be electronic noise in the circuit of an electrical instrument.

Techniques for reducing error

Designing the method carefully, including selection and use of equipment, will help reduce errors.

Appropriate equipment

Use the equipment that is best suited to the type of data being collected to validate the hypothesis. Determining the appropriate units and scale for the data will help to select the correct equipment. Using the right unit and scale will ensure that measurements are more accurate and precise, thereby minimising systematic errors.

Significant figures represent precision and reliability of a measurement. The number of significant figures used depends on the scale of the instrument. It is important to record data to the number of significant figures available from the equipment or observation. Using more or fewer significant figures can be misleading.

Review the following examples to learn more about significant figures:

- 15 has two significant figures
- 3.5 has two significant figures
- 3.50 has three significant figures
- 0.037 has two significant figures
- 1401 has four significant figures.

To calculate gravitational potential energy (E_g), the formula is $E_g = mg\Delta h$.
If $g = 9.80\,\text{m}\,\text{s}^{-2}$, mass (m) = 7.50 kg, height (h) = 0.64 m (64 cm):

$$E_g = 9.80 \times 7.50 \times 0.64 = 47.09\,\text{J}$$

When reporting data, quote the result to the least number of significant figures found in the measured values. In this example, height is accurate to two significant figures while g and mass have three significant figures, so report the result to two significant figures, for example $E_g = 47\,\text{J}$.

Although digital scales can measure to many more than two figures and calculators can give 12 figures, be sensible and follow the significant figure rules.

Calibrated equipment

Some equipment, such as some motion sensors, needs to be calibrated before use to account for the temperature at the time. Before carrying out the investigation, make sure the instruments or measuring devices are properly calibrated and functioning correctly. For example, measure the temperature and apply a correction to the speed of sound to calibrate a motion sensor if necessary.

Correct use of equipment

Use the equipment properly. Ensure training has been completed and that you have practised using the equipment before beginning the investigation. Improper use of equipment can result in inaccurate data with large errors, and the validity of the data can be compromised.

Incorrect reading of measurements is a common misuse of equipment. Make sure all the equipment needed in the investigation can be used correctly and record the instructions in detail so they can be checked if the data doesn't appear correct.

RECORDING AND PRESENTING QUANTITATIVE DATA

Raw data is unlikely to be used directly to validate the hypothesis. However, raw data is essential to the investigation and plans for collecting the raw data should be made carefully. Consider the formulas or graphs that will be used to analyse the data at the end of the investigation. This will help to determine the type of raw data that needs to be collected in order to validate the hypothesis.

For example, to calculate take-off velocity for a vertical jump, three sets of raw data will need to be collected using a force platform: the athlete's standing body weight, the ground reaction force and the time during the vertical jump. The data can then be processed to obtain the take-off impulse.

Once you have determined the data that needs to be collected, prepare a table to record the data.

ANALYSING AND PRESENTING DATA

The raw data that has been obtained needs to be presented in a way that is clear, concise and accurate.

There are several ways to present data, including tables, graphs, flow charts and diagrams. The best way of visualising the data depends on its nature. Try multiple formats before making a final decision to create the best possible presentation.

Presenting raw and processed data in tables

Tables organise data into rows and columns, and can vary in complexity according to the nature of the data. Tables can be used to organise raw and processed data or to summarise results.

Data in the table should be ordered in columns. The first column should contain the independent variable (the one being changed). Subsequent columns should include the dependent variable results from all trials, with one column for each trial. The final column should then show the average of all of the trials for the dependent variable.

Tables should have the following features:

- a descriptive title that contains both the independent and depended variables
- column headings (including the unit and the uncertainty of measurement)
- aligned figures (align the decimal points)
- the independent variable placed in the left column
- the trials of the dependent variable placed in the right columns with the average column on the end
- an overarching heading for all columns showing the dependent variable results (including the average column).

You may sometimes need to process data to assist with producing a linear graph. This processed data can be added as an additional column to the right of the average column. An example of processed data would be if I^2 needed to be plotted on a graph instead of I. Any processed data should have appropriate units and uncertainty in the heading if the units and uncertainty remain the same, or alongside the data if they vary.

Look at the table in Figure 1.2.3, which has been used to organise raw and processed data about the effect of current on voltage.

The current through a resistor at different potential differences ← clear title

	Current I (±0.01 A)				
Potential difference ΔV (±0.01 V)	Trial 1	Trial 2	Trial 3	Average	I^2 (A^2)
1.50	0.31	0.34	0.32	0.32 ± 0.02	0.10 ± 0.01
2.00	0.42	0.45	0.41	0.43 ± 0.02	0.18 ± 0.02
2.50	0.50	0.51	0.52	0.51 ± 0.01	0.26 ± 0.01
3.00	0.62	0.65	0.58	0.62 ± 0.04	0.38 ± 0.05
3.50	0.70	0.71	0.72	0.70 ± 0.01	0.49 ± 0.01

headings for each column with units and uncertainties of measurement

consistent number of significant figures

independent variable

dependent variable trials with consistent number of significant figures

averages calculated with uncertainty of averages displayed

processed data with processed uncertainties, correct significant figures and heading with appropriate units

FIGURE 1.2.3 A simple table listing the raw data obtained in the second, third and fourth columns with the common uncertainty in the overarching column heading, the average of each trial calculated in the fifth column with individual uncertainties, and the processed data, which is the average values squared along with their processed individual uncertainties, in the sixth column.

FIGURE 1.2.4 An analogue pressure scale.

A table of processed data usually presents the average values of trials, the **mean**. However, the mean on its own does not provide an accurate picture of the results. To report processed data more accurately, the uncertainty should be presented as well.

UNCERTAINTY

Measuring from an analogue scale

An analogue scale is a fixed scale from which measurements are taken. Examples of an analogue scale include rulers or pressure gauges, such as the one shown in Figure 1.2.4. When measuring with an analogue scale and the value falls between increments, an estimate should be made to one decimal place beyond the nearest increment. For example, if you measure the length of a block of wood using a ruler marked in centimetres and it aligns precisely with the 10 cm mark, the length is 10.0 cm. However, if the length is approximately halfway between the 10 and 11 cm marks, it should be recorded as 10.5 cm.

Types of uncertainties

When presenting a range of measurements for a particular value, it is essential to include both the mean and the associated **uncertainty** to accurately convey the results. In other words, the mean must be accompanied by an indication of the range of data obtained, reflecting variability in the measurements.

uncertainty = ± (half the range of the values)

For example, if the velocity, in km h^{-1}, of cars travelling down a certain road was:

46.0, 50.0, 55.0, 48.0, 50.0, 58.0 and 45.0

the average velocity would be:

$$\frac{46.0 + 50.0 + 55.0 + 48.0 + 50.0 + 58.0 + 45.0}{7} = 50.2857 = 50.3\,\text{km}\,\text{h}^{-1}$$

The uncertainty would therefore be half the maximum velocity minus the minimum velocity. In this case, 58.0 is the maximum velocity and 45.0 is the minimum velocity, meaning that the range is 13.0 and half the range is 6.50, so the uncertainty is ± 6.50 km h^{-1}.

This data should be presented as:

Average speed is 50.3 ± 6.50 km h^{-1}.

This is called the **uncertainty of averages** as it is taken from the calculation of the mean. Make sure that the final value is expressed to the appropriate number of significant figures, and remember that the uncertainty should never exceed the number of decimal places of the measured value itself.

There is also uncertainty associated with using measuring devices. This is called the **uncertainty of measurement**. This type of uncertainty arises from the precision of the measuring device's scale. The uncertainty of measurement varies depending on the type of measuring device you are using.

- Some devices will have a given uncertainty; for instance, a measuring cylinder might have an uncertainty of ± 0.1 mL printed on it.
- If the uncertainty is not provided, it will depend on whether the measuring device is digital or analogue.
  - If you are measuring on a digital scale, the uncertainty is the smallest possible increment. For instance, a set of scales that gives a result of 100.01 g will have an uncertainty of measurement of ± 0.01 g.
  - If the measuring device is analogue (i.e. those with a fixed scale), the uncertainty of measurement is typically half of the smallest scale division. For instance, if you use a ruler with a millimetre scale and measure the length of an object as 25.0 mm, the uncertainty would be ± 0.5 mm. It is important to note that the uncertainty should have the same number of decimal places as the measurement, but not necessarily the same number of significant figures.

When stating a final value with its uncertainty, you may have two choices to make:

1. If the uncertainty of the measuring device is different from the uncertainty of the averages, you should use the larger of the two values for the average uncertainty. This ensures your reported data reflects the limitations of the instrument, not potentially overstating the precision of the average.
2. You should consider the nature of the investigation, the measuring devices used and the method of data collection in relation to the calculated uncertainty of the average. If it was difficult to take the measurements or you experienced issues with the measuring devices, then you may choose to use a reasonable percentage uncertainty to replace the uncertainty of the averages. For example, if the percentage uncertainty of the averages is around ± 1.5%, but you believe this does not adequately represent the precision of your data collection, you might opt for a higher percentage uncertainty, such as ± 5.0%. If you make this adjustment, make sure you include a note under your data table explaining your rationale.

Calculating percentage uncertainties

Uncertainties that are displayed in the same units as the measurement are known as **absolute uncertainties**. You can use these absolute uncertainties to calculate a percentage uncertainty using the equation below.

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

Percentage uncertainties are helpful because they allow for the comparison and combination of uncertainties across different units.

Combining uncertainties

It is common to process data in a physics investigation. This may include altering a single set of data, like the column titled 'I^2' in Figure 1.2.3; or perhaps you may use two data sets to calculate a new value, for instance, combining a measured current and potential difference to calculate the power. As these are values calculated using measurements with their own uncertainties, it is crucial to combine the uncertainties to get an overall uncertainty for the calculated value.

The method for combining uncertainties depends on the type of mathematical operation used in the calculation: whether measurements are raised to a power, multiplied or divided, or added or subtracted.

Measurements raised to a power

If a measurement is raised to a power, such as squared or cubed, the percentage uncertainty associated with the measurement will be multiplied by that power. This is shown in step three of Worked example 1.2.1.

Multiplying or dividing measurements

When multiplying or dividing measurements, the total uncertainty is found by adding together the percentage uncertainties for each value. Since the measurements may not have the same units, it is important to use the percentage uncertainties rather than absolute uncertainties, which cannot be added directly. This is outlined in Worked example 1.2.1.

Worked example 1.2.1

COMBINING UNCERTAINTIES WHEN MULTIPLIED OR DIVIDED

A researcher wants to determine the density of a sample of an unknown substance that is in the shape of a cube. The following measurements are taken.

- Length of each side of the cube: $\ell = 25.5 \pm 0.5$ mm
- Mass of the cube: $m = 32.2 \pm 0.1$ g

Calculate the density with the appropriate absolute uncertainty.

Thinking	Working
Convert all absolute uncertainties to percentage uncertainties.	$\%\text{uncertainty} = \frac{\text{uncertainty}}{\text{measurement}} \times 100$ $\%\text{uncertainty}_{length} = \frac{(0.5)}{(25.5)} \times 100$ $\%\text{uncertainty}_{length} = \pm 1.96078\%$ $\%\text{uncertainty}_{mass} = \frac{(0.1)}{(32.2)} \times 100$ $\%\text{uncertainty}_{mass} = \pm 0.31056\%$
Calculate the density of the cube with the data converted to the SI units of kg and m^3.	$\rho = \frac{m}{V}$ $\rho = \frac{m}{\ell^3}$ $\rho = \frac{(32.2 \times 10^{-3})}{(25.5 \times 10^{-3})^3}$ $\rho = 1.26275$ $\rho = 1.26\,\text{kg}\,\text{m}^{-3}$
As the volume is found by cubing the length value, the percentage uncertainty for the volume is three times that of the length.	$\%\ \text{uncertainty}_{volume} = 3 \times (\pm 1.96078)$ $\%\ \text{uncertainty}_{volume} = \pm 5.88235\%$
Calculate the total percentage uncertainty. As the density is found by dividing the mass by the volume, you must add the percentage uncertainties of the mass and volume.	$\text{total}\ \%\ \text{uncertainty} = (0.31056) + (5.88235)$ $\text{total}\ \%\ \text{uncertainty} = \pm 6.19291\%$
Convert the total percentage uncertainty to the absolute uncertainty of the answer.	absolute uncertainty = $\pm(1.26275) \times \frac{(6.19291)}{100}$ absolute uncertainty $= \pm 0.078201\,\text{kg}\,\text{m}^{-3}$
State the answer to the correct number of significant figures with the absolute uncertainty to the correct decimal place and the correct units.	Therefore, the density is $1.26 \pm 0.08\ \text{kg}\,\text{m}^{-3}$.

Worked example: Try yourself 1.2.1

COMBINING UNCERTAINTIES WHEN MULTIPLIED OR DIVIDED

A student wanted to investigate the electrical power drawn by a kettle. The kettle had a measured resistance of $50.0 \pm 0.1\ \Omega$ and was drawing a measured current of 4.21 ± 0.01 A.

Using the formula:

$P = I^2R$

where

P = power (W)

I = current (A)

R = resistance (Ω)

calculate the power drawn by the kettle and include the uncertainty with the value.

Adding or subtracting measurements

When adding or subtracting measurements, make sure that all measurements are in the same units. To find the total uncertainty of an addition or a subtraction, add together the absolute uncertainties of the individual measurements.

Evaluating investigations using uncertainties

Uncertainties provide a useful way of evaluating the accuracy and precision of your investigation's results. They indicate the potential variability or how scattered your values are in the measurement; a low total uncertainty suggests higher precision. Additionally, you can use the uncertainty to calculate possible minimum and maximum values, which could be useful for comparing your experimental results to a known values. If the known value falls within the range of uncertainty of the experimental results, this can be an indication of accuracy.

Other descriptive statistics measures

The mean and the uncertainty are statistical measures that help describe data accurately. Other statistical measures that can be used, depending on the data obtained, are:

- **mode:** the mode is the value that appears most often in a data set. This measure is especially useful to describe qualitative or discrete data. For example, the mode of the values 0.01, 0.01, 0.02, 0.02, 0.02, 0.03, 0.04 is 0.02.
- **median:** the median is the 'middle' value of an ordered list of values. For example, the median of the values 5, 5, 8, 8, 9, 10, 20 is 8. The median is particularly useful when the data range is wide or includes outliers (unusual results), which can make the mean less reliable.

Graphs

In general, tables provide more detailed data than graphs, but it is easier to observe trends and patterns in data in graphical form than in tabular form.

Graphs are used when two variables are being considered and one variable is dependent on the other. The graph shows the relationship between the variables.

Several types of graphs can be used, including line graphs, bar graphs and pie charts. The best one to use will depend on the nature of the data.

General rules to follow when making a graph (Figure 1.2.5) include the following:

- Keep the graph simple and uncluttered.
- Use a descriptive title that contains the independent and dependent variables.
- Represent the independent variable on the x-axis and the dependent variable on the y-axis.
- Make axes proportionate to the data.
- Clearly label axes with both the variable and the unit in which it is measured.

- Include error bars showing the uncertainty of each point. The error bar should extend above and below the plotted point by the uncertainty in the dependent variable and to the left and right of the plotted point by the uncertainty of the independent variable.
- If the y-axis intercept is important in your investigation, then the x-axis must not be broken (e.g. interrupted or truncated).
- Do not force the line of best fit through the origin of the graph (0, 0). If the line of best fit does not pass through the origin, it may indicate the presence of systematic errors in your investigation.

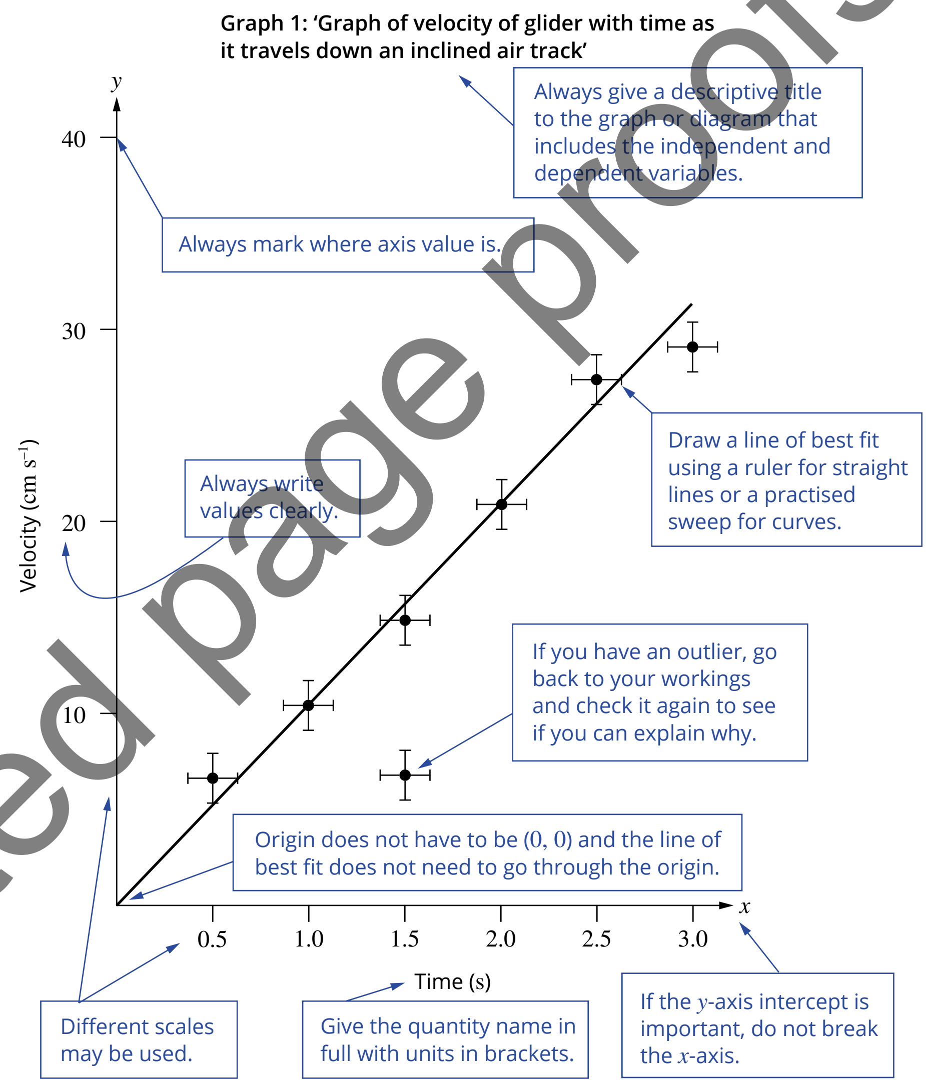

FIGURE 1.2.5 A graph shows the relationship between two variables.

Line graphs

Line graphs are a good way of representing continuous quantitative data. In a line graph, the values are plotted as a series of points with error bars on the graph. There are two ways of joining these points:

- A line can be ruled from each point to the next (Figure 1.2.6a). It shows the overall trend; it is not meant to predict the value of the points between the plotted data. These graphs are rarely used in physics.

- The points can be joined with a single smooth straight or curved line (Figure 1.2.6b). This creates a trend line, also known as a line of best fit or a curve of best fit. The line of best fit does not have to pass through every point but should go through as many error bars as possible. It is used when there is an obvious trend between the variables. These graphs are most commonly used in physics.

Outliers

Sometimes when the data is collected, there may be one point that does not fit with the trend and is clearly an error. This is called an **outlier**. An outlier is often caused by a mistake made in measuring or recording data, or from a random error in the measuring equipment. If there is an outlier, include it on the graph, but ignore it when adding a line of best fit (as in Figure 1.2.5, where the point (1.50, 6) is an outlier).

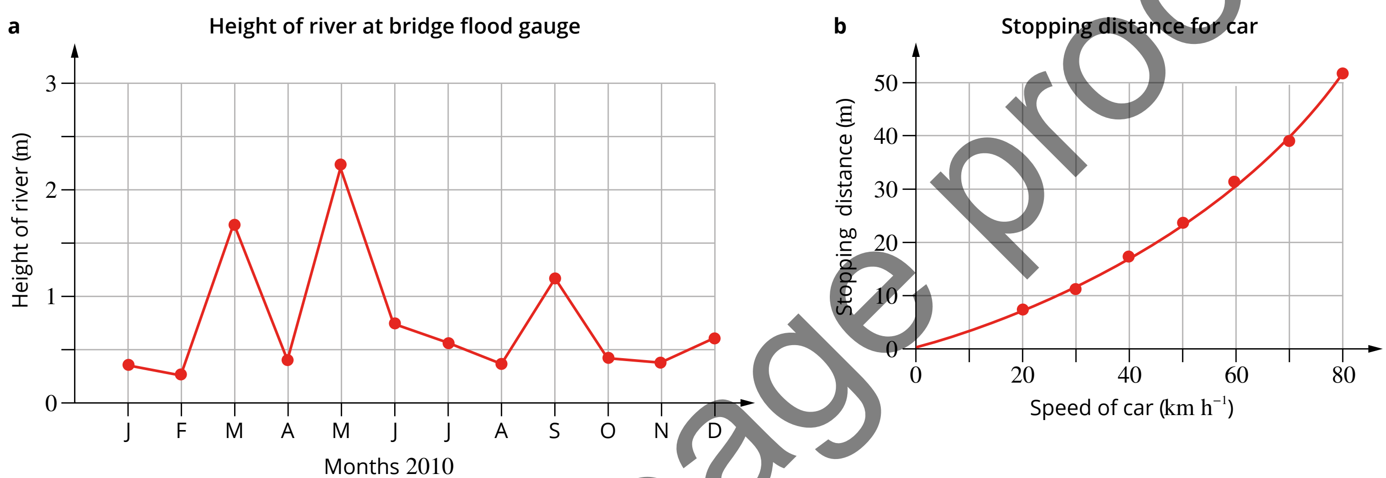

FIGURE 1.2.6 (a) The data in the graph is joined from point to point. (b) The data in graph is joined with a line of best fit, which shows the general trend.

1.2 Review

SUMMARY

- It is essential that during the investigation, the following are recorded:
  - all quantitative data collected
  - the methods used to collect the data
  - any incident, feature or unexpected event that may have affected the quality or validity of the data.
- A systematic error is an error that is consistent and will occur again if the investigation is repeated in the same way. Systematic errors are usually a result of instruments that are not calibrated correctly or methods that are flawed.
- Random errors occur in an unpredictable manner and are generally small. A random error could be, for example, the small fluctuations in the ambient temperature affecting a heat transfer investigation.
- The number of significant figures used depends on the scale of the instrument used. It is important to record data to the number of significant figures available from the equipment or observation.
- The simplest form of a table is a five-column format in which the first column contains the independent variable (the one being changed), the second to fourth columns contain the trials of the dependent variable (the one that may change in response to a change in the independent variable) and the final column contains the average of the trials.
- When there is a range of measurements of a particular value, the average must be accompanied by the uncertainty of averages. These uncertainties can be represented as absolute values or as a percentage of the measurement (percentage uncertainty).

1.2 Review *continued*

- When processing data, you must combine uncertainties:
  - If a measurement is raised to a power, the percentage uncertainty must be multiplied by the power value, i.e. if a measurement is squared, the percentage uncertainty is multiplied by two.
  - If measurements are multiplied or divided, the percentage uncertainties must be added together.
  - If measurements are added or subtracted, the absolute uncertainties must be added together.
- General rules to follow when making a graph include the following:
  - Keep the graph simple and uncluttered.
  - Use a descriptive title that contains the independent and dependent variables.
  - Represent the independent variable on the *x*-axis and the dependent variable on the *y*-axis.
  - Make axes proportionate to the data.
  - Clearly label axes with both the variable and the unit in which it is measured.
  - Include error bars showing the uncertainty of each point. The error bar should extend above and below the plotted point by the uncertainty in the dependent variable and to the left and right of the plotted point by the uncertainty of the independent variable.
  - If the *y*-axis intercept is important in your investigation, the *x*-axis must not be broken.
  - Do not force the line of best fit through the origin of the graph (0, 0). If the line of best fit does not pass through the origin, it can indicate that there may be systematic errors in your investigation.

KEY QUESTIONS

1 The masses of 1.00 cm^3 cubes of potato were recorded and the cubes placed in distilled water. After 60 minutes, the cubes were weighed again and the difference in mass was calculated. What type of error is involved:

a if the electronic scales were not tared properly?

b if the electronic scales were affected briefly by a power surge?

2 If using the quantities mass = 7.505 kg and speed = 1.40 $m\,s^{-1}$ in a calculation, what would be the appropriate number of significant figures in the answer?

3 For the data set 21.0, 28.0, 19.0, 19.0, 25.0, 24.0, determine:

a the mean

b the mode

c the median

d the uncertainty of averages.

4 Plot the following data set with error bars, assigning each variable to the appropriate axis on the graph.

Potential difference ± 5.00% (V)	Current ± 0.01 (A)
2.07	0.06
1.56	0.05
1.24	0.04
0.93	0.03
0.63	0.02

5 How can the general pattern (trend) of the data set in Question 4 be represented once the points are plotted?

6 Compare the error bars for the current in Question 4 to the error bars for the potential difference.

1.3 Discussing investigations and drawing evidence-based conclusions

Now that the chosen topic has been thoroughly researched and the investigation has been conducted and data collected, it is time to draw it all together. The final part of the investigation involves summarising the findings in an objective, clear and concise manner.

FIGURE 1.3.1 To discuss and conclude your investigation, use the raw and processed data.

EXPLAINING RESULTS IN THE DISCUSSION

The discussion is the part of the investigation where the evaluation and explanation of the investigation methods and results takes place. It is the interpretation of what the results mean.

The key sections of the discussion are:

- analysing and evaluating data
- evaluating the investigative method
- explaining the link between investigation findings and relevant physics concepts.

When writing the discussion, consider the message you want to convey to the audience. Statements should be clear and concise. By the time the discussion concludes, the audience must have a clear idea of the context, results and implications of the investigation.

ANALYSING AND EVALUATING DATA

In the discussion, the findings of the investigation need to be analysed and interpreted.

- State whether a pattern, trend or relationship was observed between the independent and dependent variables. Describe what kind of pattern it was and specify the conditions under which it was observed.
- Were there discrepancies, deviations or anomalies in the data? If so, these should be acknowledged and explained.
- Identify any limitations in the data you have collected. Consider whether a larger sample size or further variations in the independent variable would lead to a stronger conclusion.

Trends in line graphs

Graphs are drawn to show the relationship, or trend, between two variables, as shown in Figure 1.3.2.

- Variables that change in linear or direct proportion to each other produce a straight sloping trend line.
- Variables that change exponentially in proportion to each other produce a curved trend line.
- With an inverse relationship, one variable increases as the other variable decreases.
- When there is no relationship between two variables, one variable will not change even if the other changes.

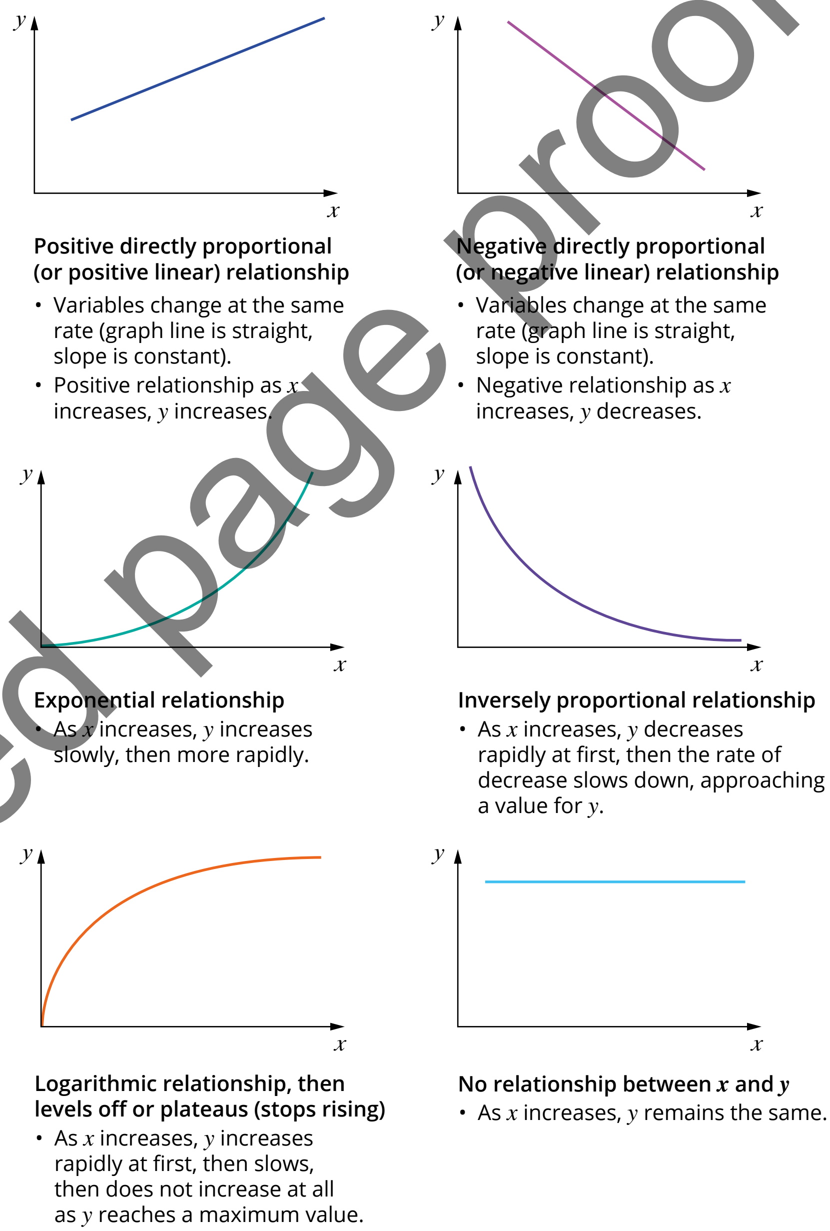

FIGURE 1.3.2 Various relationships can exist between two variables.

Remember that the results may be unexpected. This does not make the investigation a failure. However, the findings must be related to the hypothesis, aims and method.

EVALUATING THE METHOD

It is important to discuss the limitations of the investigation method. Evaluate the method and identify any issues that could have affected the validity, accuracy, precision or reliability of the data. Sources of errors and uncertainty must also be evaluated in the discussion.

Once any limitations or problems in the methodology have been identified, recommend improvements on how the investigation could be conducted if repeated; for example, suggest how bias could be minimised or eliminated.

Bias

Bias may occur in any part of the investigation method, including sampling and measurements.

Bias is a form of systematic error resulting from the researcher's personal preferences or motivations. There are many types of bias, including:

- poor definitions of both concepts and variables (e.g. classifying cricket pitch surfaces as slow or fast without defining 'slow' and 'fast')
- incorrect assumptions (e.g. assuming that footwear type, model and manufacturer do not affect ground reaction forces, and as a result failing to control this variable during an investigation on slip risk on different indoor and outdoor surfaces)
- errors in the investigation design and methodology (e.g. taking a sample of a particular group of athletes that includes one gender more than the other in the group).

Some biases cannot be eliminated, but should still be addressed in the discussion.

Accuracy and precision

In the discussion, evaluate the degree of accuracy and precision of the measurements for each variable of the hypothesis. Address the uncertainties associated with these measurements and discuss their impact on the results.

When applicable compare the chosen method to alternative methods that could have been used, evaluating the advantages and disadvantages of the selected method and the effect on the results.

If your investigation involves comparing your results to a known accepted value, you should calculate a percentage difference. The percentage difference can be calculated by using the following formula:

$$\text{percentage difference} = \frac{\text{accepted value} - \text{experimental value}}{\text{accepted value}} \times 100$$

A smaller percentage difference indicates a more accurate result. For example, a percentage difference of less than 5% suggests that the difference between the accepted value and your experimental value is not significant.

Reliability

When discussing the results, indicate the range of the data obtained from replicates. Explain how the sample size was selected. Larger samples are usually more reliable, but time and resources might have been scarce. Discuss whether the results of the investigation have been limited by the sample size.

The control group is important to the reliability of the investigation. A control group helps identify whether an uncontrolled variable has been overlooked and may explain any unexpected results.

Error

Discuss any source of systematic or random error and suggest ways of improving the investigation.

FIGURE 1.3.3 Honest evaluation and reflection play important roles in analysing methodology.

DISCUSSING RELEVANT PHYSICS CONCEPTS

To make the investigation more meaningful, it should be explained within the right context; i.e. using related physics ideas, concepts, theories and models. Within this context, explain the basis for the hypothesis.

For example, if studying the impact of temperature on linear strain of a material (e.g. a rubber band), some of the contextual information to include in the discussion could be:

- the definition of linear strain
- the functions of linear strain
- the relationship between linear strain and temperature
- definitions of material behaviour (such as plastic and elastic)
- factors known to affect linear strain
- existing knowledge on the role of temperature on linear strain
- ranges of temperatures investigated and the reason they were chosen
- materials studied and the reasons for this choice
- methods of measuring the linear strain of a material.

Relating your findings to a physics concept

Once a context is established, you can use this as a framework to discuss whether the data supported or refuted the hypothesis. Ask questions such as:

- Was the hypothesis supported?
- Has the hypothesis been fully addressed? (If not, give an explanation of why this is so and suggest what could be done to either improve or complement the investigation.)
- Do the results contradict the hypothesis? If so, why? (The explanation must be plausible and must be based on the results and previous evidence.)

Providing a theoretical context also enables comparison of the results with existing relevant research and knowledge. After identifying the major findings of the investigation, ask questions such as:

- How does the data fit with the literature?
- Does the data contradict the literature?
- Do the findings fill a gap in the literature?
- Do the findings lead to further questions?
- Can the findings be extended to another situation?

Be sure to discuss the broader implications of the findings. Implications are the bigger picture. Outlining them for the audience is an important part of the investigation. Ask questions such as:

- Do the findings contribute to or impact the existing literature and knowledge of the topic?
- Are there any practical applications for the findings?

DRAWING EVIDENCE-BASED CONCLUSIONS

A conclusion is usually a paragraph that links the collected evidence to the hypothesis and provides a justified response to the research question.

Indicate whether the hypothesis was supported or refuted, citing the evidence that led to this conclusion. Do not provide irrelevant information. Only refer to the specifics of the hypothesis and the research question, and do not make generalisations.

Read the examples given for the following hypothesis and research question.

Hypothesis: An increase in temperature will cause an increase in linear deformation (change in length) before failure.

- Poor response to the hypothesis: Linear deformation has value y_1 at temperature 1 and value y_2 at temperature 2.
- Better response to the hypothesis: An increase in temperature from 1 to 2 produces an increase in linear deformation of z in the rubber band.

Research question: Does temperature affect the maximum linear deformation the material can withstand?

- Poor response to the research question: The results show that temperature does affect the maximum deformation of a material.
- Better response to the research question: Analysis of the results indicates that increasing the temperature from 1 to 2 in the rubber band correlates with an increase in the maximum linear deformation, which is consistent with existing knowledge on how temperature influences material deformation.

REFERENCES AND ACKNOWLEDGEMENTS

All the quotations, documents, publications and ideas used in the investigation need to be acknowledged in the 'references and acknowledgements' section to avoid plagiarism and to ensure authors are credited for their work. References and acknowledgements also give credibility to the study and allow the audience to locate information sources should they wish to study the topic further.

When referencing a book, include, in this order:

- author's surname and initials
- date of publication
- title
- publisher's name
- place of publication.

For example: Moran G. et al. (2025), *Pearson Physics 12*, Pearson Education, Melbourne, Victoria.

When referencing a website, include, in this order:

- author's surname and initials, or name of organisation, or title
- year website was written or last revised
- title of webpage
- date website was accessed
- website address.

For example: Wheeling Jesuit University/Center for Educational Technologies (2013), *NASA Physics Online Course: Forces and Motion*, accessed 16 June 2015, from http://nasaphysics.cet.edu/forces-and-motion.html.

1.3 Review

SUMMARY

- The discussion is the part of the investigation where the evaluation and explanation of the investigation methods and results takes place. It is the interpretation of what the results mean.
- In the discussion, the findings of the investigation need to be analysed and interpreted.
  - State whether a pattern, trend or relationship was observed between the independent and dependent variables. Describe what kind of pattern it was and specify under what conditions it was observed.
  - Were there discrepancies, deviations or anomalies in the data? If so, these should be acknowledged and explained.
  - Identify any limitations in the data collected. Perhaps a larger sample or further variations in the independent variable would lead to a stronger conclusion.
- It is important to discuss the limitations of the investigation method. Evaluate the method and identify any issues that could have affected the validity, accuracy, precision or reliability of the data. Sources of errors and uncertainty must also be stated in the discussion, and suggestions could be given as to how to reduce these errors.

1.3 Review *continued*

- When discussing the results, indicate the range of the data obtained from replicates. Explain how the sample size was selected. Larger samples are usually more reliable, but time and resources are likely to have been scarce. Discuss whether the results of the investigation have been limited by the sample size.
- To make the investigation more meaningful, it should be explained within the right context, including the related physics ideas, concepts, theories and models. Within this context, explain the basis for the hypothesis.
- Indicate whether the hypothesis was supported or refuted and the evidence that led to this conclusion. Do not provide irrelevant information or make generalisations.

KEY QUESTIONS

1 What relationship between the variables is indicated by a sloping linear graph?

2 What relationship exists if one variable decreases as the other increases?

3 What relationship exists if both variables increase or both decrease at the same rate?

4 What might cause a sample size to be limited in an investigation?

5 Consider this investigation hypothesis: An increase in the potential difference across a single resistor in an electric circuit will cause an increase in the current through the resistor.
Improve this hypothesis given the data below:
When the current was 0.03 A, the voltage was 0.93 V and when the current was 0.04 A, the voltage was 1.86 V.

Chapter review

01

KEY TERMS

absolute uncertainty
accuracy
controlled variable
dependent variable
independent variable
mean
median
mode
outlier
personal protective equipment (PPE)
precision
qualitative variable
quantitative variable
random error
raw data
reliability
significant figures
systematic error
uncertainty
uncertainty of averages
uncertainty of measurement
validity
variable

1 What is a hypothesis and what form does it take?

2 Consider the hypothesis provided below. What are the dependent, independent and controlled variables?
Hypothesis: Releasing an arrow in archery at an angle greater or smaller than 45° will result in a shorter flight displacement (range).

3 What is the dependent variable in each of the following hypotheses?

- **a** If you push an object with a fixed mass (e.g. shot-put) with a larger force, then the acceleration of that object will be greater.
- **b** As the vertical displacement of a falling object increases, the vertical acceleration of the falling object is constant.
- **c** A springboard diver rotates faster when in a tucked position than when in a stretched (layout) position.

4 List the following types of hazard controls from the most effective to the least effective.
substitution, personal protective equipment, engineering controls, administrative controls, elimination, isolation

5 The speed of a toy car rolling down an inclined plane was measured six times. The measurements obtained (in $cm\,s^{-1}$) were 7.0, 6.5, 6.8, 7.2, 6.5, 6.5.
What is the uncertainty of the average of these values?

6 Which of the statistical measurements of mean, mode and median is most affected by an outlier?

7 What relationship between variables is indicated by a curved trend line?

8 If you hypothesise that impact force is positive directly proportional to drop height, what would you expect a graph of the data to look like?

9 What is meant by the 'limitations' of the investigation method?

10 What is 'bias' in an investigation?