CHAPTER

13 Practical investigations

KEY IDEAS

After completing this chapter, you should be able to:

- recognise and generate independent, dependent and controlled variables
- apply physics concepts to the topic of the investigation
- demonstrate the methods of scientific research and techniques of data collection with reference to their precision and reliability and the significance of uncertainty in the data
- conduct an investigation safely
- fully analyse the data, identifying patterns and relationships and acknowledging the limitations due uncertainty in the data
- identify evidence that supports or refutes their expected findings or physics explanations
- describe the key findings of the investigation and their relationship to concepts studied
- use the conventions of scientific report writing and scientific poster presentation, including physics terminology and representations, symbols, equations and formulae, units of measurement, significant figures, standard abbreviations and the acknowledgment of references, if used.

As part of Unit 4, you will conduct a practical investigation on one area of one of these topics: electric and magnetic fields, gravitational fields, forces and energy of motion, electromagnetism, and the properties of waves and light.

What is the benefit to you?

As part of Unit 4, you will conduct a practical investigation on any aspect of the content in this book. This includes electric and magnetic fields, gravitational fields, forces and energy of motion, electromagnetism, and the properties of waves and light.

The practical investigation lets you follow your own interests. Enjoy creating solutions to questions that are important to you, managing your work and telling others about what you have done. Your study of Physics should help you to be more scientific.

Reflect on what it means to be 'scientific', and the characteristics of scientific ways of doing things compared to non-scientific ways. You will improve your ability to solve problems, use resources and communicate ideas. These attributes are useful in everyday life and highly valued in the workplace.

Being scientific means making use of observations, experiments and logical thinking to test ideas.

What is involved?

Many of the experiments you have done as part of this course were designed with clear instructions and specific questions to answer. They are often designed to experimentally confirm a known relationship such as $F = m\frac{4\pi^2 r}{T^2}$ or $F = nBIl$. In this investigation, there is more responsibility on you to plan and carry out the task. It gives you the opportunity to show your skill and imagination in experimental design, commitment to a task and your communication ability in explaining your results.

The topic can be one of your choosing and you can work individually or with another student. It is a rare topic that requires three pairs of hands and eyes.

The investigation will require a significant amount of class time. Your teacher will set aside two to three weeks for the activity, so some planning and organisation on your part will be needed to achieve a personally satisfying outcome. The table below will assist with your planning.

Your teacher has some flexibility as to when to schedule this activity. It could be towards the end of Term 3, when you have been exposed to all the Areas of Study from which you can select a topic, or it could be earlier in the year as part of or after Unit 3, which is rich in possible topics.

How does this investigation differ from the Unit 2 investigation?

Much of the process of undertaking the Unit 4 investigation is unchanged from the Unit 2 investigation, but the Unit 4 investigation is more substantial. It requires more class time, consideration of more aspects, and a deeper level of analysis. The assessment is also more significant.

For Unit 4 you will again investigate the effect of varying two independent variables, but this time both variables must be continuous. This increases the amount of data collection, and the opportunities for data analysis and identification of mathematical relationships between your dependent variables and both independent variables.

The investigation will also contribute to your study score for this subject. Your teacher's assessment of your investigation will make up 7% of your score. Each of the three Areas of Study in Unit 3 contributes 7%, while the other two Areas of Study in Unit 4 each contribute 6%, giving a total of 40% for your teacher's assessment of your work for the year. The end-of-year exam makes up the remaining 60%.

You will also present a summary of your investigation as a poster, preferably as an electronic poster, that is, one PowerPoint slide, as that will be an easier format to work with than an A1 sheet of paper.

It is also expected that the end-of-year exam will include questions on the student-designed practical investigation. Given that students across the state and in your class will be investigating a diverse range of topics, any questions would need to be of a generic nature, that is, they could be answered by any student regardless of the topic they investigated. Examples of such questions include:

- A student's procedure is described with some faults. You are asked to identify the faults and suggest alternatives.
- Data has been graphed and analysed, but with some errors in both the graphing and analysis. You are asked to correct the graph and recalculate some parameters from the graph.

The end of the chapter has some sample questions with more on JacPlus.

TABLE 13.1 Investigation planning with sample schedule

Task	Due date
Your teacher spends some class time introducing the task, explaining what is expected of you, suggesting some possible topics or brainstorming other topics with the class. They will also outline the timeline and distribute a form for you to write down one or more topics that you would like to investigate.	About two weeks before formal experimentation begins
You return your list of possible topics for approval by your teacher, who then provides feedback, recommendations and finally approval.	A few days later
Submission of your detailed research proposal Your teacher may decide to make this a formal task, done under test conditions in class and assessed, but with feedback provided afterwards on aspects that might need to be addressed before you begin.	At the beginning of the week before your experiment begins
Your requested equipment is assembled by the teacher and lab technician.	By the end of the week before your experiment begins
Your investigation begins. First period: Set up your equipment, take some preliminary data, finetune your procedure, and troubleshoot any difficulties with the equipment and the taking of measurements Second period: Begin the cycle of measurements and data analysis. Progressively graph your results, evaluate trends and adjust your procedure.	Week 1
Continue the cycle of measurements and data analysis, leading to a review of progress and further more detailed measurements. Move on to investigating the second continuous independent variable.	Week 2
Finalise the investigation of the second variable. Begin preparing your overview of the investigation: summarising your procedure, what you have found out, what difficulties you had and how you addressed them.	Week 3
Finalise writing the sections of your report and paste them into a poster template. Submit your log book and poster.	Beginning of week 4

Selecting a topic

Coming up with a topic is not something that happens straight away. You need to take some time to consider it. You want to investigate a topic that interests you, that provides opportunity for some challenge, yet can be done in the time available and with the resources available within the school.

The topic of your investigation can come from any of the content you are studying this year, so as you and your teacher are going through the course, you should be recording for future reference any possible topics that come to mind.

When your teacher formally introduces the task, you may wish to get together with some of your classmates and brainstorm a batch of topics. This can be an effective way to identify possible topics.

- Form a group of three to five and appoint a leader.
- Draw a grid on a large sheet of paper with headings across the top such as: Hobbies and interests, Sports, Science in the news, Investigations you did in previous years, and Course topics. Down the side have types of investigations such as: Investigating the operation of a device or technology, Solving a technological problem, Investigating a physical phenomenon.
- Pick a box from the grid and brainstorm some topics for that box, then move onto another one.
- If other groups have done the same task, combine your entries with theirs.

Hints for brainstorming:

- Concentrate on quantity, not quality. Get down as many ideas as you can, as fast as you can. Resist the temptation to evaluate as you go — do that later.
- Be prepared to be outlandish. Humour is creative. Ideas that are preposterous might trigger ideas that are not.

Practical investigations have been a popular feature of physics courses in many countries for several decades, so there are thousands of possible topics if you search around. Some are listed below, and a document that contains weblinks and many more additional topics can be found in your eBookPLUS. You should check through these lists and see what sparks your interest because choosing a topic that intrigues you will ensure a high level of commitment and a sense of pride in the finished work. Avoid seemingly sophisticated topics; everyday topics are not only readily accessible and initially straightforward to investigate, but they often have hidden subtleties.

Turning the topic into a good question

Turning the topic into a question focuses your mind on what you want to find out. The question needs to be:

- one that experimenting can answer
- one worth investigating to you
- practicable, given your knowledge, time and the school resources
- asked in a way that indicates what you will do.

Submitting a research proposal

Once your teacher has approved your topic, the real work begins. On the next page is a typical proposal sheet that you could be asked to complete.

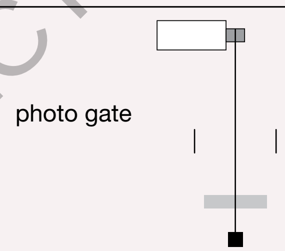
Keep a log

Use a separate, bound exercise book. Use it for thinking, calculating, drawing, leaving messages and preparing your report. You can use it to record your data if you don't want to use a computer. You can use the logbook to show your teacher how your work is progressing. Your logbook will also be assessed by your teacher.

Your logbook can include:

- your initial ideas
- notes from brainstorming
- notes from background reading
- equipment set up and plan
- your observations, measurements, data analysis and graphs
- difficulties you experience.

Practical investigation proposal

Name:	Jill
Partner's name: *(optional)*	Jac
Title of your investigation:	The efficiency of a DC motor
Briefly describe its purpose: *(A brief sentence, but needs to be precise)*	To investigate how efficiently a DC motor converts electrical energy into gravitational potential energy by raising a mass
Write down three starting questions you want to answer. *(These are to help focus your planning.)*	What is the most efficient voltage for a given mass? How does this voltage vary with the mass? For a given voltage is there a mass the motor cannot lift? Is the mass raised at a constant speed?
List independent variables, indicating which are continuous and which are discrete, as well as dependent variables. *(Enables your teacher to see if you have thought of all the obvious variables.)*	Independent: voltage supplied to the DC motor, the mass being raised, the diameter of the spindle about which the string from the mass is wrapped, the type of DC motor (discrete) Dependent: The current drawn by the DC motor, energy supplied to the DC motor, the time for the mass to travel a measured distance, gain in gravitational potential energy
List the Physics concepts and relationships that you expect to use in your investigation. *(To give your teacher an indication of the extent of your understanding of the topic)*	Electric energy consumption, $W = VIt$ Gain in gravitational potential energy, $\text{GPE} = mg\Delta h$ Efficiency $= \frac{mg\Delta h}{VIt}$
List the equipment and measuring instruments that you plan to use. *(For your teacher to see whether you have the right tools for the task.)*	DC motor with spindle on the shaft Masses — either slotted masses and/or plasticine Light, thin string, possibly with a small card of known length attached near the bottom to trigger a photo gate Variable power supply, voltmeter and ammeter, switch Ruler and balance Timer, preferably electronic, e.g. a photo gate
Sketch your experimental set up. *(This will make your first day of investigating smoother, and your teacher may be able to suggest refinements.)*	
List the steps in your experimental design. *(This is an important stage in your planning and it will enable your teacher to see if there is anything you have forgotten.)*	1. Connect the circuit and attach a mass to the string. Set to a low voltage and turn on the power supply. Adjust arrangement of equipment and voltage and mass values to get a safe set-up that is capable of producing data without damaging the motor. 2. Adjust timer, card and photo gate set-up to produce consistent readings. 3. Set the mass at a known value, set the voltage at a low value, and measure the current and time at least five times. 4. Increase the voltage settings in increments of 1 V and repeat the measurements. Use a voltage divider circuit if in-between voltage values would be useful. 5. Increase the mass progressively and repeat steps 3 and 4 each time. 6. Check for possible intermediate mass values to identify maximum efficiency.
Any special requests *(E.g. equipment may need to be left set up between classes, or access at lunchtime or after school may be needed.)*	Not really.

If you are using a computer or a school server as your log book, you should ensure that the software enables your entries to be reliably date stamped. This authenticates the work as your own.

Variables

Variables are the physical quantities that you measure. For some variables you will set the value at the start of each experiment; others will be determined by your experiment; and sometimes there may be variables that you calculate using your measurements.

- *Independent variables* are the ones whose value you determine.
  You would not investigate all of these; you should choose just two that interest you. However, your report should mention them all to show your deep understanding of the problem you are investigating. The ones you don't investigate will have constant values during your experiment, so they could be called *fixed* or *controlled variables*.
  There are two types of independent variables:
  - *Continuous variables* are ones that can take any numerical value, such as the release height of a parachute. This means they can be graphed using *x*- and *y*-axes. A graph can reveal a mathematical relationship between two quantities.
  - *Discrete variables* are ones that allow for different types, for example different-shaped parachutes. These can only be presented as a column graph, which enables comparison but does not reveal a mathematical relationship.
- *Dependent variables* are the ones that come from your experiment. Their values are determined by the independent variables.
  Again, you would not analyse all of them. Just one will normally suffice.

Revision question 13.1

In this investigation, two independent continuous variables are needed.

Jill and Jac plan to investigate the sweet spot of a cricket bat. The variables they are considering are: (i) the position on the bat where the ball hits, (ii) the speed of the ball at impact, (iii) the mass of the bat, (iv) the profile of the bat (e.g. a length of timber as a model for the bat versus a real bat), (v) the mass distribution of the bat (e.g. whether the bat is hollowed out or not), (vi) whether the handle is fixed but the bat is able to swing or whether the handle is free to move. Classify these independent variables into the two categories: continuous and discrete.

Revision question 13.2

List as many dependent variables as you can think of that Jac and Jill might consider for their investigation, including ones that can be calculated from others.

The end of this chapter has some more questions on identifying variables.

Selecting your measuring instruments

Your school will have a range of measuring instruments. They will vary in precision and ease of use.

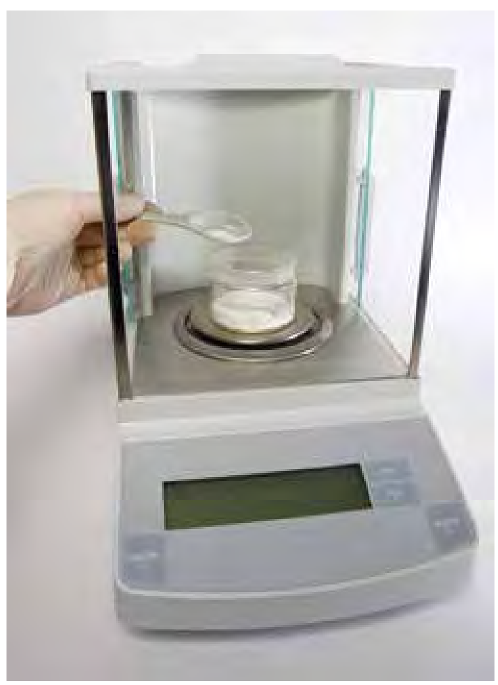
You won't always need to use the most accurate instrument. A simple instrument that allows for quick measurements will be enough more often than not. Sometimes a simple stopwatch is just as good as an electronic timer, and a beam balance may compare well to a very accurate top loading balance.

Some instruments that you might consider are listed below based on what they measure.

Mass

- Slotted masses of known mass. Simple to use; accurate; comes only in multiples of a set weight, e.g. 50 g.
- Beam balance. Accurate with a large range of values; can be time consuming to measure several masses.

- Spring balance. Quick to use; covers a large range of masses; not very accurate.
- Top loading balance. Very accurate; very good for small masses; simple to use. With equipment set up above the balance, it can be used to measure small variations in attractive and repulsive forces such as magnetic force, electric force and surface tension. If the balance sits on a laboratory jack, force against distance can be easily measured.



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Length

- Metre ruler. Accurate; good for a range of distances; can be read to about 0.5 mm.
- Laboratory jack. For fine adjustment of height.
- Vernier calliper. For precision measurement of short distances; takes some time to learn how to use.
- Micrometer. For precision measurement of thicknesses; takes some time to learn how to use and can be easily damaged.

Time

- Stopwatch. Simple to use; accurate down to your response time; not reliable for short time intervals.
- Electronic timer. Requires some instruction; very accurate; best suited for short time intervals; can be used with electrical contacts and photogates.

Motion

- Ticker timer. Simple to use; limited in accuracy; best with objects moving over a short distance; can be time consuming to analyse.
- Air track. Very accurate, particularly if used with photogates; very effective in studying collisions; takes some time to set up, but data collection is very efficient once done.

- Ultrasound motion detector. Quite accurate; useful with real motions; lots of data which means data analysis in Excel can be time consuming.
- Video with analysis software. Quite accurate; requires some setting up; data obtained from software; data analysis in Excel can be time consuming. Free video motion analysis software are Tracker and PhysMo. Digital cameras with high-speed video are useful for measurement of short, fast events.

Electrical

- Meters: Voltmeters, ammeters, galvanometers. Easy to set up, but care is needed to ensure the meter is wired into the circuit correctly, otherwise the meter can be damaged; large range of values; usually analogue displays.
- Multimeters. Easy to set up; more tolerant of incorrect use, but can be damaged if incorrectly connected to a high current; large range of values; usually digital displays.

Specialist equipment

- Cathode-ray oscilloscope (CRO). Even though the CRO is basically a visual voltmeter, it is a versatile instrument. It can measure both constant and varying voltages. The sweep of the trace across the screen can be used to measure time intervals of the order of millionths of a second. Many transducers, such as microphones, produce a voltage that can be displayed on the screen, either for analysis or measurement of very short time intervals. There are also computer versions of CROs that can be freely downloaded.
- Data loggers. There are sensors now available for most physical quantities, such as temperature, pressure, light intensity, motion, force, voltage, current, magnetic field, ionising radiation. The recording of data by these sensors for later analysis greatly facilitates practical investigations.
- Apps. There are increasing numbers of apps that perform measurement functions. The accuracy of each needs to be confirmed before being used in a formal investigation, but it is an area worth exploring. Some sources include Physics Toolbox and Sensor Kinetics.

Making the most of a measurement

Limits to precision and uncertainty

Every instrument has a limit to how precisely it measures. The scale or digital display imposes a constraint on how many digits you can record. The scale or display also reveals the tolerance of the measurement.

A metre ruler has lines to mark each millimetre, but there is space between these lines. You could measure a length to the nearest millimetre, but because of the space between the lines, if you look carefully, you can measure to a higher precision. You can measure to the nearest 0.5 mm.

The best estimate for the length of the red line in the figure at left is 2.35 cm. The actual length is closer to 2.35 cm than it is to either 2.30 cm or 2.40 cm. The measurement of 2.35 cm says the actual length is somewhere between 2.325 cm and 2.375 cm.

The way to write this is:

The length of the red line = 2.35 ± 0.025 cm

The 0.025 represents the tolerance or uncertainty in the measurement.

In this case, with well-spaced millimetre lines, the tolerance is $\frac{1}{4}$ of the smallest division. For a dense scale where measurement lines are close together, the tolerance would be $\frac{1}{2}$ of the smallest division.

The reading on a digital scale is 8.94 grams. This means the mass is not 8.93 g nor 8.95 g. The actual mass is somewhere between 8.935 and 8.945 grams. The way to write this is:

The mass = 8.94 ± 0.005 g.

Sample problem 13.1

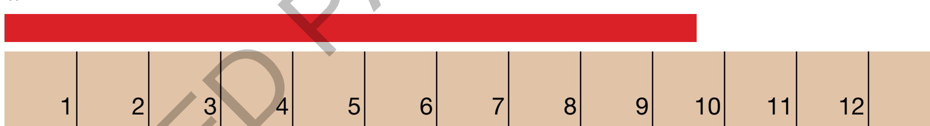
Record the reading on the scales below, including the tolerance.

Solution: The scale shows 0.250 g, so the actual weight may be between 0.2495 g and 0.2505 g. The mass is written as 0.250 ± 0.0005 g.

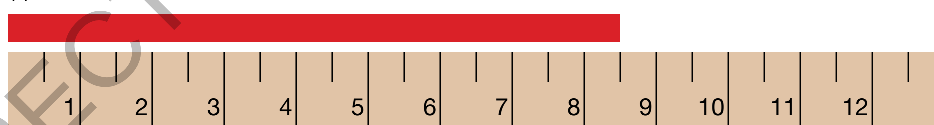
Revision question 13.3

(a) **Determine the length of each line in the diagram below, showing the tolerance in each case.**

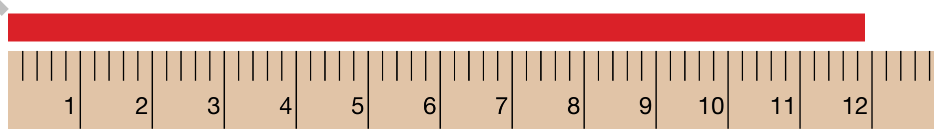
(i)

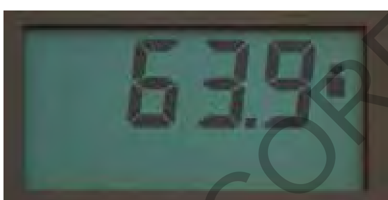


(ii)



(iii)





(b) **Record the reading on the scales at left, including the tolerance.**

Repeated measurements

Measurements of independent variables are usually precise and careful, so one measurement should be enough. However, measurements of the dependent variables are often prone to some variation.

Whether the variation is caused by the human reaction time when using a stopwatch, judging the rebound height of a basketball or in the case of the parachute, the unpredictable way the canopy will open each time, each reading may be different. So it is sensible to take several readings to obtain an average. You would expect that at least three measurements would be needed, and possibly five, but more than five is generally unnecessary.

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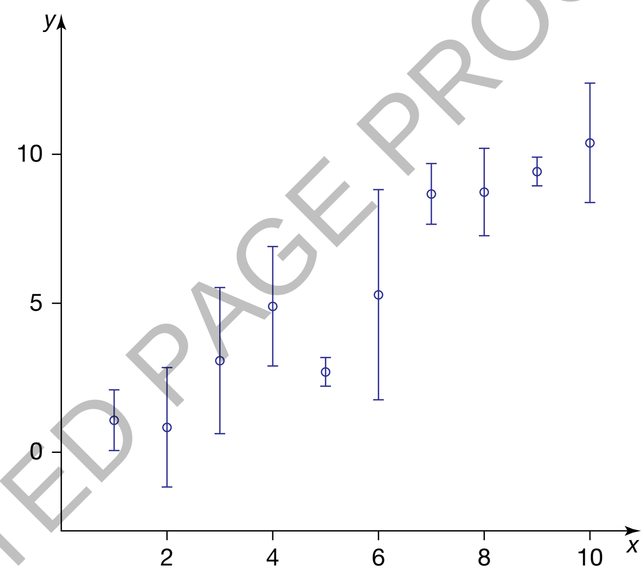
In some instances the variation between different readings will exceed the precision of the instrument. To determine which value you plot, you would use the average as well as the spread of the readings. For example, if your partner dropped the basketball from a height of 80.0 cm, and you judged the rebound height of the ball for five trials as: 68 cm, 69.5 cm, 68.5 cm, 68.5 cm and 69.5 cm. The average is 68.8 cm, which you would round to the nearest 0.5 cm because of the difficulty of judging a moving ball, giving an average of 69 cm. The full range of your measurements is from 68 cm to 69.5 cm, so your uncertainty would need to be 1 cm to cover the full range. This set of measurements would then be written as 69 ± 1 cm.

This format is useful in two ways: graphing and calculating.

When you graph your results, the number you will plot is 69 cm. To represent the '±1 cm', you can draw a line through the point, up 1 cm and down 1 cm, with a short line across the top and bottom of the line to make the ends evident.



Example of error bars

Rather than graphing rebound height against drop height, it is more revealing of the physics of the situation to calculate and graph the ratio of the rebound height to drop height against drop height. The ratio is a measure of how much of the original gravitational potential energy is restored.

In this case the ratio would be $\frac{69}{80.0} = 0.8625$, but how many digits are we entitled to use and how big should the error bar be? The first question is reasonably straightforward. The number of digits in your answer should equal the smallest number of digits in the data you used in the calculation. In this instance the average height has two digits, so the answer would be written as 0.86. You are not justified in including more digits because you don't know the original data accurately enough.

Working out the size of an error bar takes more effort. If the two pieces of data are 69 ± 1 cm and 80.0 ± 0.3 cm, we can just add the uncertainties to get ±1.3 cm, but that doesn't make sense when the calculated value is 0.86. Dividing the uncertainties would produce another unusual result.

The method used is to first express the uncertainty for each data value as a percentage. For example:

$$\text{Percentage error of } 69 \pm 1\text{ cm} = \left(\frac{1}{69}\right) \times 100 = 1.4\%$$

$$\text{Percentage error of } 80.0 \pm 0.3\text{ cm} = \left(\frac{0.3}{80}\right) \times 100 = 0.4\%$$

Now add the two percentage errors together:

Total percentage error = 1.4% + 0.4% = 1.8%

Next use this total percentage error to find the error in the calculated answer.

Error = 0.86 × 1.8% = 0.016, which would be rounded to one digit as 0.02.

The full calculated answer would now be 0.86 ± 0.02.

The percentage errors are added together regardless of whether the data values are divided, multiplied, added or subtracted. For example:

- Calculating speed using $v = \frac{\Delta x}{\Delta t}$, the percentage errors of displacement and time would be added together.
- Calculating momentum using $p = mv$, the percentage errors of mass and velocity would be added together.
- Calculating the change in momentum using $\Delta p = p_{\text{final}} - p_{\text{initial}}$, the actual uncertainties of each are added together.

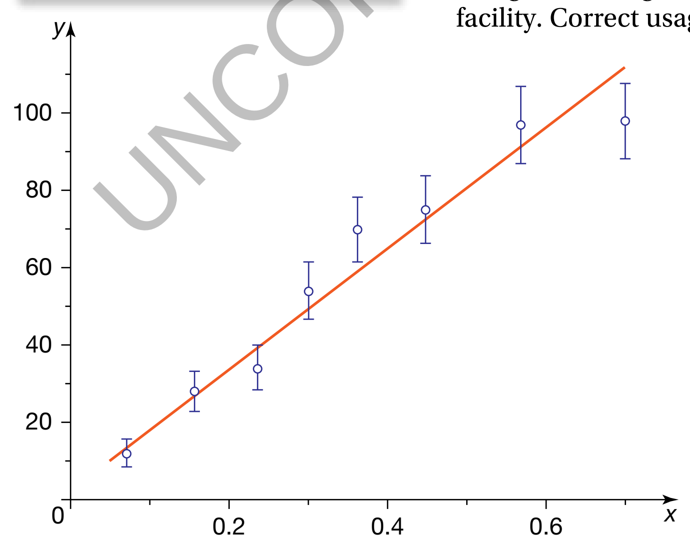
Finding patterns

Graphs are an effective way of summarising your data and looking for a physical relationship between the quantities you are investigating.

To present your data clearly, your graph should have the following features:

- Each axis labelled with the physical quantity it represents. It is convention to put the independent variable on the x-axis and the dependent variable on the y-axis. You want to find out how 'y' depends on 'x'. So, you might graph terminal velocity on the y-axis and mass on the x-axis.
- A scale with the units displayed.
- Include the origin, the zero value for the variables, on both axes. Sometimes the origin is a data point, even though you did not technically measure it. For example, if the drop height is zero, the rebound height would also be zero, and so the origin is a data point, but the energy lost cannot be determined and is not a data point. The inclusion of the origin on the axes makes any relationship more apparent. Truncating the values on either the y- or x-axis exaggerates the variation in the data, and may disguise any relationship between the variables.
- An error bar for each data point. Sometimes, given your scale, the error bars will be too small to be seen and so would not be worth including. If you are using Excel to generate your graphs, be careful when using the error bar facility. Correct usage is described below.

Graph showing a line of best fit



Drawing a line of best fit

A line of best fit summarises your graph. The line can be used to find the gradient of your graph and also a y-intercept.

The line of best fit doesn't need to pass through each data point, although you should try to draw the line through each error bar if possible, but you may not be able to go through all of them. As a general rule, try to have as many data points above your line as you have below. Don't assume your line must pass through the origin.

Of course, not all graphs can be summarised by a straight line. A gentle curve may be more appropriate, which can be analysed further.

Using Microsoft Excel

The Excel spreadsheet is a very useful tool to the experimenter. It can:

- store your measurements. Make sure you save your data every few minutes and do a backup every day.
- calculate any derived physical quantities, such as speed and acceleration of a parachute or the percentage of energy lost by a bouncing ball. The 'Fill down' command is a time saver.
- be a powerful graphing tool, but it must be used wisely. Because you are looking for a relationship between the variables, you must choose 'X Y (Scatter)' as your type of graph. This has the key scientific features of a proper scale and the presence of the origin. It is also preferable to choose a graph of unconnected data points as your sub-type. You don't want a line, straight or curved, going from data point to data point; some of your data points may be a touch out. A better choice is a 'line of best fit,' which Excel can do for you.
- generate a line of best fit. If you right-click on any data point, a window pops up with the option 'Add Trendline.' This is the Excel command to create a line of best fit. Once selected, you have several choices. If your graph looks like a straight line, choose 'Linear.' If the graph looks like a curve passing through the origin, choose 'Power.' Students often think any curve is exponential, but unless the phenomenon involves growth or decay, it is very unlikely that a graph from a physics experiment would generate an exponential graph.
- create error bars. Excel can add in errors bars, but this is best avoided in most instances. It is likely that the size of your error bars will vary from data point to data point. Excel can't handle that. It assigns a fixed-size error bar to each data point. Error bars can be added by clicking on any part of the chart and going to the 'Layout' tab.

Note: These instructions may vary depending on the version of Excel you are using.

Note: In the 'Add Trendline' window, you can select to display the equation of the line of best fit on your graph. Care needs to be shown with numbers in the equation. The numbers of digits may not be justified by your data.

Other aspects of scientific measurement

For your investigation, the aspects of scientific measurement that are most important are the ones discussed earlier: precision and uncertainty.

Precision means recording a measurement to the greatest detail possible for that measuring instrument. The word 'precision' is being used in the same sense as a 'precision tool.'

Uncertainty is acknowledging that no matter how precise an instrument might be there is a limit to that precision. The uncertainty is a range within which a measurement lies. An error bar is a way of representing that uncertainty graphically.

Aspects of scientific measurement that are not likely to be relevant to your investigation are qualities such as accuracy, validity and reliability.

Accuracy: If an archer is accurate, their arrows hit close to the target. If you are conducting an experiment to measure the acceleration due to gravity, which has a known value, your accuracy as an experimenter can be determined. However, in your investigation, you are keen to understanding the physics of the situation by identifying relationships between the variable, rather than determining the value of a quantity that you can just as well look up in a textbook.

Validity applies more to Biology and Psychology, where precise measurement is more difficult and there is the risk of bias on the part of the researcher.

In Physics and Chemistry, the variables are quantifiable and physically measurable. If your experimental method clearly relates to the purpose of the investigation and you take care to be precise in your measurements and thorough in your analysis, your results should be valid and meaningful.

Reliability refers to whether another researcher could repeat your investigation by following your method and obtain similar results. Obviously this cannot be determined by you or your teacher. However, the clarity and detail with which your experimental method is described will give the reader confidence that your investigation is reproducible, which is the key to scientific success.

Handling difficulties

There will be times when:

- your results show no pattern
- your results aren't what you expected
- the equipment doesn't work
- you don't know what to do next
- you don't understand the references you have been reading.

How you handle such problems is important.

- Go back to basics. Check your logic, understanding and planning. Clarify the issue. Draw diagrams and concept maps if they help. Look for options. Go to a textbook.
- Talk to other students or members of your family. Sometimes just talking through a situation can help you see a solution.
- Seek help from your teacher.

Record in your logbook how you tackled the problem, what solution you found and where you got it from. This is good science and good management.

Safety

Part of the enjoyment of a practical investigation is that the topic may be unconventional or use an innovative method. Such situations, however, can present some risk, so special care needs to be taken to ensure yourself and others are safe.

Some simple rules to follow are:

- Do the investigation as outlined in your approved plan. Don't vary your plan without approval from your teacher.
- Don't do experimental work unsupervised unless you have prior approval from your teacher.
- Investigations can take up more space than usual experiments, so be sensitive to the needs of other students in the classroom.
- When first setting up electrical experiments, ask your teacher to check the circuit.
- Don't interfere with the equipment set-up of others.

Presenting your work for assessment

It is likely that there will be three components that contribute to the assessment of your investigation:

1. your initial research proposal
2. your logbook
3. your poster.

Your initial research proposal will have already been submitted and assessed. The poster will be only a summary of your investigation, the overall structure and the highlights; it is unlikely to be able to fit all your graphs, data analysis and consideration of uncertainties. Your logbook will be an essential complement to the poster for your teacher to get a full idea of what you have accomplished. It is therefore important that supplementary material is included and is easy to find.

The poster should have an obvious and logical structure. There is no one prescriptive format, but it should include the elements listed in table 13.2.

TABLE 13.2 Aspects of a written report

Section	Description
Title	A precise and complete description of what you investigated
Physics concepts and relationships	A short paragraph explaining the relevant concepts and relationships and how they apply to this investigation
Aim or purpose	Why are you doing this investigation? What do you hope to find?
Procedure	This is a major section. It describes what you measured, your selection of equipment and measuring instruments, and your step-by-step method. Include diagrams and photos. Refer to how you controlled variables; achieved the desired accuracy; and overcame, avoided or anticipated difficulties.
Observations and measurements	Include your data and graphs. If there is too much data, then refer to your logbook for the full set. Show how calculations were done using actual data. Also include illustrations of how uncertainties were calculated.
Analysis of results	How does your data support your initial intentions? How much is your analysis limited by uncertainties? Identify strengths and weaknesses in the investigation, indicating how you would do it differently if you repeated it, and what your next steps in the investigation would be if you had more time.
Conclusion	A short summary related to the initial purpose, summarising the meaning of your results

Presenting your work as a digital poster

The logbook would be read in depth by your teacher, who will often spend more than 20 minutes going through it in detail. A poster has a different intent and a different audience. The structure of your investigation should be apparent and give the viewer a good sense of the investigation within several minutes' perusal.

A poster should address the sections outlined in table 13.2 without going into too much detail. For example, you would display only a subset of the data to convey your findings and accuracy. Similarly, not all your graphs need appear.

PowerPoint templates can assist with designing posters and make it much easier than putting together a hard copy on a large sheet of card. Check out the weblinks in your eBookPLUS for templates as well as examples of science posters.

Advice on assembling a poster

Layout

- Set up a clearly visible structure for your poster.
- Include a photo, diagram or graphs in each section, if possible.
- Have a short title.

- Start with an engaging statement about the topic you investigated.
- Give a quick overview of your approach, with images of experimental set-up and equipment used. A flow chart is an effective way of conveying your procedure.
- Present results in graphical form with commentary; this will be the largest section of the poster.
- Discuss your results with perceptive comments.
- Decide on font size and line spacing to achieve the best impact for your poster.

Language

- Restrict the text to 800–1000 words.
- Adopt a more personal tone in the writing; use the active voice.
- Avoid large blocks of text and long sentences.
- Don't plagiarise; if you must quote, then acknowledge your sources.
- Use sentence case; that is, no all upper case sentences and avoid italicised sentences.
- Use serif fonts, such as Times New Roman and Palatino.
- Use italics for emphasis, rather than underlining or bold.
- Check spelling and grammar as well as whether the correct word has been chosen, e.g. affect or effect, it's or its etc.

Graphs

- Avoid grid lines on graphs, they complicate the picture.
- Ensure scales are readable.
- Use informative titles to support the communication message of the poster.

Topics

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Digital doc
Investigation topics
doc-16176

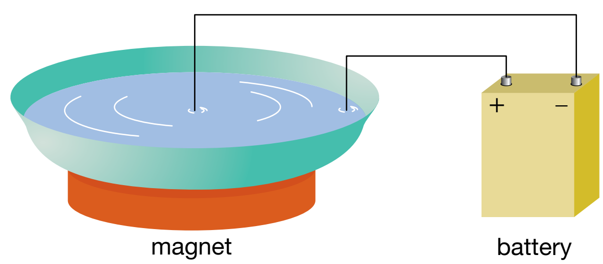
Here are some sample topics to get you thinking.

- The sweet spot of a tennis racket
- Bat (or club) and ball impacts
- The changeover from sliding to rolling
- Flight of a shuttlecock
- Surface tension of a liquid
- Performance of a parachute
- Effect of spikes on running shoes
- The performance of a CD hovercraft
- The performance of a water-driven rocket
- The impact force on and the energy lost by bouncing ball
- Flight of a table tennis ball
- The energy delivered by a catapult
- Dry sand is soft, wet sand is hard, wetter sand is soft again: investigate
- Factors affecting the design of a good paddle wheel
- The physics of a bicep curl
- The thrust of a propeller (in air or in water)
- The drag on spheres in an airstream
- The motion of spheres in a viscous medium
- The effect of changing the size or shape of the wings of a glider
- The flight of a magnus glider
- Physics of the long jump
- Effect of the blocks on a sprint start
- Modelling the impact of the head with the dashboard in a car crash
- Doing the 'ollie' on a skateboard
- Electric force between charged plates
- Magnetic force between two magnets

- Strength of an electromagnet
- Interaction between two glider-mounted magnets
- Efficiency of a DC motor
- The performance of a homopolar motor
- Efficiency of a DC motor used as a generator
- Efficiency of a bicycle dynamo
- The performance of a homopolar generator
- Refractive index of a sugar solution
- Patterns in stressed materials between crossed polaroids
- Polarisation and optically active substances
- Does the resolution of the eye depend on the illumination?
- The resolution of a microscope
- Measuring the thickness of a soap film by interference

Topics with catchy titles

Rolling can: A stoppered can is partially filled with water and is rolled down an incline. Investigate the motion.
Rocking bottle: Fill a bottle with some liquid. Lay it down on a horizontal surface and give it a push. The bottle may first move forward and then oscillate before it comes to rest. Investigate the bottle's motion.
Water ski: What is the minimum speed needed to pull an object attached to a rope over a water surface so that it does not sink? Investigate the relevant parameters.
Bouncing ball: If you drop a table tennis ball, it bounces. The nature of the collision changes if the ball contains liquid. Investigate how the nature of the collision depends on the amount of liquid inside the ball and other relevant parameters.
Popping body: A body is submerged in water. After release, it will pop out of the water. How does the height of the pop above the water surface depend on the various parameters?
Ionic motor: An electrolyte (an aqueous solution of a salt such as $CuSO_4$ or NaCl) in a shallow tray is made to rotate in the field of a permanent magnet. An electric field is applied from a battery in such a way that one electrode is in the form of a conducting ring immersed in the electrolyte. The other electrode is the tip of a wire placed vertically in the centre of the ring. Study the phenomenon and find possible relationships between the variables.



An ionic motor

Magnetic brakes: When a strong magnet falls down through a non-ferrous tube, it experiences a retarding force. Investigate the phenomenon.
Transformers: The 'simple transformer law' relates output voltage to input voltage and turns ratio. Investigate the importance of frequency and other parameters in determining the non-ideal behaviour of transformers.
Magnetohydrodynamics: A shallow vessel contains a liquid. When an electric field and a magnetic field are applied, the liquid can start moving. Investigate this phenomenon.

Vikings: According to a legend, Vikings were able to navigate in an ocean even during overcast weather using tourmaline crystals. Investigate whether it is possible to navigate using a polarising material. What is the accuracy of the method?

Photoelectric effect: When light shines on some metals, electrons are ejected with a range of energies. How does the distribution of electron energies vary with the intensity of the light and the frequency?

Brainstorming variables

Here are two topics with some variables identified. Complete the table for three others.

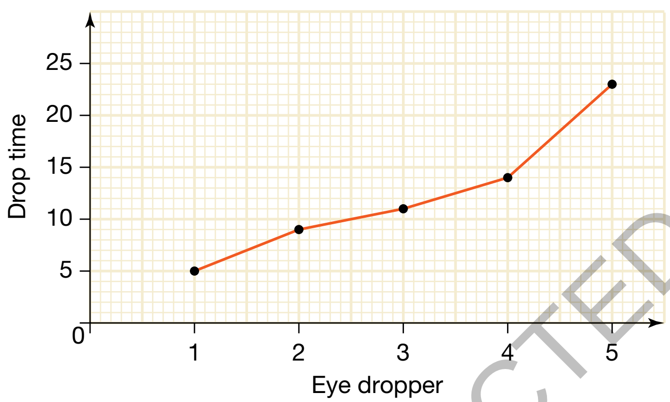
Topic	Independent variables		Dependent variables
	Continuous	Discrete	
Bouncing basketball	(i) Drop height (ii) Pressure of the ball	Surface ball lands on, ball type	Rebound height, impact time, energy loss, change in momentum, average force of impact
Efficiency of a DC motor	(i) Voltage drop across motor (ii) Mass being raised (iii) Diameter of spindle	Type of DC motor	Current through motor, time to travel fixed distance, power supplied, rate of gain of GPE, efficiency
(a) Performance of a parachute			
(b) Electric force between charged plates			
(c) The optical activity of sugar solutions			

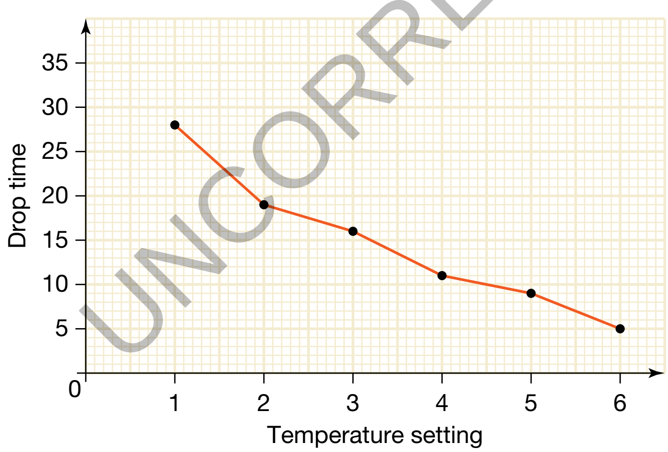
Chapter review

Questions

1. Terry observes that when a droplet of water falls on a hot plate, it fizzes and shoots around the plate for some time. The droplet slowly gets smaller and finally disappears to nothing. Terry decides to investigate how long the droplet lasts, and how that might be affected by the temperature of the hot plate and the size of the droplet.

The equipment used was a hot plate, several droppers and a stop watch. The time was measured three times for each eye dropper and for six different temperature settings. The middle reading of the three readings was plotted. The graphs are shown below.





(a) In one sentence, describe the purpose of the investigation.
(b) List the variables in Terry's investigation. For each variable, indicate whether it is an independent or dependent variable, and for each independent variable, indicate whether it is a continuous variable or a discrete variable. Give a reason for each answer.
(c) Suggest further data analysis. Include reasons.
(d) Write a conclusion for this investigation.
(e) A number of limitations may be identified in this investigation. Discuss these limitations and suggest some suitable improvements. Your discussion could address the following: selection of variables, experimental design, scientific method, data analysis, interpretation of results.
(f) Suggest another independent variable.
(g) Suggest a method for estimating the size of a water droplet.

2. Jackie decided to investigate an experiment found in the Amateur Scientist section of a very old edition of *Scientific American*.

A large watch glass was placed on the cone of an upright loudspeaker. A small amount of water was added to the watch glass to a depth of a few mm. A signal generator was connected to the speaker, turned on and set at a high frequency. The water began to vibrate like a standing wave pattern. An eye dropper was then used to drop a water droplet onto the water surface. The droplet did not disappear into the water; instead, it moved around on the surface for some time before being absorbed.

Write an experimental design for Jackie.