1 The Scientific Endeavour

Everyone has a natural curiosity about the world around us. Why is the sky blue? Where does electricity come from? Science attempts to answer these questions through the study of natural phenomena. Science is not just a body of facts to be memorised but is a way of thinking and doing. These ways of thinking and doing include asking scientific questions, designing investigations and proposing solutions to problems. We can then apply these solutions to help improve our daily lives. Technology such as global positioning system (GPS), smart watches and diagnostic imaging such as X-ray imaging are only a few examples of modern technology that has improved our daily lives.

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1.1 What is Science

1. Science is a **human** endeavour.
2. Scientific knowledge is built and contributed by different civilisations over the centuries.
3. Some important events that led to our understanding of atmospheric air:

	A few important events
450 B.C.	• Ancient Greeks identified air as one of the four elemental components of creation. • The other three elements are earth, fire and water.
1754	• Joseph Black identified a component of air that could be returned, or fixed, into the sort of solids from which it was produced. • He called this "fixed air". Today, we call it carbon dioxide.
1776	• Henry Cavendish produced a highly flammable gas that produces water when burnt. • Antoine Lavoisier would name this gas hydrogen, from the Greek words for "water maker".
1772	• Daniel Rutherford burnt a material in a bell jar, then absorbed all the "fixed air" (carbon dioxide) by soaking it up with a substance called potash. He found that a gas remained. • This gas suffocated mice placed in it. • Rutherford called it "noxious air". Today, we call it nitrogen.
1774	• Joseph Priestley produced a gas that was "five or six times as good as common air." • He discovered that the gas can cause a flame to burn intensely and kept a mouse alive about four times as long as a similar quantity of air. • Priestley called it "dephlogisticated air". Today, we call it oxygen.

1.2 Ways of Thinking and Doing in Science

1. Science is a way of thinking and doing and is an evidence-based, model-building endeavour to understand the world.
2. Scientists generate hypotheses, theories, or laws after they analyse and interpret their data. These help explain their results and contribute to the larger body of scientific knowledge.
3. These different kinds of explanations are tested by other scientists. Thus, the body of scientific knowledge builds on previous ideas and is constantly growing.
4. Scientific discoveries are deliberately shared with colleagues through the process of peer review, where scientists comment on each other's work. Their work is then published as scientific literature where it can be evaluated and integrated into the body of scientific knowledge by the larger scientific community.
5. As new data are collected, existing data may be reinterpreted. This may cause scientific knowledge to change, considering new evidences.
6. This scientific process is a way of building knowledge by asking questions that can be answered through analysis of the data that is collected or creating a model. These ideas are then tested.
7. This scientific process includes:
   - Investigation
   - Evaluation and reasoning
   - Developing explanations and solutions

1.3 Investigation

1. Scientific inquiry may begin with one question or a set of questions that scientists seek to answer.
2. From their questions, they will propose a hypothesis, a possible explanation to the questions they have.
3. Scientists then plan investigations that will help them answer these questions.

4. Scientists will consider carefully what is the changed variable in their experiments and how to keep other variables constant. In most experiments, there is only one changed variable.
5. This changed variable is also known as the **independent variable**.
6. Science is evidence-based. Scientists need to decide what data can and should be collected.
7. To collect data as evidence, observations and measurements need to be made.
8. This data that is measured is also known as the **dependent variable**.

1.4 Collecting Data

1. We can also collect data based on observations made using our five senses (e.g. colour change, texture and smell). This type of data is known as **qualitative data**.
2. Data can also be collected using instruments to make measurements. Instruments are extensions of one's senses.
3. Data collected using instruments usually gives us numerical values (e.g. 3 m, 5 kg). This type of data is known as **quantitative data**.
4. The following table shows some common instruments we use, the types of measurements they make and their SI units (International System of Units).

Measuring instrument	Function	SI Unit
Measuring cylinder	To measure volume of a liquid or an irregular solid	m^3
Electronic balance	To measure mass of a substance	kg
Ruler	To measure length of a substance	m
Liquid-in-glass laboratory thermometer	To measure temperature in the range of –20 °C to 110 °C	K

5. Both quantitative and qualitative data provide evidence in scientific research.

1.5 Reliable and Valid Data

1. When making a measurement, the reading should be as accurate and precise as possible.
2. An accurate measurement is one that is close to the true value.
3. A precise measurement refers to how close the agreement is between repeated measurements (which are repeated under the same conditions).
4. The dartboard analogy helps us to understand accuracy and precision in measurements. The bullseye in the dartboard represents the true value of the measurement. Each dot on the dartboard represents one measurement taken.
5. The closer the dots are to the bullseye, the more accurate the measurements.
6. The more clustered the dots are, the higher the precision of the measurements.

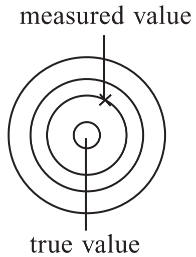


Fig 1.1 The closer the measurement is to the true value, the more accurate the measurement is.

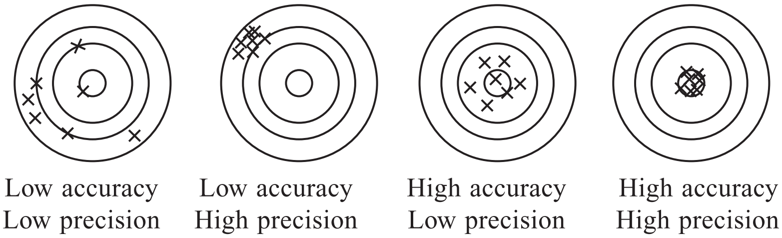


Fig 1.2 Measurements should be as accurate and precise as possible.

7. Data values that are precise are reliable but may not be valid if they are inaccurate.
8. Data values that are accurate are valid but may not be reliable if the measurements are imprecise.

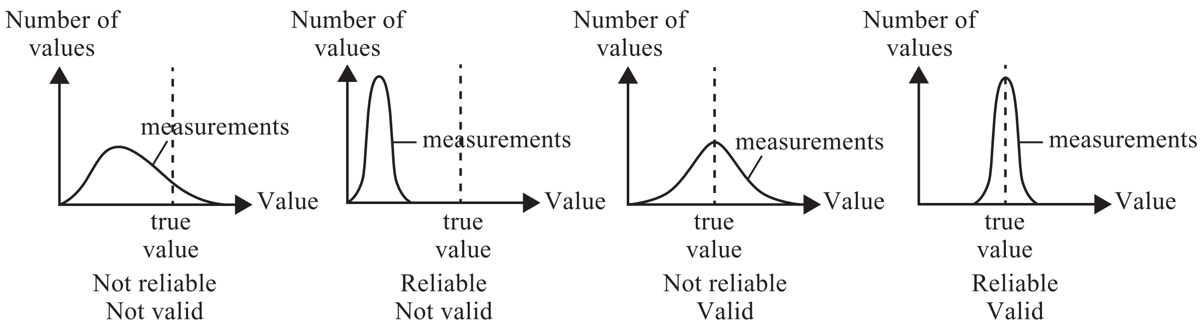


Fig 1.3 Reliable and valid data is important to help draw accurate conclusions for the experiment.

9. Reliable and valid data obtained during experiments will enable scientists to propose scientifically sound conclusions.

1.6 Errors in Measurements

1. Errors in taking a measurement can affect its accuracy. These errors include zero error and parallax error.
2. **Zero error** is defined as the condition where a measuring instrument registers a reading when there should not be any reading.
3. **Positive zero error** shows a positive reading even when it is not in use. (Fig 1.4)
4. **Negative zero error** shows a negative reading even when it is not in used. (Fig 1.5)
5. **Parallax error** occurs when the eye is being positioned at an angle to the measurement markings. The line of sight should be directly above the measurement marking. (Fig 1.6 and 1.7)

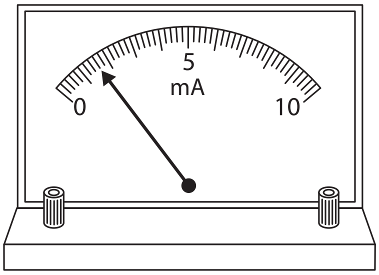


Fig 1.4 Ammeter with positive zero error

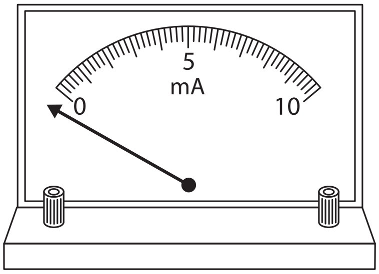


Fig 1.5 Ammeter with negative zero error

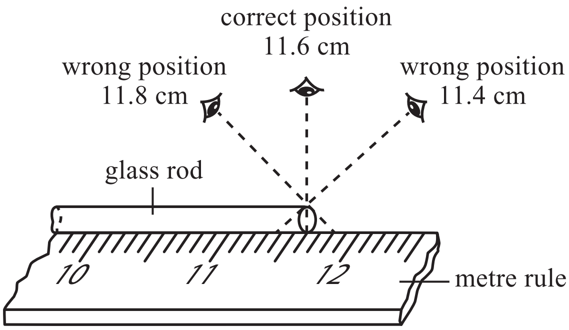


Fig 1.6 When measuring the length of the glass rod, the line of sight should be directly above the ruler.

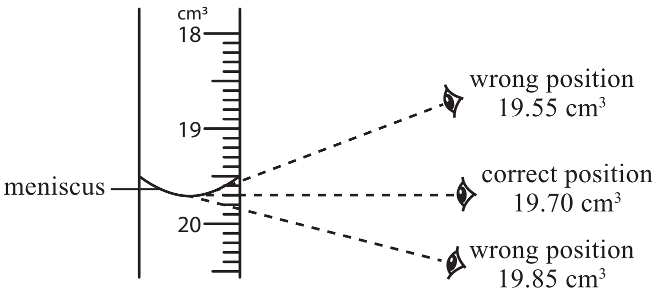


Fig 1.7 When measuring the volume of a liquid in a burette or measuring cylinder, the line of sight should be directly below the meniscus.

Note

When taking measurements, care must be taken to remove zero and parallax errors.

6. **Optional** for N(A)
   Zero error and **consistent** parallax errors are **systematic errors**. Systematic errors are consistent, repeatable errors due to faulty equipment or a flawed experiment design.
7. Errors can also be random. **Random error** has no pattern. Random error cannot be predicted, and these errors are usually unavoidable.
8. Random error cannot be replicated by repeating the experiment again.

Systematic error	Random error
Consistent, repeatable error due to faulty equipment or a flawed experiment design	Cannot be predicted and are usually unavoidable
Can be avoided by removing zero error, parallax error and using well-maintained instruments	Can be reduced by using an average measurement from a set of measurements or increasing sample size

1.7 Evaluation and Reasoning

1. Scientists will analyse the data collected and look for patterns.
2. These patterns will help scientists to propose explanations to their observations.
3. Data is usually collated in a table to help scientists identify patterns more easily.

1.8 Data Presentation

1. For example, a group of scientists would like to find out how temperature affects plant growth.
2. These scientists decided to put pots of plants in rooms with different temperatures. The temperature is our independent variable.
3. To determine how well the plant is growing, scientists will measure the height of the plant. This is the dependent variable.

4. When collating the data in a table, the independent variable is usually in the left column and the dependant variable is in the right column.

independent variable (x-axis) | dependent variable (y-axis)

Temperature / °C	Height of plant / cm
20	14.2
25	15.5
30	17.3
35	18.6
40	19.1

Fig 1.8 Collating the data in a table makes it easier to analyse.

5. This data may also be plotted in a graph.
6. The independent variable is plotted on the x-axis and the dependent variable is plotted on the y-axis.

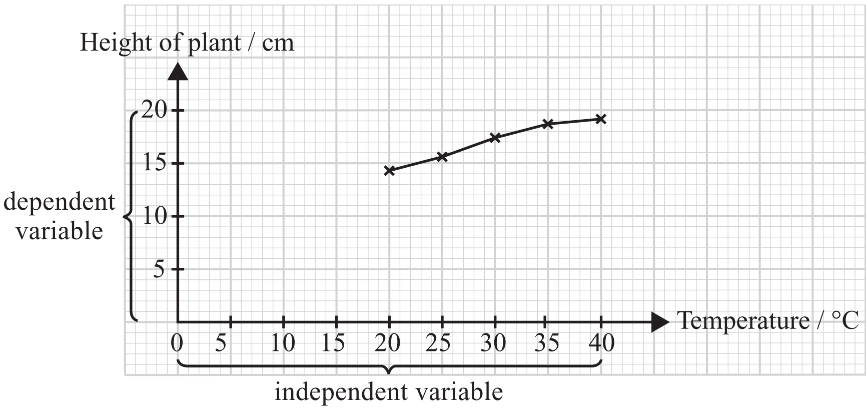


Fig 1.9 A graph shows a pictorial representation of data and makes it easier to identify patterns.

7. From the graph, we can see that as temperature increases, the height of the plant increases.
8. We can also see that from 35 °C to 40 °C onwards, the height of the plant did not increase as much as from 20 °C to 30 °C.
9. By plotting a best-fit line graph (line that passes through most of the points), it will also help scientists to identify possible anomalous data.

10. An **anomalous data** value is one that does not fit the expected data pattern.

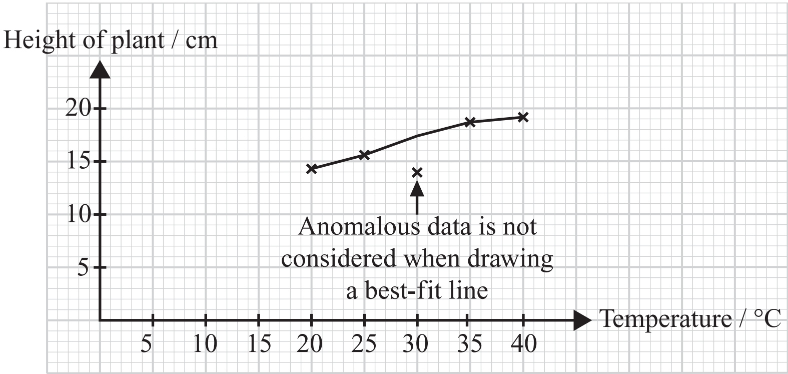


Fig 1.10 A best fit line passes through most of the points.

1.9 Developing Explanations and Solutions

1. Scientific evidence can support or reject a scientific theory or hypothesis.
2. If the conclusion in the experiment contradicts the hypothesis, the hypothesis is rejected.
3. From the data collated, scientists will develop explanations for the data and if necessary, suggest solutions.
4. For example, the data in the previous example could indicate that plants grow better at higher temperatures since the plants at higher temperatures grew taller compared to other temperatures.
5. The data in the previous experiment could also indicate that beyond 40 °C, any increase in temperature will not cause an increase in the height of the plant as the height from 35 °C to 40 °C starts to plateau. However, to confirm this hypothesis, scientists would need to repeat this experiment at temperatures above 40 °C.
6. Experiments may not give room for solutions to be developed. However, they may give rise to more questions that scientists may seek to solve.
7. One of these questions may be looking at how to encourage plants to grow better at lower temperatures so that crops may grow better at countries with temperate (i.e. cooler) climates.

8. To draw conclusions, science assumes that there are natural causes, orders and consistency in nature. This allows scientists to make predictions based on observed trends.

1.10 Multiple Interpretations of Science

1. For scientists to develop their explanations, they would need to analyse and interpret their data.

Extra

We hear the phrase 'correlation does not imply causation'. Correlation between variables shows us that the variables tend to move together. A positive correlation occurs when variable A increases with increasing variable B. A negative correlation occurs when variable A decreases with increasing variable B. No correlation occurs when there is no connection between the two variables. However, correlation does not show us whether the variables are moving together because one variable causes the other. Causation refers to the relationship between cause and effect. One variable causes the outcome of the other variable. For example, smoking is correlated with alcoholism, but it does not cause alcoholism. However, smoking causes an increase in the risk of developing lung cancer.

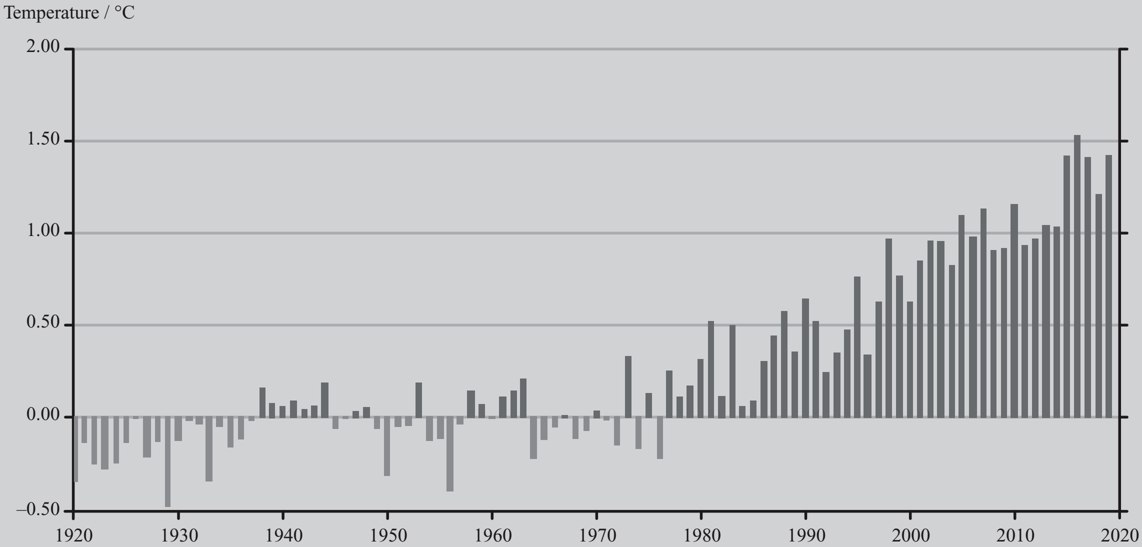
2. As interpretation of data draws on a scientist's own background knowledge, it can be subjective.
3. Another scientist, given the same set of data but with different background knowledge, may interpret the data differently.
4. For example, given the data from the previous example, another group of scientists may question the type of plants used in this experiment and conclude that only such plants grow faster at higher temperatures while plants that grow in tundra climates (e.g. in the Artic) will not respond similarly as they tend to grow at lower temperatures.
5. This type of disagreement is common in science and encourages scientists to gather more data and further their research.
6. To minimise the subjectivity of the interpretation of data, scientific concepts go through a peer review process where other scientists analyse and comment on a scientific experiment and their explanations before the concept is communicated to the scientific community.

7. Scientific knowledge is generated through established procedures and critical debate.

SCIENCE AROUND US

The graph below shows the temperature anomalies on land from 1920 to 2020. Temperature anomaly means a difference from a reference value or long-term average. A positive anomaly indicates that the observed temperature was warmer than the reference value, while a negative anomaly indicates that the observed temperature was cooler than the reference value.

(a) What does a longer bar indicate? [1]
(b) Describe the trend that can be observed. [2]
(c) What can you infer from this data? [2]



ANSWER

(a) A longer bar indicates a greater difference from the reference value.
(b) From 1920 to 1977, the temperature anomalies are between –0.50 °C and +0.40 °C.
From 1978 onwards, there is an increasing trend of positive temperature anomalies from +0.30 °C to +1.45 °C.
(c) This data shows that from 1920–1977, land temperature fluctuates around ±0.5 °C, undergoing periods of global cooling and global warming.
However, from 1978 onwards, global temperature has been rising steadily.

1.11 Safety Precautions in the Science Laboratory

1. Science can be practised anywhere, in a laboratory or out in nature.
2. Whenever science is practised, it is important to observe safety measures.
3. The table below shows some safety measures to be taken in the laboratory.

Do	Don't
• Keep your workbooks and paper away from heating equipment, chemicals and flames. • Tie long hair back whenever you use a Bunsen burner. Keep hands and arms away from open flames. • Wear safety glasses while mixing or heating substances. • Tell your teacher immediately if you cut or burn yourself. • Tell your teacher immediately if you break any glassware or spill chemicals. • Wash your hands after experiments. • Listen and follow your teacher's instructions.	• Push others or behave roughly in a laboratory. • Eat in a laboratory. Food may get equipment dirty or contaminate samples. • Drink from glassware or laboratory taps. • Look down into a container (e.g. test tube) or point it at a neighbour when heating or mixing chemicals. • Smell gases or mixtures of chemicals directly. Instead, waft them near your nose, and only when instructed. • Mix chemicals at random as mixing can cause violent reactions or release poisonous gases. • Throw matches, paper or other substances down the sink. • Carry large bottles by the neck. • Enter a preparation room without your teacher's permission.

1.12 Apparatus in School Science Laboratory

These are some common apparatus you will find in the school science laboratory.

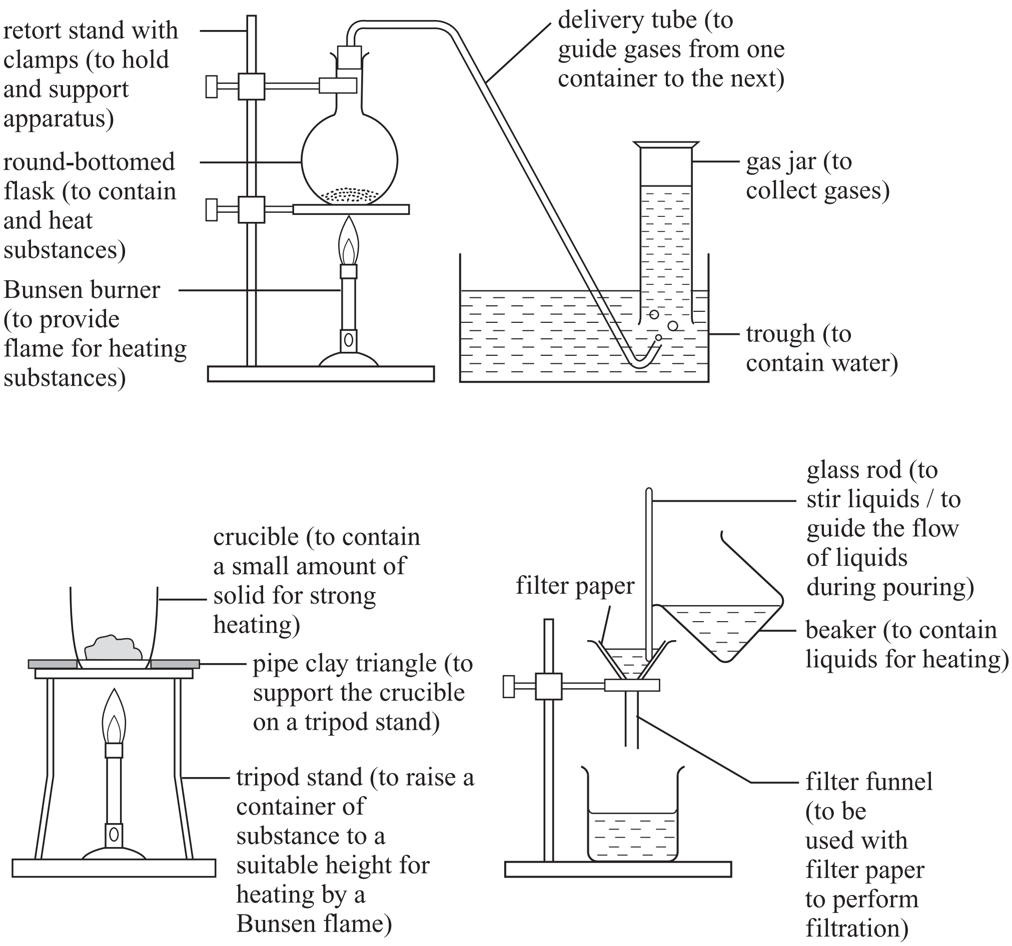


Fig 1.11 Some common apparatus in the school science laboratory

1.13 The Bunsen Burner

1. The Bunsen burner is a common laboratory apparatus. It is important to be able to use it correctly and safely.
2. The Bunsen burner mixes a flammable gas (e.g. methane) with air and burns the mixture to produce a flame. When more air is supplied, the flame gets hotter.

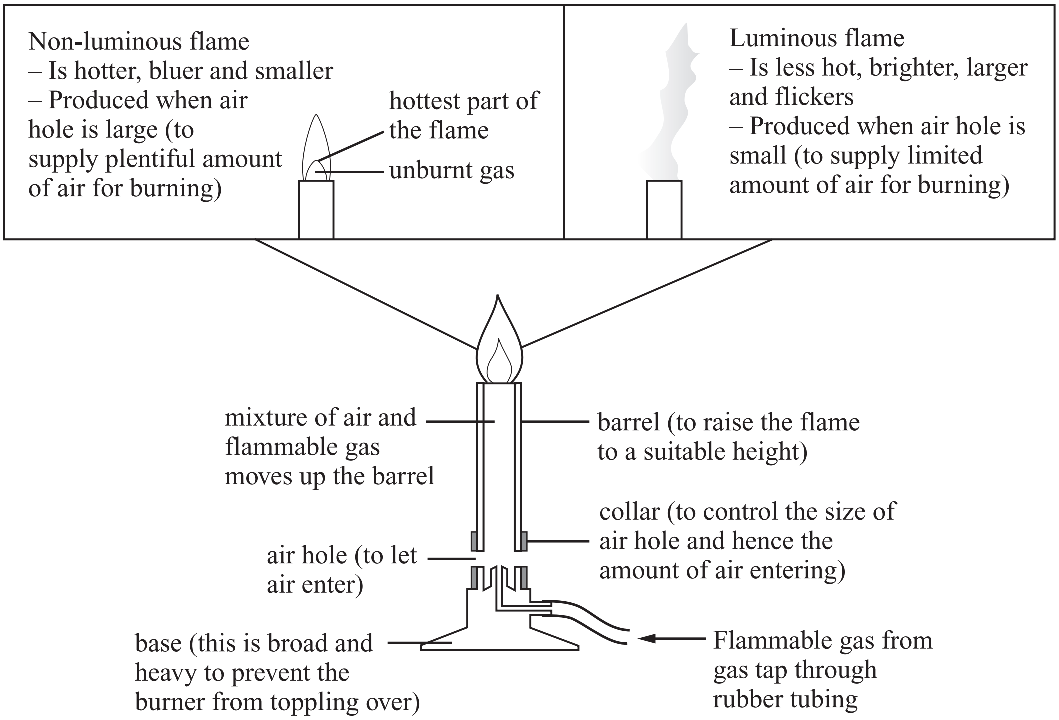


Fig 1.12 The Bunsen burner and Bunsen flames

Extra

- The burner was named after Robert Bunsen because he improved on the burner, not because he invented it.
- The combustion is a chemical reaction.
  methane + oxygen → carbon dioxide + water vapour

3. In heating a beaker or flask of liquid on a tripod stand, place a wire gauze on the tripod stand to spread out the Bunsen flame.

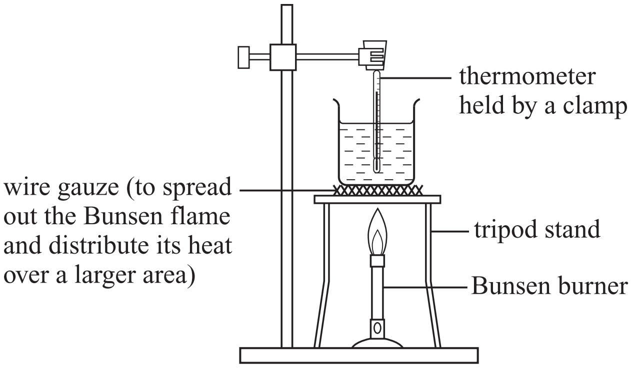


Fig 1.13 Heating a substance

1.14 Hazard Symbols

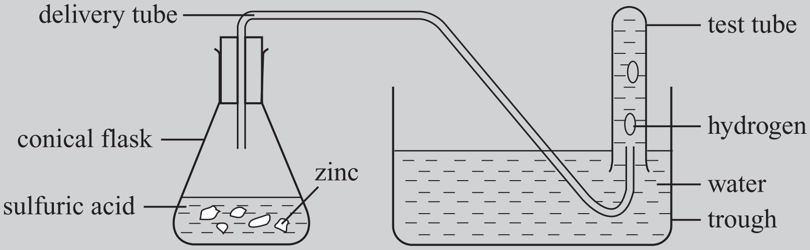
1. In the laboratory, there are many dangerous reagents and apparatus.
2. These reagents and apparatus will be labelled with a hazard symbol to inform you of the danger.
3. The infographic below shows you the different hazard symbols, what they represent, and the safety precautions you should take when using these reagents and apparatus.

 **Environmental Hazard** Substances that are toxic to aquatic organisms or may cause long lasting environmental effects. Dispose of them responsibly.	 **Acutely Toxic** Life-threatening effects even after limited exposures in some cases. Avoid skin contact or ingestion.	 **Gas Under Pressure** Pressurised gas may be cold when released and explosive when heated. Do not heat containers with pressurised gas. Store gas cylinders in cool, dry, well-ventilated areas in an upright position.
 **Corrosive** May cause burns to skin, damage the eye (which is the most vulnerable). May also corrode metals. Do not pour water into acids, and instead slowly add acids to water. Avoid skin and eye contact and do not breathe vapours. Wipe bench surfaces after use.	 **Explosive** Have great amounts of chemical potential energy. May explode due to fire, heat, shock or friction. Keep away from ignition sources (e.g. open flames). It is illegal to carry out unauthorised experiments with chemicals with this symbol.	 **Flammable** Flammable when exposed to heat, fire or sparks, or give off flammable gases when reacted with water. Flammable liquids should be heated in a water bath. Containers storing flammable liquids should be earthed (connected to the earth using a low-resistance wire).
 **Moderate Hazard** May irritate the skin, or exhibit minor toxicity. Keep away from the skin or eyes as a precaution.	 **Oxidising** Burns even in the absence of air, and can intensity fires in combustible materials. Keep away from ignition sources.	 **Health Hazard** Short or long term exposure may cause serious long term health effects. Avoid skin contact and ingestion.

Fig 1.14 Hazard symbols

SCIENCE AROUND US

1. A student knows that when pieces of zinc are added to dilute sulfuric acid, bubbles of hydrogen gas are evolved. He wishes to prepare a test tube of hydrogen gas using this reaction. He set up the experiment as shown below to collect the hydrogen gas.



   (a) For hydrogen gas to be collected in the test tube, what property should hydrogen gas have? [1]
   (b) What would the student expect to observe if hydrogen gas is collected in the test tube? [1]
   (c) How can the student measure the volume of hydrogen gas produced in the test tube? [2]
   (d) Describe the safety precautions the student should take when conducting this experiment and give a reason. [2]

ANSWER

   (a) *Hydrogen gas should be insoluble in water.*
   (b) *Water in the test tube should be pushed down/ displaced downwards, leaving a space at the end of the test tube.*
   (c) *Measure the height of space at the end of the test tube using a ruler. Use formula, $\pi r^2 h$ to measure the volume occupied where h = height of the space and r = radius of the test tube. (Assume the test tube is a perfect cylinder.)*
   (d) *Wear gloves and goggles as sulfuric acid is corrosive.*

2. The combustion of methane in a Bunsen burner can be complete or incomplete. Explain how and why complete combustion results in a non-luminous flame while incomplete combustion results in a luminous flame. [4]

ANSWER

When the air hole is fully opened, an abundant supply of air is mixed with the gas to allow the gas to burn completely.
When the air hole is closed, a limited supply of air is mixed with the gas, so the gas does not burn completely. Carbon particles are formed in incomplete combustion. When these carbon particles burn, light is given off resulting in a luminous flame.

1.15 Good Attitudes of Scientists

Attitudes needed in scientific inquiry include creativity, objectivity, integrity, open-mindedness and perseverance.

Attitude	Example
Creativity	Jabir ibn Hayyan, an Arabic alchemist, created many laboratory equipment (e.g. retort) and experimental techniques (e.g. distillation and crystallisation).
Open-mindedness	While other scientists (e.g. Joseph Priestley) strongly adhered to the phlogiston theory, Antoine Lavoisier proposed that, in combustion, substances burn with an element he called oxygen.
Perseverance	Marie Curie spent years in a run-down shed with her husband Pierre Curie to discover a small amount of radium (a radioactive element) from 1 ton of uranium ore.
Integrity and Objectivity	Evelien Oostdijk retracted and replaced her paper that looked at interventions to reduce antibiotic resistance in intensive care units after another group of researchers discovered an error in her paper when analysing the data for a different study. The authors reanalysed their findings and came up with a new conclusion based on the correct data.

1.16 Applications of Science

1. Technology is the application of science. Examples of technology:

Technology	Application
Biometrics	• People now authenticate their identity through biometrics such as finger prints and iris scans. • This has improved security and prevents identity fraud.
Blockchain	• A blockchain is a digital record of transactions. Each individual record, called blocks, are linked together in a single list, called a chain. • Each record added to a blockchain is validated by multiple computers on the Internet. These computers form a peer-to-peer network. • They work together to ensure each transaction is valid before it is added to the blockchain. Each block is permanently recorded. • It can create secure, real-time communication networks with partners around the world to support information sharing in different areas such as digital payment and healthcare data.
Natural Language Processing	• Computers can analyse and understand human language. • Speech-to-text converts human language into a programming language. This enabled virtual assistant artificial intelligence (AI) technology such as Google Home and Alexa. • Text-to-speech converts a computer operation to an audible response. Computer narration is now possible, making computing more accessible to the visually impaired.

Technology	Application
3D printing	• 3D printing refers to a variety of processes in which a material is deposited and joined under computer control to create a three-dimensional object, with material being added together, typically layer by layer. • It allows for low volume manufacturing of complex parts, as well as fast local production of difficult-to-find products. • It also allows quick prototyping which helps to drive innovation.

2. Science and technology has greatly improved our lives but it also has negative consequences or impacts.
   Examples: Plastic products (e.g. bottles and carrier bags) that are not disposed of properly and toxic leaks from discarded batteries lead to land and water pollution.
3. The use of science and technology sometimes brings about ethical and moral issues.
   Example: Fritz Haber, an extremely patriotic German chemist, invented the manufacture of ammonia which is used to make fertilisers. However, he also used chlorine gas to poison French soldiers in the second battle of Ypres.
4. Advantages and disadvantages of technology:

	Advantages or benefits	Disadvantages or drawbacks
Agriculture	Chemistry allows pesticides and fertilisers to be synthesised. These increase the yield of crops to keep pace with rapid population growth.	The use of pesticides and fertilisers brings about adverse environmental impacts.
Energy	Fuels are a source of energy for vehicles and for producing electricity.	Combustion of fuels releases greenhouse gases and air pollutants.
Medicine	Chemists are able to synthesise medicine (e.g. paracetamol) from simpler organic compounds.	Medicine made may have unforeseen disastrous effects. Example: The drug thalidomide was consumed by pregnant women to alleviate nausea. Unfortunately, many of the infants born were deformed.

5. The application of science and technology must take into consideration ethical, social, economic and environmental issues.