MYP by Concept
4&5

Sciences

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DYNAMIC LEARNING

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Published by Hodder Education
An Hachette UK Company
Carmelite House, 50 Victoria Embankment, London EC4Y 0DZ

Impression number 5 4 3 2 1
Year 2022 2021 2020 2019 2018

Cover photo © stockdevil – stock.adobe.com
Illustrations by DC Graphic Design Limited and Richard Duszczak/TheCartoonStudio.com
Typeset in Frutiger LT Std 45 Light 10/14pt by DC Graphic Design Limited, Hextable, Kent
Printed in Slovenia

A catalogue record for this title is available from the British Library

ISBN 9781510425781

FSC www.fsc.org MIX Paper from responsible sources FSC™ C104740

Contents

How to use this book

Welcome to Hodder Education's *MYP by Concept* Series! Each chapter is designed to lead you through an inquiry into the concepts of science and how they interact in real-life global contexts.

Each chapter is framed with a *Key concept*, *Related concept* and set in a *Global context*.


Relationships

Evidence

Identities and relationships

1 What is science?

To be a scientist is to use experimental evidence to find relationships and test them.

CONSIDER THESE QUESTIONS:

Factual: What measurement units do scientists agree to use?

Conceptual: How do we design a valid scientific inquiry? How can we ensure that an experiment is reliable? How do scientists collaborate?

Debatable: What makes a claim 'scientific'? Has science always been around?

Now share and compare your thoughts and ideas with your partner or with the whole class.

■ Figure 1.1 How does a horse run? (a) Prehistoric running horse cave painting, Lascaux, France; (b) *The 1821 Derby at Epsom*, Théodore Géricault (c.1821); (c) photographic images of a galloping horse, Eadweard Muybridge (c.1878)

IN THIS CHAPTER, WE WILL ...

- **Find out** what scientists do and how they try to make reliable scientific knowledge.
- **Explore** the way scientists work and the stories behind today's science.
- **Take action** to work out how to distinguish unreliable claims from scientific knowledge.

2 Sciences for the IB MYP 4&5: *by Concep*

The *Statement of Inquiry* provides the framework for this inquiry, and the *Inquiry* questions then lead us through the exploration as they are developed through each chapter.

KEY WORDS

Key words are included to give you access to vocabulary for the topic. **Glossary terms** are highlighted and, where applicable, **search terms** are given to encourage independent learning and research skills.

As you explore, activities suggest ways to learn through *action*.

■ ATL

Activities are designed to develop your *Approaches to Learning* (ATL) skills.

◆ Assessment opportunities in this chapter:

Some activities are *formative* as they allow you to practise certain parts of the MYP Sciences *Assessment Objectives*. Other activities can be used by you or your teachers to assess your achievement *summatively* against all parts of an assessment objective.

Key *Approaches to Learning* skills for MYP Sciences are highlighted whenever we encounter them.

Hint

In some of the activities, we provide hints to help you work on the assignment. This also introduces you to the Hint feature in the e-assessment.

SEE–THINK–WONDER

Look at the images in Figure 1.1. What do you **see**? What does it make you **think**? What does it make you **wonder**?

KEY WORDS

collaborate	impact
control	inquire
environment	publish
ethical	risk
experiment	test

All the images in Figure 1.1 show horses galloping. The first picture was painted in prehistoric times on the wall of a cave in Lascaux, France. The second picture is much more recent, painted in 1821 by the French artist Géricault. Did you notice that in both cases the horses appear to be running with their front and hind legs outstretched, as though they were flying through the air? Eadweard Muybridge actually photographed a galloping horse in 1878 using a basic 'stop–motion' technique. (He positioned cameras with trip-wires along a race track and ran a horse in front of a white sheet.) When the photographs were developed, the positions of the horse's legs could be seen clearly. Can you find either of the other two images in Muybridge's pictures?

Horses do not, in fact, ever adopt this 'flying' position when they gallop. So why did people persist in painting them this way? We can speculate that perhaps it was because it seemed right that horses *would* do this and that an image drawn that way would make the horse seem very fast. But the artists were certainly not painting what they saw. Muybridge demonstrated this by conducting an experiment which produced data that everybody could see and agree on. This illustration might guide us in our inquiry in this chapter: What is science?

These Approaches to Learning (ATL) skills will be useful …

- Collaboration skills
- Information literacy skills
- Critical-thinking skills
- Transfer skills
- Media literacy skills

Assessment opportunities in this chapter:

The activities in this chapter will help you develop and evaluate your learning in these MYP Sciences learning objectives:

- **Criterion D:** Reflecting on the impacts of science

We will reflect on this learner profile attribute …

- Inquirers – we will consider how science asks questions about the world and what scientists do to find answers we can rely on.

1 What is science? 3

We will reflect on this learner profile attribute …

- Each chapter has an *IB learner profile* attribute as its theme, and you are encouraged to reflect on these too.

Links to:

Like any other subject, science is just one part of our bigger picture of the world. Links to other subjects are discussed.

You are prompted to consider your conceptual understanding in a variety of activities throughout each chapter.

We have incorporated Visible Thinking – ideas, framework, protocol and thinking routines – from Project Zero at the Harvard Graduate School of Education into many of our activities.

You can measure your conceptual understanding using the summary problems at the ends of the chapters, organized by level of difficulty.

Finally, at the end of the chapter you are asked to reflect back on what you have learnt with our *Reflection table*, maybe to think of new questions brought to light by your learning.

Use this table to evaluate and reflect on your own learning in this chapter

Questions we asked	Answers we found	Any further questions now?			
Factual					
Conceptual					
Debatable					
Approaches to learning you used in this chapter	Description – what new skills did you learn?	How well did you master the skills?			
		Novice	Learner	Practitioner	Expert
Learner profile attribute(s)	Reflect on the importance of this learner profile attribute for your learning in this chapter.				

EXTENSION

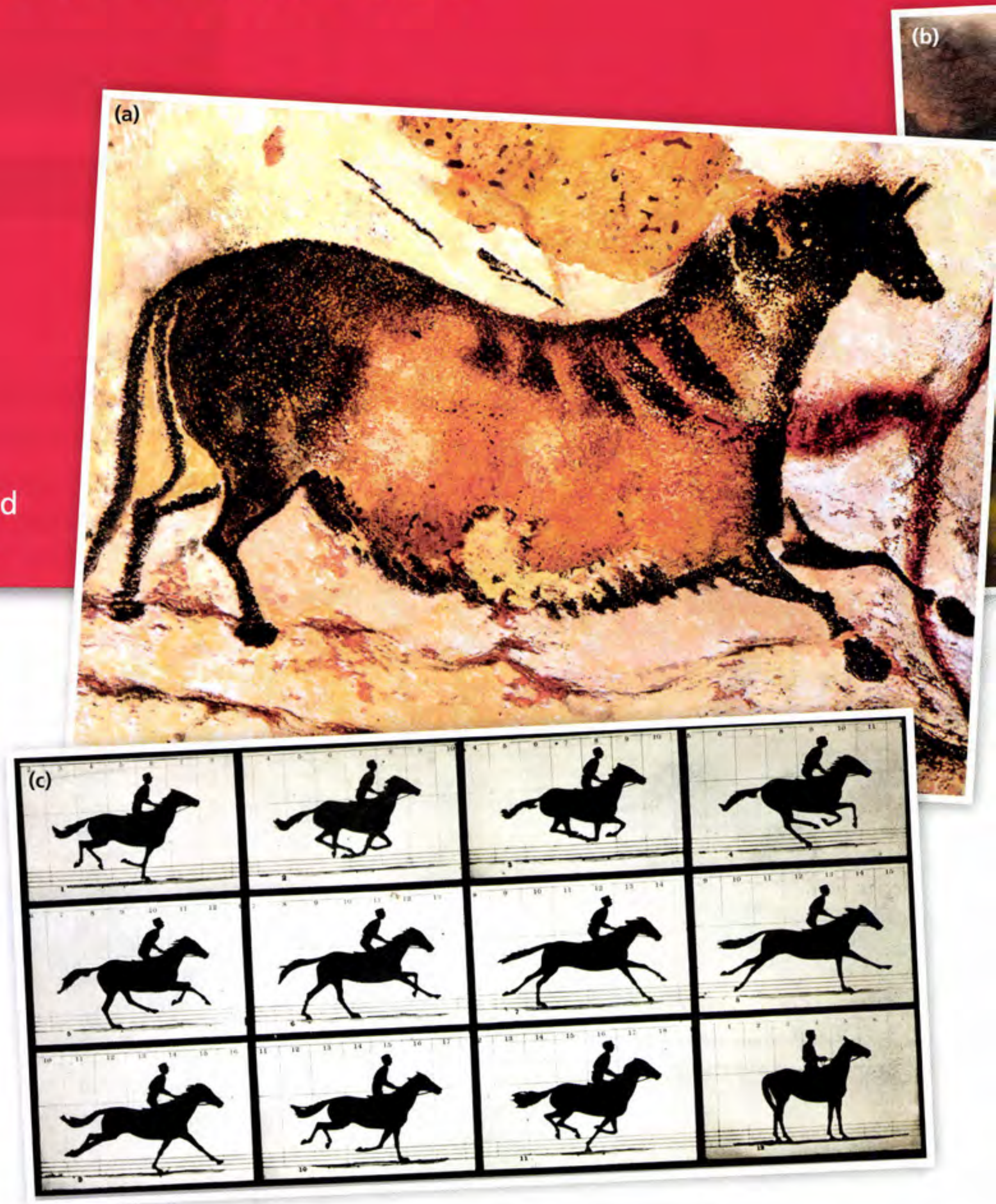
Extension activities allow you to explore a topic further.

Take action

- While the book provides opportunities for action and plenty of content to enrich the conceptual relationships, you must be an active part of this process. Guidance is given to help you with your own research, including how to carry out research, guidance on forming your own research question, as well as linking and developing your study of science to the global issues in our twenty-first-century world.

1 What is science?

To be a scientist is to use experimental **evidence** to find **relationships** and test them.



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We will reflect on this learner profile attribute …

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■ **Figure 1.2** How well do you understand the devices you use?

The modern world is highly technological; technology is the application of scientific understanding to solve real-life problems. Yet few people understand the science behind many of the devices they use every day, from microwave ovens to smartphones to aircraft to radios.

ACTIVITY: The word is science

ATL

- Collaboration skills: Listen actively to other perspectives and ideas; Give and receive meaningful feedback

In this activity you will work collaboratively to collect ideas about what scientists do.

Either use a shared online document or small pieces of paper to **write down** the first five words that come into your mind when you ask the question:

'What do scientists do?'

Now take all of your words and enter them into a word-cloud generator such as Wordle (**www.wordle.net**) or Word it Out (**https://worditout.com/word-cloud/create**).

Generate your word cloud. What does it show you?

As a class, **discuss** the results. Are the largest words the ones you think are most important? Share your views with the class.

Display the word cloud in your classroom and refer to it as you progress through this inquiry.

ACTIVITY: Science or not?

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument

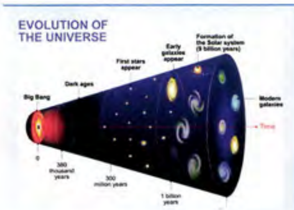
1. **Can you put the ideas in Table 1.1 in order of their 'invention' (i.e. when did people suggest them)?**
2. **Now categorize the ideas into three groups:**
   - **ideas that were *never* considered to be 'science'**
   - **ideas that *used* to be considered 'science' (but no longer are)**
   - **ideas that are currently considered to be 'science'.**
3. **Discuss how you decided on the different groups. What criteria did you use?**

	**Wave–particle duality** All matter behaves like waves of energy in space; conversely, all waves behave like particles of matter. Light, for example, can behave like a wave travelling through space, but it can also behave like tiny particles of matter called 'photons'. Even though these two properties can lead to completely contradictory results in the same experiment, this is just because our experiments are not adequate to represent what light really is: both waves and particles.
	**Lamarckian evolution** Living creatures adapt to their environment. Thus, a repeated need means that creatures develop a certain ability, which is developed over each generation. The giraffe has a long neck because over many generations giraffes have stretched to reach the highest leaves in a tree. The grandchild of blacksmiths is likely to be born with strong arms and will pass this propensity to his or her children.

■ **Table 1.1**

What makes a claim 'scientific'? Has science always been around?

To many people, science tells us the 'real' truth. To others, it is just another point of view. Where does your opinion lie? Perhaps one of the most important things to realize about science is that it is (as the philosopher Karl Popper put it) 'open' knowledge. Scientists should not be afraid of being proved wrong. In some ways, that is the whole point of science: to learn from our mistakes, in order to know with greater certainty next time.



Big Bang theory

The Universe – not only space, but time itself – began in a single point around 15 billion years ago. This point was called the 'singularity'. After this all of space–time 'unfolded' and cooled, so that energy was turned into matter with different properties. The rate of unfolding of space–time depends on the strength of forces in the Universe, most important of all gravitation.

Alchemy

All natural substances have properties related to their place in the Universe. They consist of a mixture of the four principal elements – Earth, Air, Fire, Water – in different quantities. Thus, heavy elements such as lead contain more Earth than Air. Each element is also responsible for a part of the human body, and imbalances in the correct amounts of elements lead to illness.

The 'perfect element' is the fifth element, or *quintessence*, also known as the 'Philosopher's Stone'. This element can convert all elements into any other element.

Phrenology

Each part of our brain is responsible for a different aspect of our personality. The distinguishing features of our personalities are caused by different growth rates in different parts of our brains. We can therefore 'read' our personalities by looking for bumps on the cranium that indicate which parts of the brain have developed the most.

Astrology

All events on Earth are determined to some extent by the motions and positions of the five planets: Mercury, Venus, Mars, Jupiter and Saturn. Our own lives are strongly determined by the positions of these planets at the time of our birth, and subsequent events can be related to planetary motions.

Plate tectonics

The Earth's surface is in fact a very thin layer of hard rock that floats on a softer substrate of molten lava. The surface is cracked into 'plates' which have moved over many billions of years. For this reason, the continents as we see them today were different many millennia ago: originally, all land on Earth was one huge continent which has been called 'Gondwanaland'.

ACTIVITY: ABC of scientific thinking

ATL

- Information literacy skills: Access information to be informed and inform others

Look at the scientists in Figure 1.3.

Research the work of an important scientist or mathematician who is from a culture different to your own.

Summarize one of the important contributions they made to our understanding of the world. **Outline** what problem of the time this contribution solved or what it enabled us to do.

Describe some of the challenges your scientist faced, whether scientific, political, economic, social or otherwise.

Don't forget to **document** all your sources using a recognized citation standard and bibliography.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion D: Reflecting on the impacts of science.

Figure 1.3 Science has always been international, but were all of these really 'scientists'? Were they always right? (a) Ibn Sīnā, known as Avicenna (980–1037 CE); (b) Aristotle (384–22 BCE); (c) Galileo (1564–1642 CE); (d) Newton (1642–1727); (e) George Washington Carver (c.1860–1943); (f) Lise Meitner (1878–1968)

To Greek classical thinkers, the world of the senses – that which we observe – was unreliable and uncertain, because the senses could be deceived. For many of them (with notable exceptions, such as Aristotle) *true* knowledge could only be obtained through *thinking*. This view of knowledge is sometimes called **rationalism**.

In Europe it took a long time to change this view and a large number of writers and thinkers contributed to the process, such as Thomas Aquinas, Francis Bacon and Galileo Galilei. By around 1600, however, European thinkers were beginning to reconsider the role of observation in making knowledge. Francis Bacon, for example, asked: why should thinking be any more reliable or certain than what we, ourselves, can experience? He proposed that we could be more certain about the world if we made careful, controlled observations of the way things behaved in it.

The idea that knowledge can be gained from observation and experience is sometimes called **empiricism**.

However, if our knowledge of the world is to be reliable, not just any experience or observation will do. Our observations must be controlled carefully so that we can determine the exact **relationships** between things; in other words, we must do an *experiment*.

Links to: Language and literature

The language of science

ATL

- Transfer skills: Inquire in different contexts to gain a different perspective

The word 'experiment' derives from the Latin *experiri*, meaning *experience*. If you study a Latinate language such as Italian, French or Spanish, you may know that the word for experiment is the same as the word for experience.

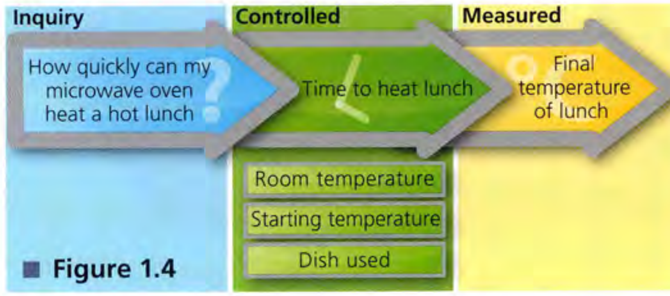
Use Google 'ngrams' to find out when the word experiment began to be used more frequently in books and other texts: **https://books.google.com/ngrams/**

How do we design a valid scientific inquiry? How can we ensure that an experiment is reliable?

Galileo Galilei (Figure 1.3c) was one of the first people to realize that reliable experiments required controlled variables. A variable is any factor that can be controlled or measured in order to investigate a **relationship** experimentally.

Imagine an experimental inquiry to be like a sort of machine. The **controls** of the machine determine the **outcomes** that we can measure (Figure 1.4). We feed in our questions and out of the process – hopefully – come the answers!

While scientific inquiry may begin with wonder, scientific questions need to be a little more focused than that. As scientists, we have to make questions that can be tested in some way, such that we can find an answer or explanation for what we observed. Often a problem in nature will turn out to be much more complicated than it seems at first and we will only be able to answer a big question by first identifying a number of smaller questions and finding the answers to those.



■ **Figure 1.4**

Look again at Figure 1.4. What other variables might affect the temperature of my lunch? If we change any of these, they might also affect the outcome – the final temperature of my lunch.

We therefore have to divide the **controlled variables** into those we will **change** and those we will **keep the same**. The variable that we will be changing in the experiment is called the independent variable (because it depends only on us); the variable that is being measured is called the dependent variable.

ACTIVITY: The right variable for the job

■ ATL

■ Critical-thinking skills: Gather and organize relevant information to formulate an argument

For the different experimental inquiries below, choose variables that it might be important:

- **to control by changing**
- **to control by keeping the same**
- **to measure.**

Variables

temperature	colour	area
time	brightness	speed
height	distance	

Experimental inquiries

- **How long does an ice cube stay frozen?**
- **What size of parachute will save a dropped egg?**
- **What is the best colour to wear if you want to keep cool?**
- **How long does an aircraft stay on the runway before it can take off?**

Asking the right question

In designing an experiment, the first thing we do is select our variables and figure out which variables we are going to change (independent variables) and which we are going to measure (dependent variables).

To do this, we need to have an idea of the problem we are trying to solve. This is why the first stage in the scientific investigation cycle is to write an 'inquiry question' for the experiment. A good inquiry question should include the variables that you are going to control, for example:

How does variable 1 affect variable 2?

or

What is the relationship between variable 1 and variable 2?

Once we have the question and the variables, we can suggest what we think the answer might be. When scientists suggest a **theory** as an explanation for the way something might work, it is called a **hypothesis**. If we then state exactly what we expect to see happening in a given situation, it is called a prediction. For example, I might make a *hypothesis* that whenever the temperature drops in winter, it is more likely to snow; this might lead me to *predict* that on Saturday it will be snowing.

Some scientific inquiry is carried out by looking at data that others have already gathered; these are called **secondary data**. Much science, however, requires new or **primary data**. Scientists need to carry out their experiments to gather data in a controlled environment: the laboratory. A laboratory is a specially equipped room where all the equipment and apparatus the scientists require is available. It is kept very clean and tidy to ensure that nothing can affect the experiments carried out, other than the effect of the independent variable.

In *MYP Sciences by Concept 1*, we explored the laboratory as a working environment. All the experiments you will carry out in this book require care and safe practice, so this is a good time to review the laboratory codes again.

We follow safety rules in order to minimize risk. Before you begin an experiment it is a good idea to carry out a **risk assessment**. This involves reviewing in advance everything you will do in the experiment and considering what possible dangers this could present. You should then re-evaluate your experiment design to reduce such risk. Search for **risk assessment template science lesson** or use the example shown in Table 1.3.

ACTIVITY: Making up the rules

ATL

- Collaboration skills: Take responsibility for one's own actions

Every laboratory needs a 'code' to make sure that all experiments are carried out safely and scientifically.

In pairs, **discuss** and **complete** a copy of Table 1.2 by **explaining** why it is important to take the safety measures given in the first column.

As a class, brainstorm any other safety measures that you think might be important in the laboratory.

When you have finished:

- **design** and make a poster illustrating any of the safety measures so that other MYP students will understand
- **design** and make a 'safety checklist' to use before you begin any experiment.

Safety measure	Reason
keep bags, coats and books in a safe place out of the way	
wear protective clothing and safety glasses when instructed	
walk, don't run	
do not put anything in your mouth	
do not listen to music while working	
wash hands carefully after using chemicals or organic substances	
tie back long hair	

Table 1.2 Laboratory rules

Date assessment completed: ____________________

A = Probability: 1 = Not likely B = Severity : 1 = Mild

2 = Possible 2 = Medium

3 = Likely 3 = Severe

Hazard	A	B	C (A × B)	Action to reduce risk

■ **Table 1.3** Risk assessment

It is also important to consider the effect of our actions on the environment, both inside the laboratory and outside. We should consider the way we dispose of waste materials, especially if we are using chemicals or other 'special' materials. Remember that in a laboratory, everything we use is scientific apparatus, even if it is something we might consider quite usual at home. This is why we never put anything in our mouths during experiments, we always clean any apparatus and surfaces, and we always wash our hands after we have finished.

Will your experiment involve living things or possibly affect others? If so, you should also consider whether or not your actions will be **ethical**. Is anything you plan to do likely to cause harm or upset to other living things? This can be difficult for scientists to judge and they must work closely within ethical guidelines such as those provided by the International Baccalaureate Organization (IBO) for students.

Find out about the ethical guidelines for the IB MYP and DP. Ask your teacher to find these documents and **discuss** them in class:

- IB animal experimentation policy
- Ethical guidelines for extended essay research and fieldwork
- Ethical guidelines for IB DP Psychology.

A useful preparation is to write an **environmental and ethical impact assessment** of your experiment, where you consider the effect of your experiment on the living and non-living environment.

ACTIVITY: Thinking about environmental impact

ATL

■ Collaboration skills: Take responsibility for one's own actions

In pairs, brainstorm as many ways as possible that a scientific experiment might affect the environment, both in the laboratory and outside it. Consider how your experiment might also affect the wellbeing of other living things.

Share your ideas with the class and collect all the class ideas together.

Discuss what action you should take to minimize the impact of the factors you have identified.

Organize the impact factors and the actions in the form of an easy-to-use checklist similar to the one you wrote for the activity *Making up the rules*.

What measurement units do scientists agree to use?

■ **Figure 1.5** A cabinet of international weights and measures. Before standardization, different places all used different measurements, making it very difficult to trade fairly! (The cabinet can be found in the Winton Gallery at the Science Museum, UK)

In Chapter 1 of *MYP Sciences by Concept 2*, you may have explored how humanity has created different ways to make measurements of the natural world. The first recorded forms of measurement were probably based on the size of parts of the human body. Today, the two most common forms of measurement in use are the **metric system** and the **imperial system**. Scientists worldwide use the metric system of measurement.

During the seventeenth and eighteenth centuries in Europe, philosophers were influenced by the rediscovery of classical thought from Greece and Rome. The revolution in France from 1789 not only sought to change the way society was organized or who was in charge, but also to reorganize the way humanity thought about time and space. The revolutionaries introduced a new calendar based on 10 months a year, rather than the 12 inherited from ancient times, and in 1799 the revolutionary government created new standards of measurement for length and mass, called the metre and the kilogram. These in turn were divided logically in units of 10, 100 or 1000 as the 'metric' system. The measurements were standardized using a platinum rod and a mass which were kept in the *Archives de la République* in Paris.

Just as the political changes in France were not popular everywhere in Europe, the new 'rational' measures were not immediately taken up elsewhere. In France itself the 'new calendar' of 10 months was abandoned when Napoleon Bonaparte came to power. However in the nineteenth century, physicists developed a system of units that aimed to derive all measurements from a small number of basic metric units. This was the basis of the metric Système International d'Unités (or SI unit system), although it wasn't given this name until 1960.

Unit of length	meter/metre	length of the path travelled by light in vacuum during a time interval of $\frac{1}{299\,792\,458}$ of a second
Unit of mass	kilogram	the mass of the international prototype of the kilogram
Unit of time	second	duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom

■ **Table 1.4** Definitions of the SI base 'mechanical' units (note that there are seven base units in total)

THINK–PAIR–SHARE

What do you notice about the definitions of the units in Table 1.4?

What has changed since the first definitions of the metre and kilogram in France in 1799?

Why do you think the definitions have been changed?

Power of 10	Prefix
$\times 10^{-15}$	femi
$\times 10^{-12}$	pico
$\times 10^{-9}$	nano
$\times 10^{-6}$	micro
$\times 10^{-3}$	milli
$\times 10^{-1}$	deci
$\times 10^{3}$	kilo
$\times 10^{6}$	mega
$\times 10^{9}$	giga
$\times 10^{12}$	tera

■ **Table 1.5** Common prefixes

Accuracy and precision

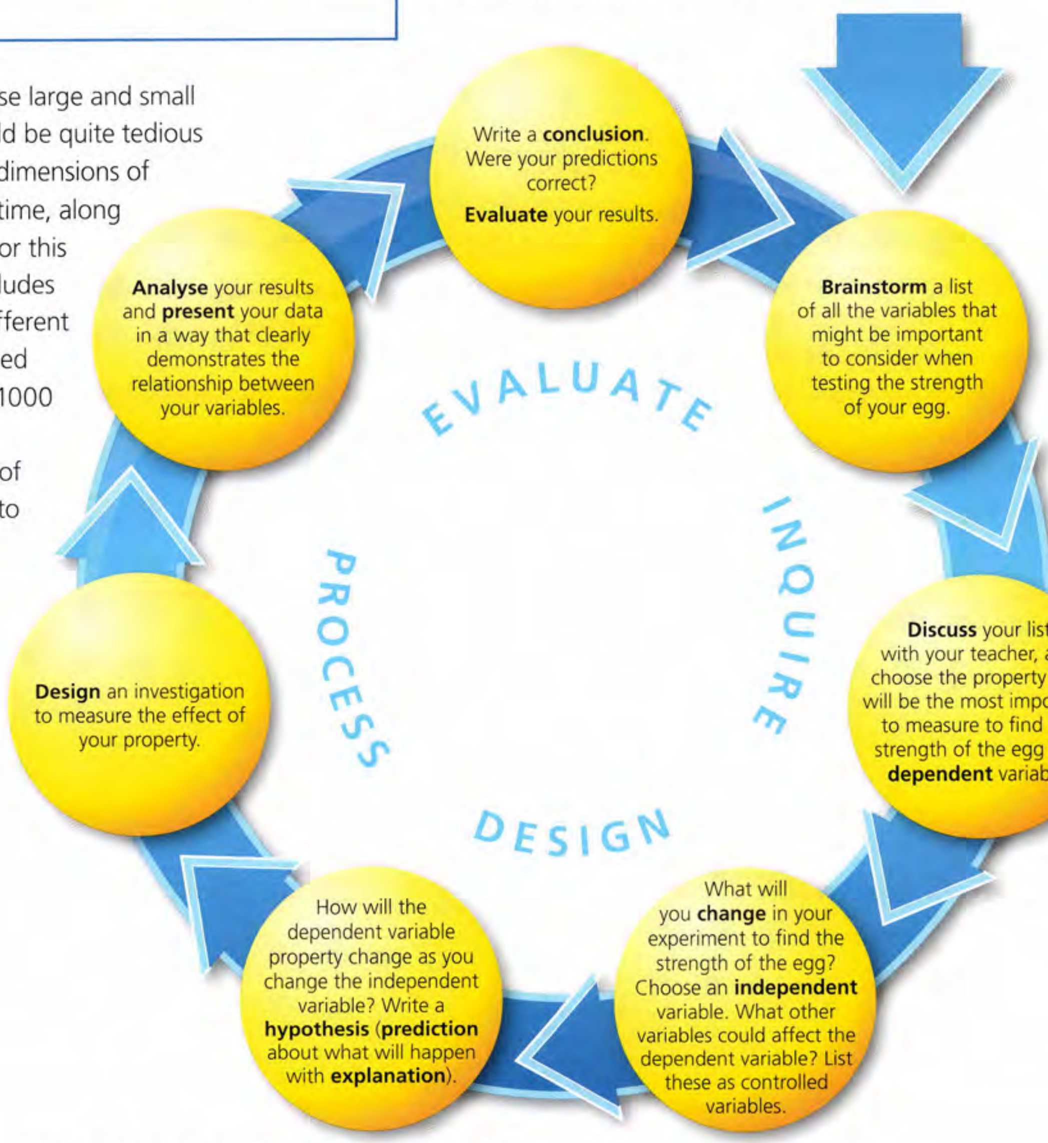
When scientists make measurements, they need to be sure that the measurements are reliable. This means that whoever makes the measurement, wherever it is made and under whatever conditions, the answer obtained will always be the same.

If a number of measurements are precise, they will be in close agreement with each other.

If a measurement is accurate, it will be close to an expected value.

A *Sciences Inquiry Cycle* (see Figure 1.6) can be used to guide us whenever we design our own investigations for our inquiry questions in this book.

Since scientists have to use large and small numbers so often, it could be quite tedious to have to write out the dimensions of objects in metres all the time, along with the powers of 10. For this reason, the SI system includes a series of prefixes for different scales. A new prefix is used every time a multiple of 1000 or 10^3 occurs. You may have encountered some of these already in relation to computer systems.



■ **Figure 1.6** A *Sciences Inquiry Cycle* for investigating the strength of eggs!

How do scientists collaborate?

Sometimes in history, a person comes along who can do everything themselves (see *Meet a scientist: Leonardo da Vinci*). However, in most cases, science is a collaboration between a number of scientists; sometimes across the world, sometimes between the different disciplines within science, such as physics, chemistry and biology, sometimes with technological disciplines such as computer science.

Scientists must make sure that their new knowledge is as reliable as possible. When a new discovery is made, scientists must publish their work in a recognized scientific journal and may present it at a conference. To be included in a journal, the work undergoes **peer review**. This means that the work is checked by other experts in the field and the experiment may also be **repeated** by other scientists to verify that the results are the same as those claimed. In doing so, scientists are checking to ensure that they all work to the highest standards of academic integrity – just as you must in your MYP studies.

Science is really one big debate that continues to throw up new questions about the world.

DISCUSS

Find out about one of the following scientific projects:

- **The Large Hadron Collider**
- **The Human Genome Project**
- **The ITER Fusion Reactor**
- **Intergovernmental Panel on Climate Change (IPCC)**

Who is involved in each project? What kind of experimental work do they do? **Suggest** why the projects require collaboration.

EXTENSION

Look at the table of scientific journals at the following link: **www.scimagojr.com/journalrank.php?category=2701**

In order to 'rank' these journals, what do you think is being measured?

MEET A SCIENTIST: LEONARDO DA VINCI

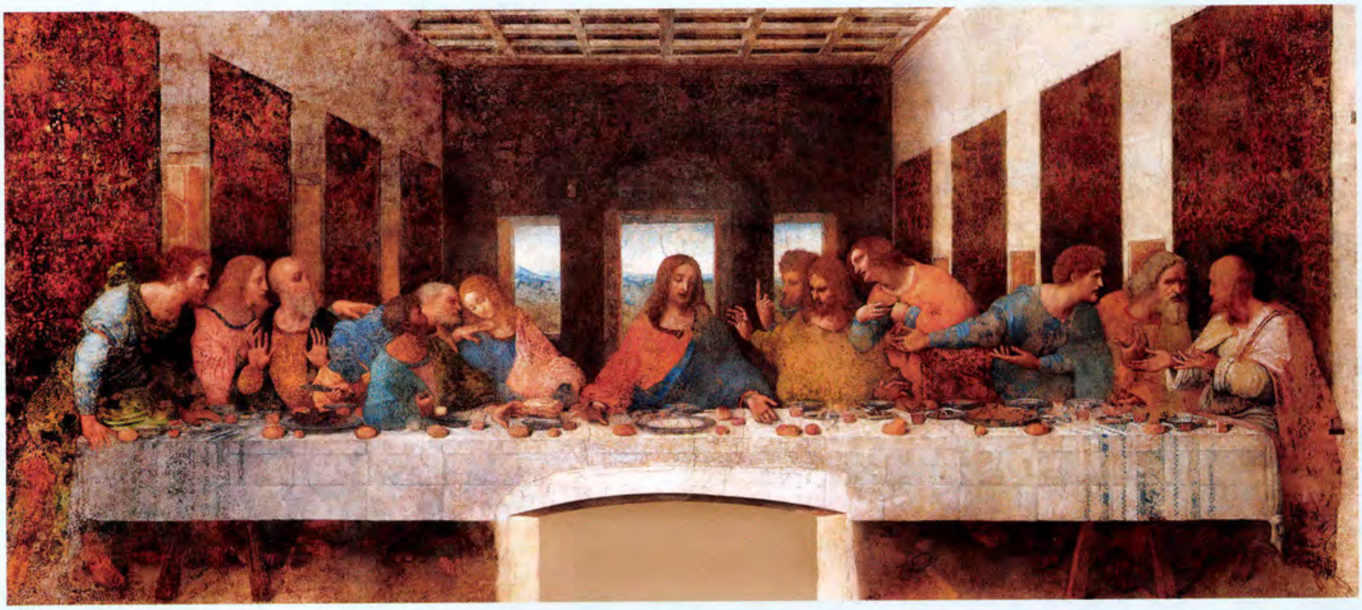
Leonardo da Vinci was an Italian **polymath** who was born in April 1452. He was hugely influential as an artist, with his famous paintings such as the *Mona Lisa*. Da Vinci's talents and knowledge went far beyond art, however. He was expert in science, mathematics, engineering, music, architecture, archaeology, literature, geology, anatomy, botany, physiology – the list goes on! His famous drawing *The Vitruvian Man,* in which he studied the proportions of the human body, is a marriage between art and science. He was fascinated by the human body and was allowed to dissect corpses in hospitals in Italy. He also dissected animals and compared them to human bodies. This is why his anatomical drawings of the human musculoskeletal system and embryos are so detailed and accurate.

■ **Figure 1.7** A portrait of Leonardo da Vinci (1452–1519)

Leonardo was a talented engineer too. His engineering skills could be seen in his sketches and designs of flying machines (Figure 1.8). He laid the foundation for biomechanics with his studies on the mechanical processes involved in human and animal movement. In modern times, his designs have been used to build working models. Examples of his designs include a parachute, a machine for testing tensile strength, an adding machine, hydraulic pumps, a flapping ornithopter and a machine with a helical rotor (a helicopter).

■ **Figure 1.8** Exhibition of da Vinci flying machines in Venice, Italy

Leonardo da Vinci relied on detailed observations of natural phenomena to drive his own experiments based on patterns he identified. His scientific thinking process had a great influence on his art. In his most famous painting, *The Last Supper* (Figure 1.9), he applied his theories on the physics of light, shade and angles and the rules of optics.



■ **Figure 1.9** Leonardo da Vinci's painting, *The Last Supper.* Da Vinci applied his theories on the rules of optics and visual perception to draw the diners around the central figure of Jesus in the painting.

! Take action: Exposing fake news

ATL

- Media literacy skills: Demonstrate awareness of media interpretation of events and ideas

! We have seen in this chapter how science stories are very popular in the media. Sometimes, though, the media get it wrong and people can be misled, because not everybody thinks scientifically.

! Here are a few of the most common misconceptions, which you may have investigated in Chapter 1 of *MYP Sciences by Concept 1*.

■ **Figure 1.10**

! Research these or search other popular scientific misconceptions. Make a poster, web presentation or a movie in which you 'debunk' these misconceptions by explaining the real science behind them!

Reflection

In this chapter we have **outlined** the way that scientists work to make new knowledge. We have **categorized** ideas according to whether or not they are 'scientific' and so **suggested** some criteria for scientific ideas. We have **designed** laboratory codes for safety and for environmental risk. We have **identified** the measurement units that scientists use. We have **discussed** how scientists collaborate across the world and between scientific disciplines.

<table>
<tr><th colspan="6">Use this table to reflect on your own learning in this chapter</th></tr>
<tr><td>Questions we asked</td><td>Answers we found</td><td colspan="4">Any further questions now?</td></tr>
<tr><td>Factual</td><td></td><td colspan="4"></td></tr>
<tr><td>Conceptual</td><td></td><td colspan="4"></td></tr>
<tr><td>Debatable</td><td></td><td colspan="4"></td></tr>
<tr><td rowspan="2">Approaches to learning you used in this chapter</td><td rowspan="2">Description – what new skills did you learn?</td><td colspan="4">How well did you master the skills?</td></tr>
<tr><td>Novice</td><td>Learner</td><td>Practitioner</td><td>Expert</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Learner profile attribute(s)</td><td colspan="5">Reflect on the importance of being an inquirer for your learning in this chapter</td></tr>
<tr><td>Inquirer</td><td colspan="5"></td></tr>
</table>

2 How does scale matter?

Changing the **scale of things** allows us to **make connections** and **build models** that help us understand how the world is structured.

Figure 2.1 The idea of changing size has been a popular subject for science fiction

CONSIDER THESE QUESTIONS:

Factual: How are living organisms structured? What building blocks do scientists use to describe living and non-living matter? What holds matter together?

Conceptual: How does changing scale change our understanding of nature?

Debatable: To what extent does our everyday experience limit our understanding of the very small and the very large?

Now **share and compare** your thoughts and ideas with your partner or with the whole class.

These Approaches to Learning (ATL) skills will be useful …

- Information literacy skills
- Critical-thinking skills
- Creative-thinking skills
- Transfer skills
- Communication skills
- Reflection skills
- Collaboration skills

We will reflect on this learner profile attribute …

- Open-minded – we will consider how changing point of view and perspective might change our understanding of the world.

Assessment opportunities in this chapter:

The activities in this chapter will help you develop and evaluate your learning in these MYP Sciences learning objectives:

- **Criterion A:** Knowing and understanding
- **Criterion C:** Processing and evaluating
- **Criterion D:** Reflecting on the impacts of science

KEY WORDS

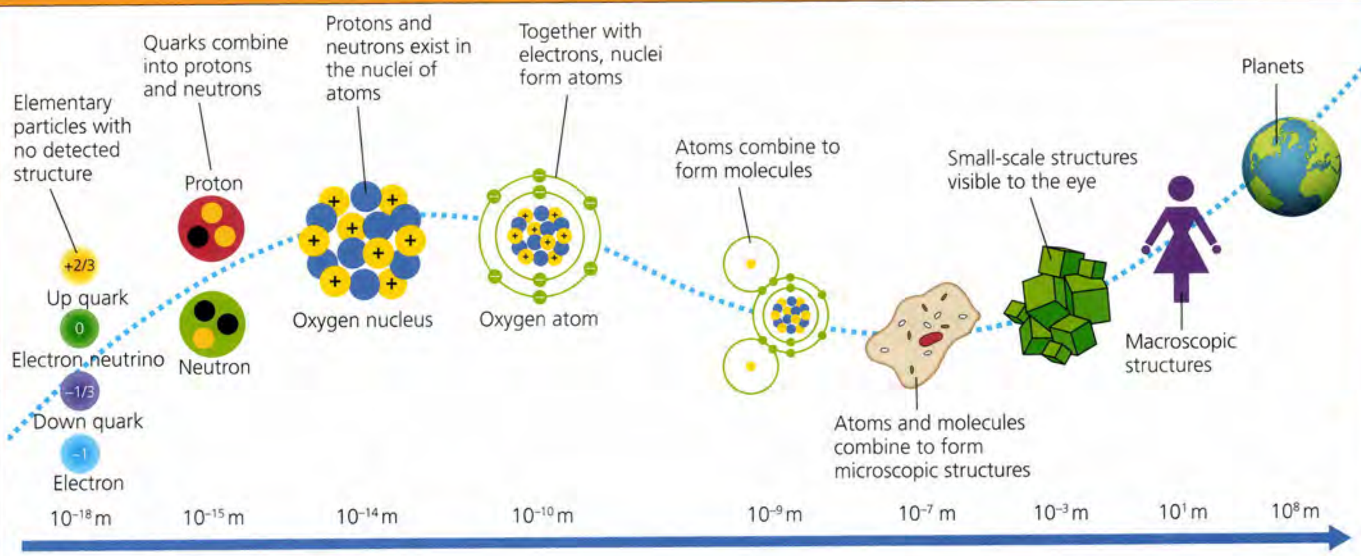
atom	nucleus
cell	organ
ecology	particle
ecosystem	

IN THIS CHAPTER, WE WILL …

- **Find out** about the 'building blocks' of organic and inorganic matter.
- **Explore** the way in which changing the scale at which we observe and measure the natural world changes our understanding of it.
- **Take action** to raise awareness of how different perspectives in science can both extend and sometimes limit our knowledge and understanding.

SEE–THINK–WONDER

Look at the images in Figure 2.2. What is changing? What do you **see**? What does this make you **think**? What does it make you **wonder**?



■ **Figure 2.2** The scale of things

ACTIVITY: Principal, I shrunk the science class!

ATL

- Creative-thinking skills: Consider multiple alternatives, including those that might be unlikely or impossible; Create original works and ideas; Use existing works and ideas in new ways
- Communication skills: Use appropriate forms of writing for different purposes and audiences
- Information literacy skills: Access information to be informed and inform others

We must be careful not to confuse science fiction with science fact. The idea of shrinking matter to a different scale is not realistic, as we will see in this chapter. In reality, scientists have to make do with using instruments and measurements to deduce how the Universe works at different scales. Still, imagination also plays an important part in science as we saw in Chapter 1; asking 'what if ...?' questions can lead to new hypotheses and so to new science.

Imagine that you are working with a research scientist who has somehow found a way to change size. Choose three different scales and draft a newspaper report describing what you see at those different scales. Use diagrams and pictures to illustrate your discoveries!

There are many online simulations that allow you to explore the Universe at different scales. **Explore** online using one of these website to find out what the Universe looks like at different scales:

http://apod.nasa.gov/apod/ap120312.html (requires Adobe Flash)

http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/ (requires Java).

At the end of this chapter, we will return to your draft report to see how it might be improved.

Figure 2.2 shows how changing our perspective can change the information that we have about the world. Science deals with the whole Universe, from the very large to the very small indeed. In this chapter we will explore how changing the scale of our observations gives us a different perspective and we will think about the connections between the systems and processes we observe at different scales. Along the way, we will encounter and use the tools of the different science disciplines of physics, chemistry and biology and see how they each work across different scales of observation.

How does changing scale change our understanding of nature?

WHAT IS SCALE?

Links to: Mathematics

ATL

- Transfer skills: Make connections between subject groups and disciplines

Important key concepts in MYP Mathematics are form and relationships.

Form in mathematics concerns the way that appearances can tell us about the purpose or the function – what something does. *Relationships* in mathematics concerns the way that things connect. So it should not surprise us that mathematics will help us work with relationships between things at different scales! When scientists are dealing with very large scales or very small scales, they must calculate very large and very small numbers. Our usual unit of length – the metre – is made to be useful to us, in our 'scale' for the Universe.

In standard notation:

10^1 is said 'ten to the power of one'	$= 10$
10^2 is said 'ten to the power of two'	$= 10 \times 10 = 100$
10^3 is said 'ten to the power of three'	$= 10 \times 10 \times 10 = 1000$

and so on …

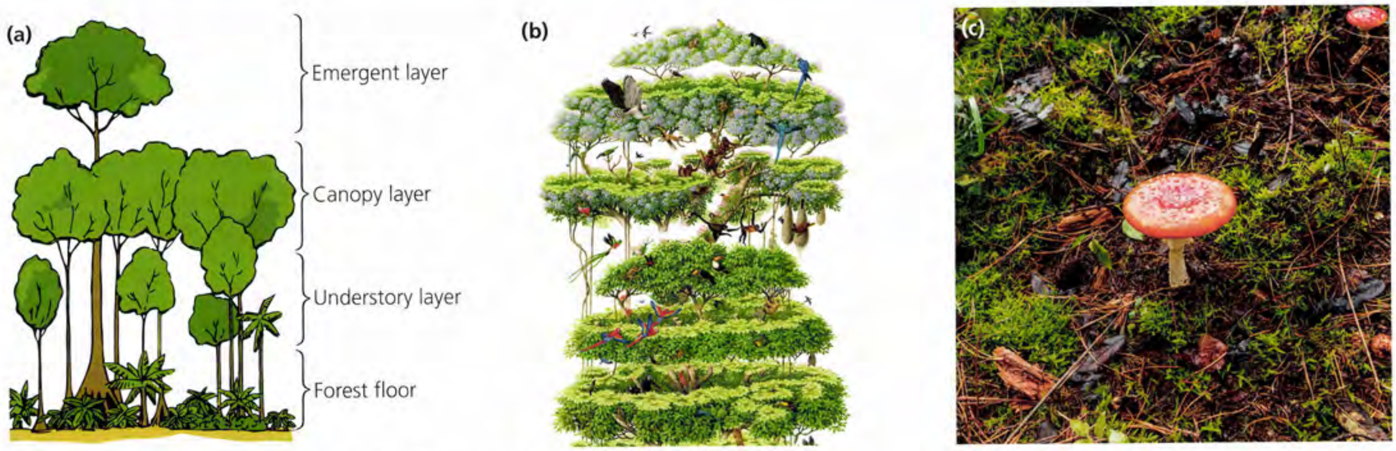
Notice that although $10^0 = 1$, for values in the range 1 to 10 we would just give the number itself. So '5' would simply be written as '5', not as 5×10^0.

For numbers that are smaller than 1 we have to go the other way, making the power of 10 smaller and smaller. We use negative powers of 10 to do this:

10^{-1} is said 'ten to the power of minus one'	$= 1 \div 10 = \frac{1}{10} = 0.1$
10^{-2} is said 'ten to the power of minus two'	$= 1 \div (10 \times 10) = \frac{1}{100} = 0.01$
10^{-3} is said 'ten to the power of minus three'	$= 1 \div (10 \times 10 \times 10) = \frac{1}{1000} = 0.001$

Links to: Language and literature

How many works of fiction – whether short stories, novels or movies – can you find that use the idea of changing size as inspiration? Try searching **Fantastic Voyage 1966** or **Honey I Shrunk the Kids** for some starter ideas!



■ **Figure 2.3** (a) Rainforest layers, (b) canopy layer, (c) forest floor layer

We look at things with our eyes, have a certain perception of them and form a mental image, but most of the time what we see is not what the things actually are. If we get closer or further from them we see them very differently. We walk in our cities every day and see the houses, trees, parks, lakes ... but when we fly in an aeroplane and look down at a familiar place we see a whole different picture. Our understanding of nature depends on observations and these observations depend on the scale we use to look at objects. The scale is determined by the **resolution** of the image and the **magnification** of what we look at.

In ecology, for example, changing the scale has a key role in understanding ecosystems and interactions between organisms. In a tropical rainforest, which is characterized by its layers (Figure 2.3a), our understanding of its ecosystems changes according to the scale we use. If we are within the forest and look at a specific layer, for example the predominant canopy layer (Figure 2.3b), we will see the large trees and a hugely diverse number of **fauna and flora**. However, at this scale we will not appreciate the complexity of other ecosystems and may miss many dynamic biological processes that cannot be seen until one undertakes deeper investigation. Looking at the forest floor layer (Figure 2.3c) will give a whole different experience of the rainforest. This layer only receives a very small amount of sunlight and therefore the fauna and flora found there are different from those found in other layers, as they must be adapted to live in such conditions.

There are many other examples where we experience such changes of understanding of nature depending on the scale we use to look at it.

The discovery of different microscopes has revolutionized our understanding of many biological processes or organisms.

Scientific discoveries depend on the available tools and technologies.

Light microscopes revolutionized science in enabling us to see cells, for example, and many other things as small as 500 nanometres (5×10^{-7} m). The later invention of **electron microscopes** offered us a whole new level of understanding. Cells can now be seen at a higher magnification, showing different organelles and enabling us to understand the metabolic reactions that happen inside them. The discovery of the **fluorescent microscope** has also helped scientists understand many processes by tagging different markers in cells with fluorescent labels and allowing us to see their location and follow their pathways through those cells.

EXTENSION

Explore this website and meet a scientist who is passionate about microscopy: www.sciencelearn.org.nz/resources/497-the-microscopic-scale

Watch this video about 'the wacky history of the cell theory' which looks at how natural scientists collaborated with physicists to use microscopes and make revolutionary discoveries: www.youtube.com/watch?v=4OpBylwH9DU

THE MICROSCOPIC SCALE

ACTIVITY: Zoom in!

ATL

- Information literacy skills: Make connections between various sources of information

Look at the second column of Table 2.1 showing an image of some bedbugs as you can see them on a bedsheet; they look like small black specks. If you get closer and look at one under a light microscope, you will see it looking like the image in the third column, which has more visible features. If you zoom in further under a scanning electron microscope (SEM, last column), you will see even more details on the surface, making the little insect look like a beast!

Copy and complete the examples in the table by finding how other things look to the naked eye, then get closer and search how they look under a light microscope and an electron microscope.

You may extend your research to other objects/organisms that are not listed in the table.

Hint

A scanning electron microscope (SEM) will give you the details of the surface structure and a transmission electron microscope (TEM) will give you the details of the inside structure of things. In your search, make sure you enter the name of the organism and the type of microscope in a search engine; for example: tardigrade under scanning electron microscope.

EXTENSION

Explore the history of the electron microscope: http://authors.library.caltech.edu/5456/1/hrst.mit.edu/hrs/materials/public/ElectronMicroscope/EM_HistOverview.htm

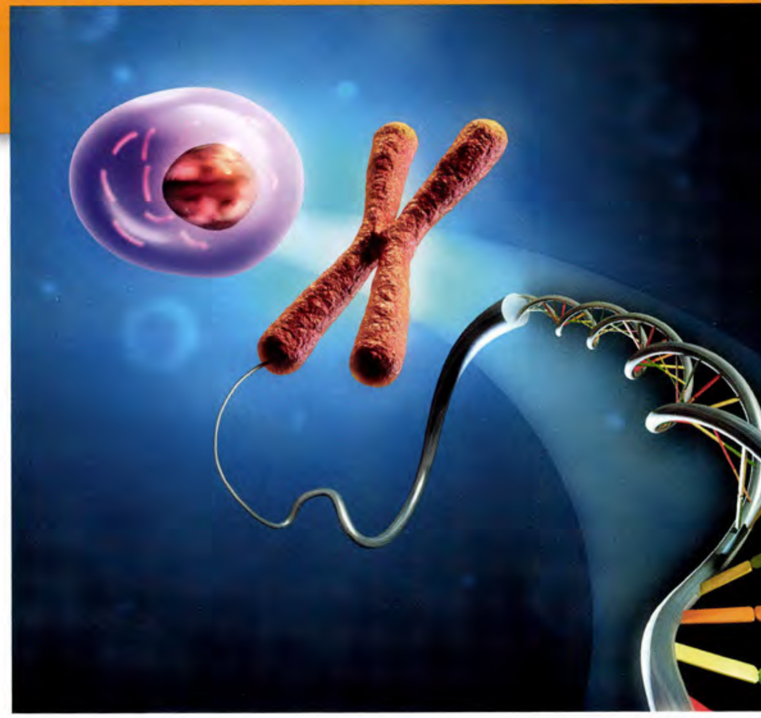
Links to: Design

Every scientific discovery was made using tools and instruments. Designing scientific instruments and apparatus requires careful consideration, so they are fit for purpose. Function is much more important than how these tools look. Designers of laboratory equipment develop and create tools that solve problems and advance scientific discovery. Find out more about these companies by searching: **laboratory equipment, design and scientific equipment**.

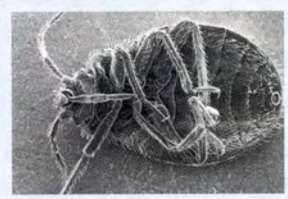
SEE–THINK–WONDER

Look at Figure 2.4, and consider the questions below. What do you **see**? What does it make you **think**? What does it make you **wonder**?

How does the DNA that measures up to 2 m when stretched fit inside a nucleus of 10 micrometres, inside a cell of 20–30 micrometres diameter?



■ **Figure 2.4** DNA inside the cell

Object/organism	As seen by the naked eye	As seen under a light microscope	As seen under an electron microscope
bedbug			
what's on your skin (skin bacteria): **staphylococcus epidermidis under light microscope** and **under electron microscope**			
coffee beans: **coffee beans under light microscope** and **under electron microscope**			

■ **Table 2.1**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

ACTIVITY: How does it fit inside?

ATL

- Information literacy skills: Collect and analyse data to identify solutions

Large natural structures can fit inside smaller ones because of special adaptations: DNA **supercoils** and folds around itself and around other proteins to make **chromatin** which then folds again to make chromosomes to fit inside the nucleus. The intestine increases its surface by having villi and the intestine itself folds tightly and is held together with **mesenteric tissue** to fit inside the abdomen.

Explore the scale of things by searching **scale and magnification** and using the following link: **http://learn.genetics.utah.edu/content/cells/scale/**

Move the slider in order to zoom in and see the things that fit inside each structure until you reach the smallest structure. Notice the scale box in the top left-hand corner; see how it changes as things get smaller. Record the structures and their sizes and **organize** from large to small.

Move the slider and zoom to the level of a red blood cell. Its actual size is 8 micrometres. In the top left-hand corner notice the scale shown as a square of 10 micrometre size. You could have figured out the real diameter of the red blood cell by measuring it using a ruler and plotting this measurement on the little squares within the 10 micrometre highlighted square. You will find that the red blood cell takes up eight small squares, meaning it is 8 micrometres.

Now **calculate** the size of the following structures:

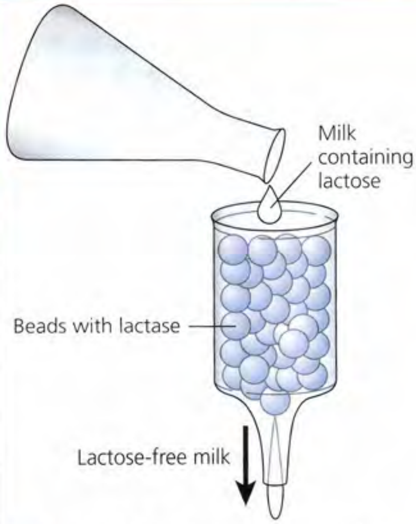
- **the length of the text 'Times regular, 12 point'**
- **the diameter of the blue nucleus inside the pink skin cell**
- **the length of the sperm cell (tail only).**

Assessment opportunities

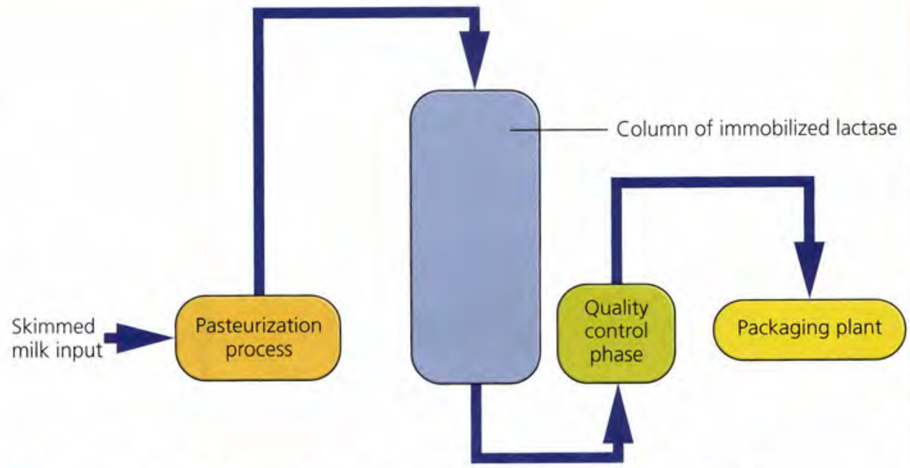
- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

SCALING IN BIOLOGICAL APPLICATIONS

Scale is not only a question of measurement and magnification. Scaling can also refer to the increase of quantities while maintaining the proportions. Scaling production can mean that we either increase the production of valuable products at a larger scale (scaling up) or we minimize the amount of substances needed to conduct tests (scaling down). Scaling up and down is key for many biological applications and processes such as the large-scale commercial production of laboratory-scale products. However, any commercial production must be tested on a small scale first before going to a large-scale production for commercial use. Small-scale productions may start in test tubes but then are scaled up in **bioreactors** to maximize the yield and increase the speed of production. For example, the production of lactose-free milk has helped many sufferers overcome their lactose intolerance and enjoy dairy products.



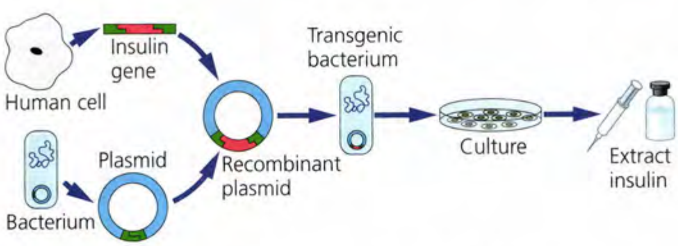
■ **Figure 2.5a** Laboratory-scale production of lactose-free milk



■ **Figure 2.5b** A bioreactor producing large-scale lactose-free milk

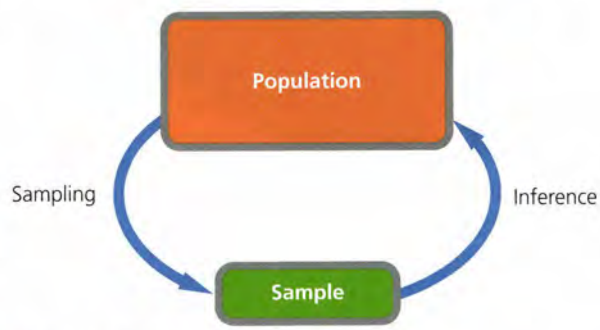
Production of insulin happens in the same way by scaling up from laboratory-scale products to commercial use. Modified **bacteria** that have been **genetically engineered** to produce human insulin are grown at large scale and the insulin protein is purified and sold commercially to help many diabetic patients worldwide.

Scaling down is just as important as scaling up. Sometimes there are processes which cannot be explored at their natural size and need to be looked at with a smaller scale to give an indication of what happens in the larger sample size. In ecology, for example, this concept is used very often to estimate population size. This is called **sampling**, where small samples of a whole are analysed as an indication of what happens in the full population. It would be nearly impossible to count every single individual of a species in the area of interest, but taking random samples in different areas will give a fair indication of the natural distribution of the species.



■ **Figure 2.6a** Production of human insulin

■ **Figure 2.6b** Growing these genetically modified bacteria at large scale in fermenters for commercial production



■ **Figure 2.7** Sampling

■ **Figure 2.8** Quadrat sampling in ecology

How are living organisms structured?

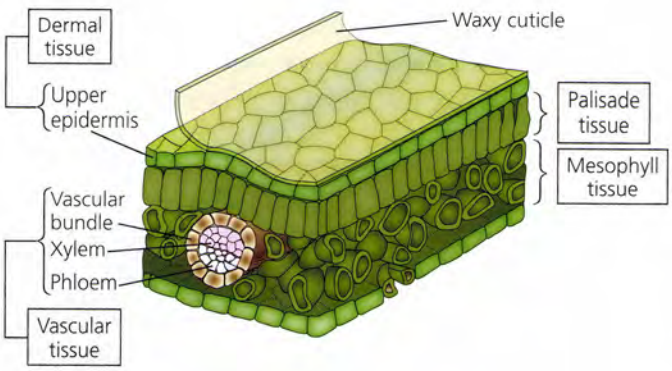
SEE–THINK–WONDER

Visit this website to see a diagram that shows the relative scale of some biological molecules and structures: **www.nature.com/scitable/content/the-relative-scale-of-biological-molecules-and-14704956**

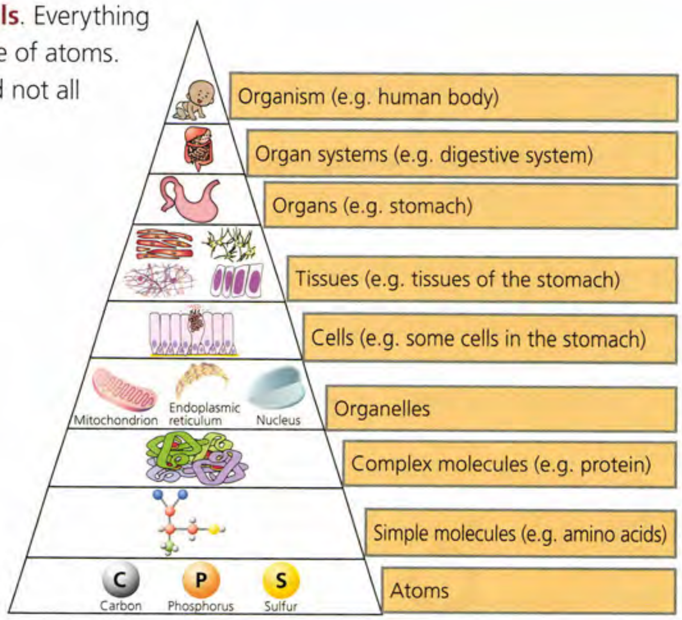
What do you **see**? What does it make you **think** about? What does it make you **wonder**?

Use scientific language to discuss the scale of the biological molecules and structures in the image.

Multicellular living organisms are usually made of organ systems that comprise various organs working together. Each organ is made of multiple tissues which are made of different smaller building blocks called **specialized cells**. Everything that is inside the cells is made of chemicals that in turn are made of atoms. Note, however, that not all living organisms are multicellular and not all multicellular organisms have this structural organization.



■ **Figure 2.9** The structural organization in a leaf showing various tissues



■ **Figure 2.10** Structural organization in the human body

Plants have a comparable structural organization to that of animals; they also have organs like roots, stems, leaves and flowers which are responsible for many functions like reproduction, food production and absorption. These organs are made of several tissue types like vascular, epidermal, parenchymal and meristem tissues. Just like in animals, these tissues are made up of numerous specialized cells (like palisade cells, cells of the phloem and xylem vessels and guard cells) that give them specific properties. A leaf, for example, is made of palisade tissue to perform photosynthesis, mesophyll tissue to allow gas exchange, vascular tissues consisting of phloem to transport sucrose around the plant and xylem to transport water from the roots to the leaves.

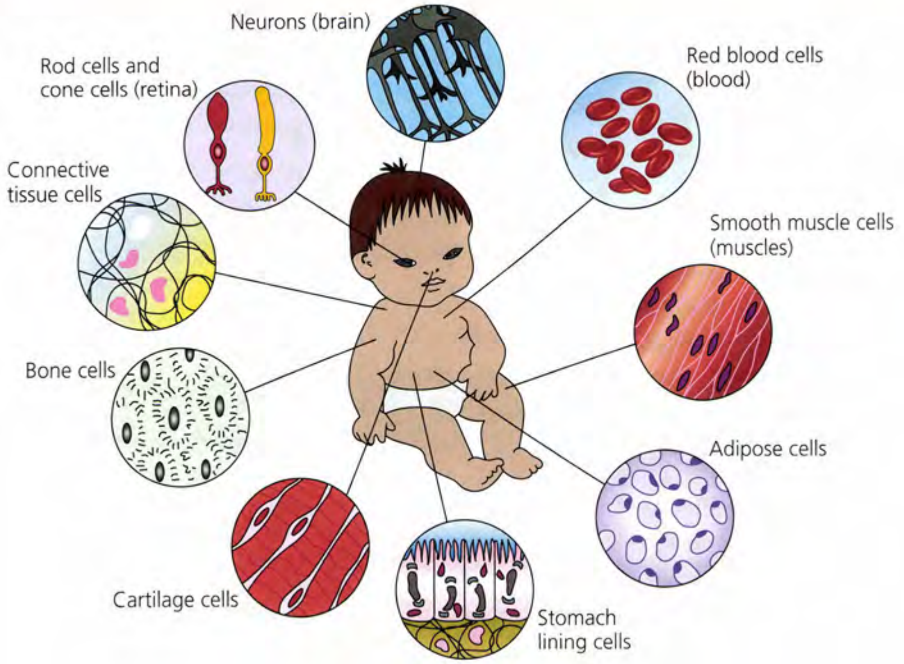
WHAT MAKES YOU SAY THAT?

Look at the structural organization of a leaf (Figure 2.9) and find corresponding organs or organ systems in humans with similar functions (Figure 2.10).

Which organ in humans is comparable to the dermal tissue? What makes you say that?

Which organ in humans is comparable to the mesophyll tissue? What makes you say that?

Which organ in humans is comparable to the vascular tissue? What makes you say that?



■ **Figure 2.11** The location of some specialized cells in the body

In humans, each **organ system** is made of a group of interacting organs that work together to form complex functional physiological systems which allow the body to perform specific functions. For example, the digestive system breaks down the food into nutrients that our body needs. Most organ systems work in synergy with other organ systems in order to fulfil their functions. The circulatory and nervous systems, for instance, work with all other organ systems to help them complete their actions. The **organs** of any organ system are fully differentiated parts of the body which are responsible for a specific function. For example, the stomach is only responsible for mechanical and chemical digestion of food and it cannot help the body to breathe or load the blood with oxygen; this is a function of another organ, the lung. Organs gain their functions from the various **tissues** that make them up. To take one example, the stomach has various tissues that work together to allow it to complete its digestive function: muscle tissue, epithelial tissue, secretory glands and connective tissue. Each tissue is again made of different types of specialized cells with a common origin, structure and function that work together to give the tissue its properties. For example, specialized cells in the blood like macrophages, lymphocytes and monocytes differentiate from **hematopoietic stem cells** to work together and give the blood its properties. Cells in a healthy tissue divide to replace dead ones and so maintain the function of the tissue. Sometimes cells start dividing uncontrollably and this can cause overgrowth and may lead to tumours.

DISCUSS

Is each organ made of the same cell type? Which organ system has the largest number of organs working together? Which organ system has the fewest number of organs working together? Which organ has the greatest diversity of cells? And which organ has the least diversity of cell types? Can you identify other organ systems that must work together in order to function?

ACTIVITY: How are we structured to function as well as we do?

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument; Revise understanding based on new information and evidence

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

Think of all the functions you can do and find what organized structures in your body are responsible for the function. Find the organ system then zoom in and find out what organs, tissues and specialized cells are involved. Conduct some research and complete Table 2.2 following the example row.

I can do this ...	What helps me do it? (organ system)	How does it work? (organs)	What is it made of? (tissues)	What gives it its properties? (some specialized cell types)
eat many foods to sustain myself	digestive system	• alimentary canal organs: mouth, oesophagus, stomach, small and large intestines • accessory organs: salivary glands, liver, pancreas, gallbladder	epithelial, connective, muscle and nervous	various epithelial cells, including secretory cells for glands, endothelial, hepatic, Kupffer, muscle and nerve cells

■ **Table 2.2** What makes our organ systems?

HOW CAN CELLS SUSTAIN THEMSELVES?

ACTIVITY: Equip a cell!

ATL

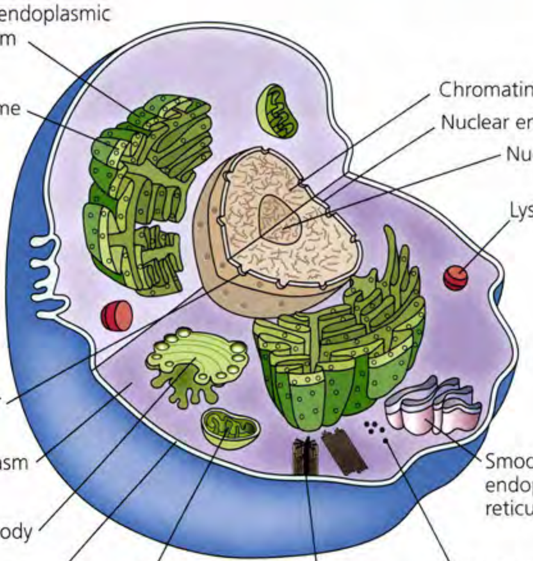
- Information literacy skills: Access information to be informed and inform others
- Critical-thinking skills: Use models and simulations to explore complex systems

We can understand the way that organelles work together to form a cell by thinking of a house analogy. In this activity you will build a model cell taking into account what a cell needs to sustain itself. How would you equip a newly built house? What facilities would you have to source from the outside and how would you divide the rooms for different functions? How does this compare to a cell? Would a cell need to source things from outside? Would it need compartments for different functions?

One way to approach this task is to think of a problem posed by a need for a function in the cell, then try to solve it by finding the organelle that is responsible for it. Use the following search terms to guide you: **functions of life, cell structure**. Use the empty house analogy to help you equip your cell. You can complete this activity on a poster made by hand or using software, or by making a 3D model using modelling clay or cardboard boxes, for example. Write a short description of your model including the type of cell and its functions then present your model to the class and receive feedback from your peers.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion D: Reflecting on the impacts of science.



■ **Figure 2.12** Organelles of an animal cell

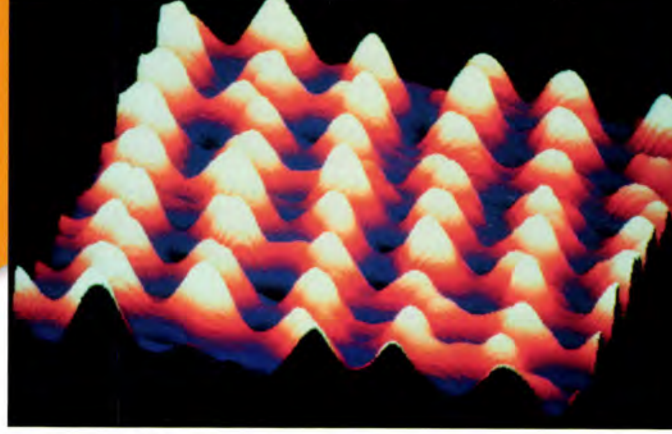
If we zoom in further inside cells we find compartments called **organelles**. However, the organelles alone would not be able to build living organisms. They must work together in an orchestrated manner to create a small sustainable block that acquires new characteristics, which then can act as a building block for more complex structures.

Each cell is isolated from the outside environment by a flexible plasma membrane that contains areas for entry and exit of materials to and from the cytoplasm. The cytoplasm provides the water needed for metabolic reactions to occur. The heritable genetic information that determines the shape and functions of the cell is packed in DNA and organized in chromosomes packaged in a designated area in the cytoplasm. **Prokaryotes** package their DNA in a designated location in the cytoplasm called a **nucleoid**, while **eukaryotes** package it in a nucleus. Proteins, which perform necessary functions in the cells, are made in the ribosomes from the code received from the nucleus. These proteins are sent inside **secretory vesicles** to the Golgi apparatus where they are modified and packaged before being transported or secreted outside the cell. The cell is always active and therefore needs energy which it produces in the mitochondria (in the form of **ATP**) by breaking down nutrients like glucose through the process of cellular respiration. Such metabolic reactions generate waste products which can be toxic to the cell. Therefore they need to be secreted outside the cell through the plasma membrane or get destroyed inside **lysosomes** which contain digestive enzymes.

EXACTLY HOW SMALL IS AN ATOM?

No doubt you will have realized by now that atoms are extremely small. Maybe you have even been presented with statistics like 'there are 500000 carbon atoms lined up in the width of a hair' or that 'one sheet of paper is about 500000 atoms thick' or 'there are more atoms in a glass of water than there are glasses of water in all the world's oceans'.

But how small is small? To attempt to understand the atomic scale it helps to put the size of an atom in a context that we are better able to understand. How does that then change our understanding of the objects and living things around us?



■ **Figure 2.14** A scanning tunnelling microscope image of the two-atom-thick lead film

SEEING IS BELIEVING

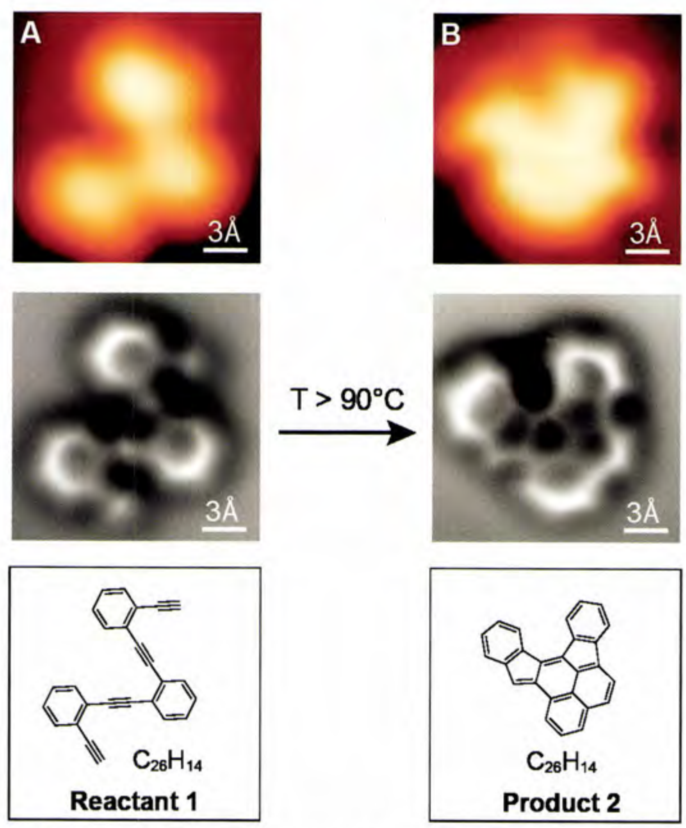
The tiny size of atoms has been the greatest obstacle to discovering ways to 'see' them. As we saw earlier in this chapter, this is impossible to do under even the most powerful light microscopes, which are only able to magnify objects that are larger than the wavelength of visible light; a typical atom is more than 10 000 times smaller. Our understanding of atoms, molecules and compounds started to change in the 1890s when X-rays were discovered. This led to a technique called X-ray diffraction or X-ray crystallography and, because of it, scientists were able to measure the size of atoms, the length of bonds and determine the structure of a huge range of materials.

■ **Figure 2.13** An X-ray crystallography machine; a crystal is held in place between a screen and a device which gives out X-rays

Developments in technology led to the creation of electron microscopes, in which a beam of electrons rather than a beam of light is shone at the sample. In the early 1980s, scientists were finally able to study the structure of the surface of an object, atom by atom, with the discovery of the scanning tunnelling microscope (STM).

Through both STM, and more recently atomic force microscopy (AFM), scientists have been able see and manipulate materials at their most fundamental scale: the atomic scale. An STM is able to pick up individual atoms one at a time and move them to create some of the smallest structures imaginable, which is necessary for the field of **nanotechnology** which deals with objects on a nanoscale.

The implications of being able to rearrange atoms on the surface of substances reach far and wide. Can we rearrange the atoms in charcoal to form diamonds? Can we use atoms of carbon, hydrogen and oxygen to create food?



■ **Figure 2.15** In 2013, scientists were able to capture (A) 'before' and (B) 'after' images of chemical reactions using non-contact atomic force microscopy

Using models

In this activity we will use a model to better understand the structure of the atom. The scales we use in science range from the very, very small to the very, very large, often making it impossible to physically see the objects we are studying. Models are, therefore, an extremely useful tool, allowing us to create a visual image of the object and making it easier to remember. As our understanding of science changes, models can be adapted to reflect changes in our theories.

WHAT IS AN ATOM?

ACTIVITY: Build an atom

ATL

- Critical-thinking skills: Use models and simulations to explore complex systems and issues
- Reflection skills: Develop new skills, strategies and techniques for effective learning

In this activity you will be building your own atoms using a simulation and exploring some of the features of the different sub-atomic particles. Some of this may already be familiar to you, some of it may be new, but use the activity to consolidate what you already know about the atom and build on your existing knowledge. Start by familiarizing yourself with the simulation you will be using.

- **Go to the following website:** http://phet.colorado.edu/en/simulation/build-an-atom
- **Press the 'Play' button to start the programme (you may need to download it first).**
- **Select the simulation called 'Atom'.**
- **Press the '+' next to 'Net Charge' and 'Mass Number' to maximize the two menus.**
- **Tick the box next to 'Stable/unstable' in the 'Show' section.**
- **Make sure your model is set to 'Orbits' not 'Cloud'.**
- **Become familiar with the controls and functions of the simulation by dragging the sub-atomic particles into and out of your atom. Observe what happens to the stability of the atom and its charge as you add and remove the different sub-atomic particles.**

When you feel you are ready to start the exercise, press the 'Reset All' button in the bottom right-hand corner. Answer the following questions, using the simulation to help you.

1 **State** which sub-atomic particles are present in the nucleus and which are not. Where are the latter located?
2 **State** which particles have a charge and **identify** their respective charges.
3 **State** which is the only sub-atomic particle that determines the type of atom (the element it is).
4 **State** the maximum number of electrons that can exist in the first 'orbit' (this is the shell or energy level).
5 **State** the maximum number of electrons that can exist in the second orbit.
6 **Describe** how you would create a neutral atom and give an example of one that you have created, **stating** how many of each sub-atomic particle is present.
7 **Describe** how you would create a stable atom and give an example of one that you have created, as well as an example of an unstable atom of the same element, **stating** how many of each sub-atomic particle is present in each.
8 **Create** three neutral, stable atoms, selecting any elements from hydrogen to neon in the periodic table. In each case **identify** the following information: number of protons, number of electrons and number of neutrons, all of which are provided in the top left-hand corner of the simulation screen. **Identify** the total mass of the atom (called the mass number and given in the 'Mass Number' box).
9 **Suggest** a relationship between the number of protons and number of electrons.
10 **Suggest** a mathematical equation for working out the number of neutrons in an element.
11 **Evaluate** your suggestions by testing them with two elements that cannot be created on the simulation. Work out how many protons, electrons and neutrons they should have and then check by researching it.

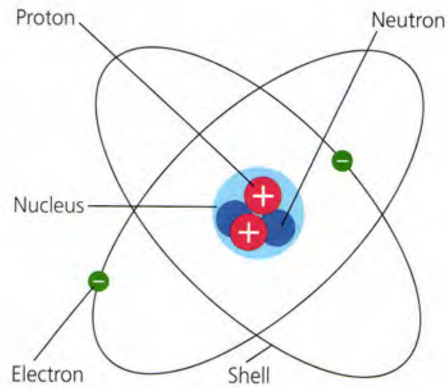
Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

Sub-atomic particle	Mass/kg	Mass (relative to proton)	Relative electrical charge
proton	1.6726×10^{-27}	1	+1
neutron	1.6749×10^{-27}	1	0
electron	9.1094×10^{-31}	0 (negligible)	−1

■ **Table 2.3** Summary of the masses and charges of the sub-atomic particles in an atom

From individual molecules, to human beings, to stars, everything is made of atoms. So what is an atom? Figure 2.16 shows the structure of an atom. An atom is a particle that consists of a central nucleus, which contains protons and neutrons, and electrons, which orbit the nucleus in **shells** (also known as **orbits** or **energy levels**). Protons, neutrons and electrons are called sub-atomic particles. The masses and charges of these sub-atomic particles are shown in Table 2.3.



■ **Figure 2.16** The structure of an atom

The number of protons in an atom is called the **proton number** or atomic number, and can be represented by the symbol Z. You will have noticed in the *Build an atom* activity that, as you changed the number of protons, you changed the type of substance or the element. This is because the number of protons in the nucleus of an atom is unique to a particular element. The proton number or atomic number of an element also represents its position in the periodic table; for example an element with 13 protons will also be the 13th element in the periodic table. There will be more about this in Chapter 3.

All atoms are neutral which means that they have no overall electric charge. Protons and electrons carry the same quantity of electric charge:

$$e = 1.6 \times 10^{-19} \text{ coulombs}$$

but with an opposite sign; their relative charges are often denoted as $+1e$ and $-1e$, respectively. For a neutral atom, the number of protons must be equal to the number of electrons as the positive charge in the nucleus is cancelled out by the negative charge of all the orbiting electrons. Neutrons do not contribute any charge to the atom.

The mass of a proton and that of a neutron is very similar, and the average mass of the nucleons is known as the **unified atomic mass unit** (u) where

$$u = 1.7 \times 10^{-27} \text{ kg}$$

Electrons are almost 2000 times lighter than these and are regarded as having a **negligible** mass. This means that the effective total mass of an atom lies in the nucleus and will be equal to the mass of the protons and the mass of the neutrons. The total mass of an atom expressed in atomic mass units is known as the **mass number** or **nucleon number** (and can be represented by the letter A).

mass number (A) = number of protons (Z) + number of neutrons (N)

EXPLANATION GAME

I notice that number of electrons = number of protons. Why is it that way?

I notice that mass number = number of protons + number of neutrons. Why is it that way?

I notice that number of neutrons = mass number – proton number. Why is it that way?

ELECTRON ARRANGEMENTS AND ELECTRON SHELL DIAGRAMS

The distribution of the electrons in the shells is fundamental to understanding the chemistry of the elements. Electrons fill their shells in order, starting with the one closest to the nucleus, because the energy of the shells increases with increasing distance from the nucleus. However, depending on how close to the nucleus a shell is, its size will vary, which in turn affects the number of electrons that it can hold.

The **electron arrangement** (also known as **electronic structure** or **electronic configuration**) describes the arrangement of the electrons in the shells. This is a series of numbers showing the total number of electrons in each shell, with each number separated by a comma. You need to be able to deduce the electron arrangement of the first 20 elements. The following tips will help you.

- You start by populating the shell closest to the nucleus.
- The first shell can hold up to two electrons.
- The second shell can hold eight electrons.
- The third and fourth shells can hold 18 and 32 electrons, respectively. However, at this level, you can regard them as 'filled' when they contain eight electrons (the reasoning for which you will discover when you study IB Diploma Chemistry).

Here are some examples of electron arrangements/electronic configurations:

- helium (Z = 2): 2
- carbon (Z = 6): 2,4
- potassium (Z = 19): 2,8,8,1.

The electron arrangement of an atom can also be shown diagrammatically. These are known as **electron shell diagrams**. Figure 2.17 shows the electron shell diagram for an atom of sodium and an atom of sulfur.

So how 'accurate' is our atomic model? We have already seen that the number of electrons in the third shell onwards isn't eight, but it is also worth noting that the shells are not always completely filled before occupying the next energy level and they are not really concentric rings at a fixed distance from the nucleus. Further, this model does not represent accurately how small the nucleus is compared to the rest of the atom and that the atom consists mainly of empty space. Our model is, therefore, an approximation that helps us explain the way things are for the moment, but which we will need to elaborate later as we learn more about atomic structure.

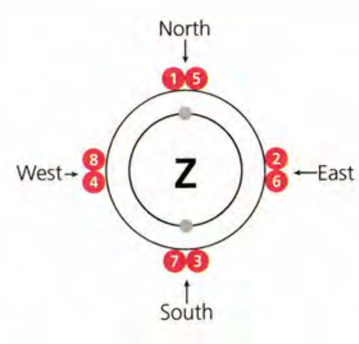
(a) Sodium 2,8,1

Points to note:

- The symbol of the element is placed in a circle in the middle of the diagram (representing the nucleus) and concentric rings are drawn around the nucleus to represent the shells.
- The electrons are then shown as dots or crosses on these rings.
- The two electrons in the first shell are placed opposite each other (top and bottom of the ring). The electrons in the remaining shells are placed successively at the north, east, south and west positions on the shells. If there are more than four electrons in that shell, pairs are formed as shown in Figure 2.18.

(b) Sulfur 2,8,6

■ **Figure 2.17** Electron shell diagram for an atom of (a) sodium and (b) sulfur



■ **Figure 2.18** How to allocate electrons to the second, third and fourth shells

ACTIVITY: Make an electron shell diagram display

ATL

- Collaboration skills: Help others to succeed; Take responsibility for one's own actions; Give and receive meaningful feedback

Materials

- **A periodic table**
- **20 A4 sheets of paper (white or coloured)**
- **Permanent pens**
- **Polystyrene balls (about 250, with a diameter of 1–2 cm)**
- **Glue**

Method

The aim of this activity is to create a display of the electron arrangements and electron shell diagrams for the first 20 elements of the periodic table.

1. In your notes, **list** the names and corresponding symbols of the first 20 elements in the order that they appear in the periodic table.
2. **Deduce** the electron arrangement of each element.
3. Select one of the elements and on an A4 sheet of paper in the landscape position **state** the element name, symbol and electron arrangement in the top right-hand corner.
4. **Construct** an electron shell diagram of the element, using polystyrene balls to represent the electrons and sticking them into their respective positions. Include the element symbol and place the electrons in the right positions by referring to Figure 2.18.
5. When you have finished, **select** a different element until the class has created models for all 20 elements.
6. Peer assess each other's work, double checking the symbol and electron arrangement, counting the total number of electrons represented in the electron shell diagram and ensuring that the electrons have been placed in the correct positions.
7. Display your models in your classroom or on a wall outside a science lab.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

ACTIVITY: Scale it up!

ATL

- Critical-thinking skills: Revise understanding based on new information and evidence; Use models and simulations to explore complex systems and issues; Identify obstacles and challenges

You have been invited to give a TED Talk on the topic of 'Using models in science'. For this task, you will create a script of the talk as well as a short video. You will be completing this task in groups of three and your audience will be other students your age.

The aim of your talk, 'Using models in science', is to explain the way in which science has been applied to address the problem of not being able to see atoms. Ensure your script makes reference to the following:

- **Describe why we create and use models of objects that are either too big or too small to see. Give examples, other than the atom, of where you have used models before in science.**
- **Analyse the advantages and disadvantages of using models.**
- **Evaluate whether these models help or hinder your understanding of scientific concepts.**

The aim of your video is to provide a more realistic model of the structure of an atom than that which appears in textbooks, using the analogy in the TED Talk video on page 33. This stated that if the nucleus was the size of a marble, the atom would be the size of a football stadium. You will need to select an area that is large enough to achieve this, so the video may need to be created in your own time at a park. Once you have determined by calculation the exact size of your model atom, have one member of your group represent the nucleus and one member represent hydrogen's lone electron in the first shell. The third member will be responsible for filming. Consider different ways to present the video; will you use a time-lapse of the 'electron' walking away from the 'nucleus'; will the 'nucleus' and the 'electron' try to communicate?

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion D: Reflecting on the impacts of science.

I USED TO THINK ... NOW I THINK ...

Watch this TED video for an alternative view of the atom: www.ted.com/talks/just_how_small_is_an_atom

Reflect on how the video has changed your thinking about the size of an atom and the size of the sub-atomic particles within it, comparing them to the size of the atom itself, by completing the following sentences:

I used to think ...

Now I think ...

HOW WAS THE STRUCTURE OF THE ATOM DISCOVERED?

The models created by scientists to understand the structure of the atom required creativity and imagination, as well as a critical approach by the scientific community, who must not accept scientific claims without adequate reason or evidence (as we saw in Chapter 1). The model of the atom that we use today is a great example of this; it is the result of the work of a number of scientists over hundreds of years, whose theories were not necessarily accepted immediately. You may have encountered some of these thinkers and their ideas in *MYP Sciences by Concept 2*, and in the activity *Unfolding the mystery of the atom* you will have an opportunity to review and synthesize this information.

The focus of this chapter so far has been on individual atoms: the structure of an atom; the atom of an element. But why focus on understanding something so small we cannot see it and that we will never come across in our everyday lives? Nothing we use and no living things are made of a single atom. To connect the properties of materials we encounter every day, we need to consider the ways in which atoms can form groups, such as those that form the copper wire we need for the conduction of electricity, or those that form the genetic material in our cells. Understanding the structure of an atom and the properties of the sub-atomic particles is fundamental to explaining how and why atoms bond to each other and the types of bonds they form. It is these bonds, formed at the atomic level, that allow structures to build up from single individual atoms to the billions and billions of atoms that comprise the everyday objects we use and that make up the parts of living organisms.

ACTIVITY: Unfolding the mystery of the atom

ATL

- Information literacy skills: Present information in a variety of formats and platforms
- Communication skills: Read critically and for comprehension
- Reflection skills: Consider content

As a class, brainstorm what a storyboard is. Come up with ideas as to what it should look like and what features would make a storyboard successful.

In this task you will **create** a cartoon storyboard explaining how scientists came to discover the structure of the atom. Choose the information that you want to include in the text box part of the storyboard carefully; it needs to be concise but detailed enough to convey the key points. **Annotate** your picture; this is how you can include extra information other than what is in the text box. Your storyboard will focus on the following scientists:

- **Democritus**
- **Dalton**
- **Thomson**
- **Rutherford**
- **Bohr**
- **Chadwick.**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

To what extent does our everyday experience limit our understanding of the very small and the very large?

602 200 000 000 000 000 000 000

Sextillions | Quintillions | Quadrillions | Trillions | Billions | Millions

■ **Figure 2.19** Avogadro's constant

As atoms are so small, it means that even tiny bits of matter are made up of a huge number of atoms. Rather than deal with these massive numbers, chemists use the term **mole** as a counting unit. One mole of a substance always has a specific number of atoms or molecules in it – specifically 6.02×10^{23}, known as **Avogadro's constant** (after the Italian scientist Amedeo Avogadro). So 1 mole of hydrogen atoms, for example, consists of 6.02×10^{23} hydrogen atoms.

Let's focus on a gold ring. An average gold ring has a mass of 10 g. One mole of gold has a mass of 197 g, which means that there are 6.02×10^{23} atoms in 197 g of gold. So how many atoms are there in a 10 g gold ring? Approximately 3×10^{22} atoms (or 30 sextillion atoms). Now that's a big number, but do we really understand how big?

ACTIVITY: Getting rich!

ATL

- Creative-thinking skills: Make guesses, ask 'what if' questions and generate testable hypotheses; Make unexpected or unusual connections between objects and/or ideas; Generate metaphors and analogies

We've just worked out that there are approximately 3×10^{22} gold atoms in a gold ring. Now imagine that instead of having 3×10^{22} atoms, you have 3×10^{22} one-cent coins. Now imagine that you are going to distribute these evenly to every person on Earth (assume the Earth's population is 7 billion). How much money do you think each person will end up with?

- Make an approximate **prediction**: will each person get hundreds, thousands, millions, billions of dollars? More or less than these numbers?
- Now **calculate** how much money each person would get.
- **Comment** on how close your prediction was to the calculated value.
- **Identify** other contexts where you use very large or very small numbers and **discuss** how this activity has changed your perception of the size of these numbers.
- Reflect on the extent to which your everyday experience helps and/or hinders your understanding of numbers such as Avogadro's constant.

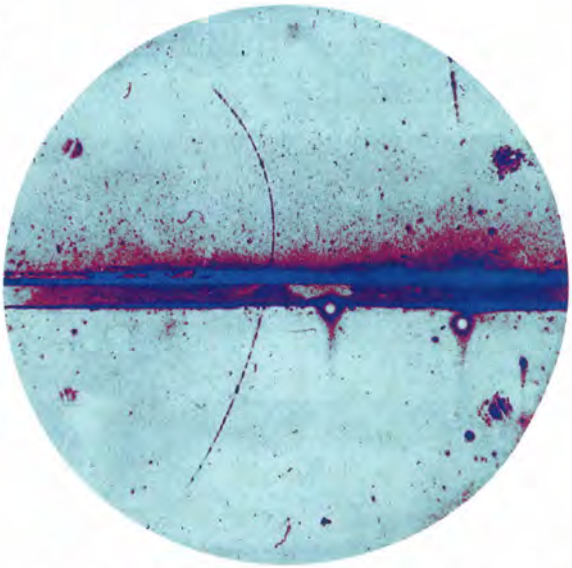
There are many different contexts in which Avogadro's constant can be presented to try to provide a better understanding of its size. Search for **Avogadro number analogies**; find another analogy in a context that you find useful and share this with a peer.

Assessment opportunities

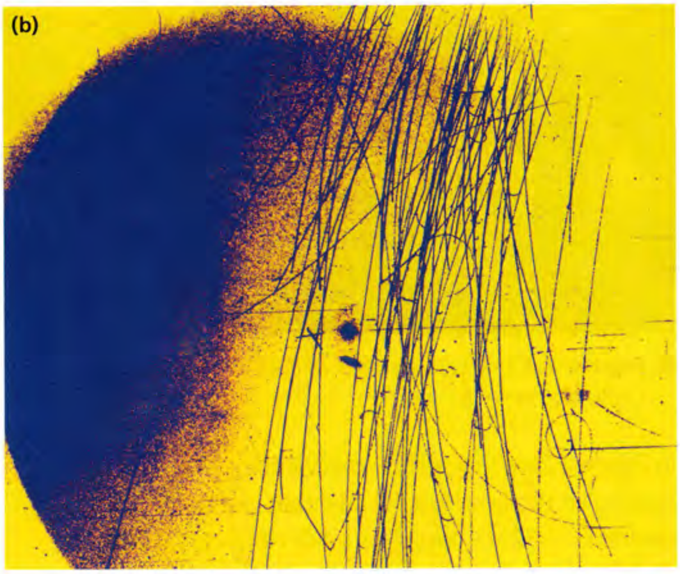
- In this activity you have practised skills that are assessed using Criterion C: Processing and evaluating

What building blocks do scientists use to describe non-living matter?

(a)



(b)



■ **Figure 2.20** (a) Physicist Carl D. Anderson's 1932 photograph of the trace made by a positron at California Institute for Technology; (b) image of a meson decay from the Nevis (Columbia University) cyclotron, 1950s

WHAT MAKES YOU SAY THAT?

Look at the images in Figure 2.20 and read their captions.

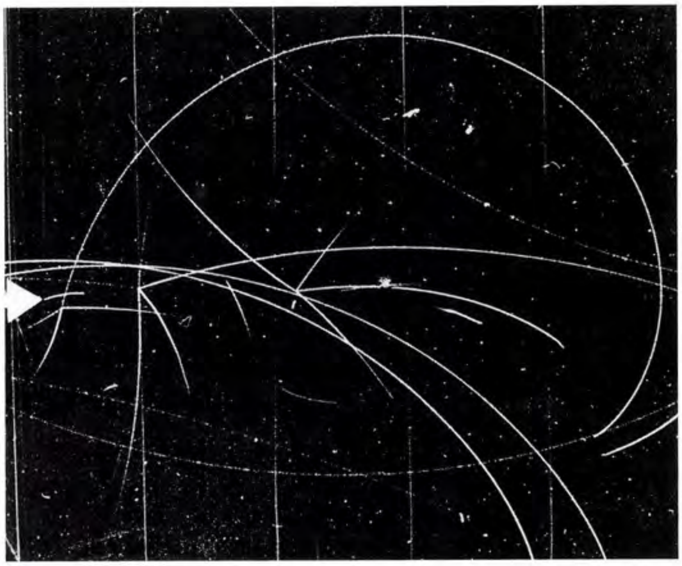
Individually, **think**: what is going on in these images?

In pairs, **discuss**: what makes you say that?

Your reaction to the images in Figure 2.20 might have been that they were works of abstract art; in fact, both these images have been used as artworks! But to a scientist their meaning is quite specific.

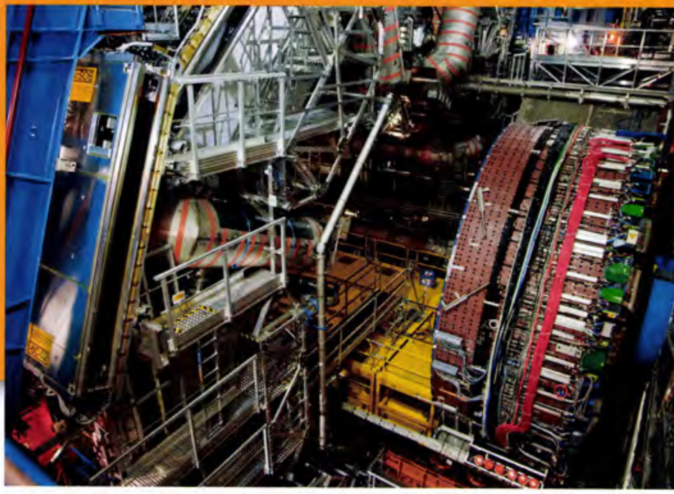
As you know it is barely possible to 'see' direct evidence of whole atoms using scanning tunnelling microscopes. In Figure 2.20 we are again observing only indirect evidence of the existence of two very strange particles. The images show the tracks produced in devices called cloud chambers or bubble chambers. The chambers contain gas or liquid that is at the very edge of a change of state. The introduction of any impurity, such as a particle, results in a trail of some kind. In cloud chambers, the trail is made from condensed vapour, like the con-trails left behind by jet aircraft high in the atmosphere. In bubble chambers, the trails consist of vapour formed by the particles as they travel through a superheated liquid – often liquid hydrogen.

Scientists place the chambers inside electromagnetic fields. This means that any particle carrying an electric charge which passes through the chamber will be affected; for example, it will be attracted to and repelled by one or other side of the chamber. The direction of the trail and the rate at which the particle is deflected gives information about the momentum the particle has (see Chapter 7).



■ **Figure 2.21** Ionization or vapour trails produced in a cloud chamber

What holds matter together?



■ **Figure 2.22** ATLAS experiment at the Large Hadron Collider, Geneva

In Figure 2.20a, the particle trail can be seen as a curve passing vertically across the chamber just to the left of centre. In 1932 US physicist Carl D. Anderson (1905–91) deduced from the trail that it had all the properties produced by a **beta particle**, which is an electron moving very fast through space, except for one: it had a *positive* electrical charge. In 1928 British physicist Paul Dirac (1902–84) had hypothesized using Einstein's theory of relativity that all particles of matter might have associated **antimatter** particles, with the same mass but the opposite electrical charge. Anderson had shown that this strange idea was a reality and in 1936 he was awarded the Nobel Prize for his discovery of an antimatter particle, the **positron**.

The complicated tangle of trails in Figure 2.20b is produced when a particle called a **meson decays** (changes) into other particles. Mesons were known at this point to have many of the properties of nucleons such as protons and neutrons, but the particles they changed *into* suggested that they themselves consisted of smaller particles of matter and antimatter joined together.

By the middle of the twentieth century, scientists felt that experimental evidence meant they were confronted with a 'zoo' of particles, all with different properties of charge and mass, and now even a whole new type of exotic antimatter. In this situation, scientists try to determine underlying patterns that suggest relationships between the particles.

If we are to make sense of this, we need to do a little fundamental physics ourselves. You may wish to refer to Chapter 4 of *MYP Sciences by Concept 3* to refresh your memories.

ACTIVITY: Feel the force – gravitation

ATL

- Critical-thinking skills: Interpret data; Draw reasonable conclusions and generalizations

■ **Figure 2.23** A force meter or 'Newton' meter (sometimes called a spring balance) uses a spring adjusted to stretch a known amount for a given gravitational force

Method

You will need:

- **masses of known quantity (for example 10 g, 50 g, 100 g)**
- **a force meter.**

Use the newton meter to find the gravitational force produced by different masses. In your experiment plan, clearly identify the variables that are:

- **controlled (changed, and kept the same)**
- **measured.**

Record your results clearly in a table, showing the units of measurement in the heading.

Analysis

Show your results on a graph with the *independent variable* on the x-axis and the *dependent variable* on the y-axis. (Unsure which variable is which? See Chapter 1.)

The points on your graph should appear to be in a straight line, although the line might 'wiggle' somewhat due to *scatter* in the points. What might have caused the scatter in the measurements?

Since the points appear to be so close to a straight line, we can probably make the assumption that the relationship between mass and force is *linear* – that is, *each mass gives the same increase in force.* We can then **draw** a 'best-fit' line through as many of the points as possible, or as close to them as possible.

Conclusion

State the relationship between mass and gravitational force.

Evaluation

Evaluate your results. How sure are you that your experimental data gave a reliable result (clue: what about that 'wiggle' and 'scatter')? How could you improve the reliability of the data?

◆ Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion C: Processing and evaluating.

THINK–PAIR–SHARE

Think about everything you know about the fundamental forces of gravitation, electricity and magnetism. Note the ideas down on a piece of paper as they occur to you.

In **pairs**, compare your ideas. **Share** with the class anything new you learnt from your partner.

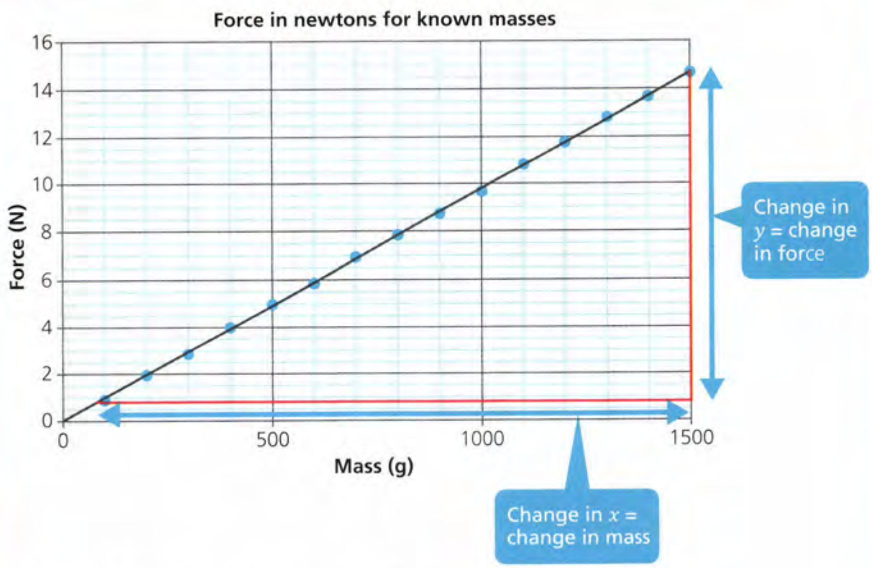
Finding the rate of change

Finding the slope or gradient of a straight line is a key skill in mathematics and enables us to deduce the equation of the line.

Using this straight line, we can now figure out the *relationship* between the mass and the force – that is, how much the force increases for each additional mass. We can do this by finding the gradient or slope of the line on the graph:

$$\text{gradient} = \frac{\Delta y}{\Delta x} = \frac{\text{change in } y}{\text{change in } x} = \frac{\text{change in force}}{\text{change in mass}}$$

One way to do this is to **draw** a right-angled triangle on the graph, as large as possible so that it encompasses the greatest possible range of results:



■ **Figure 2.24** Force in newtons for known masses

Use your graph to **calculate** the gradient of your line.

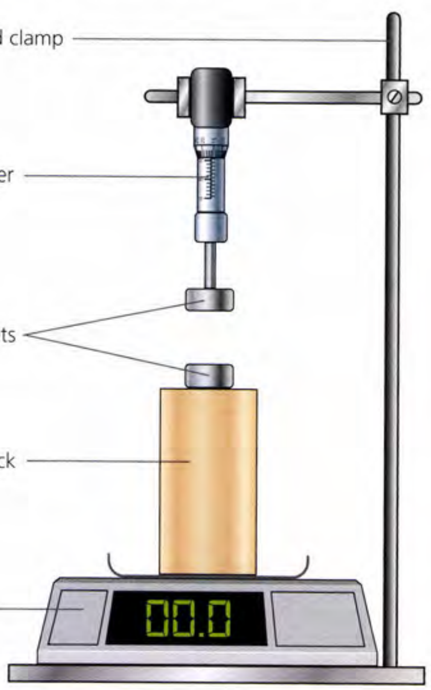
ACTIVITY: Feel the force – magnetism

ATL

- Critical-thinking skills: Interpret data; Draw reasonable conclusions and generalizations

In this experiment you will **measure** the variation of force with distance between two magnets.

Small neodymium magnets are very strong. They are usually disc shaped. One side of the disc is the 'north' pole of the magnet and the other is the 'south' pole.



■ **Figure 2.25** Experiment set-up to measure magnetic force

Equipment

You will need:

- **lab stand, boss and clamp**
- **a sensitive electronic top-pan balance**
- **two small neodymium magnets**
- **a block of non-magnetic material (wood, plastic or similar)**
- **some sticky tack, double-sided sticky tape or similar**
- **a modified Vernier micrometer or a similar screw assembly.**

Method

1. **The Vernier micrometer allows you to change the distance between the 'bits' with great accuracy. If possible, for this experiment your teacher or lab technician can remove the 'C'-shaped part to leave just one of the bits. If not possible, you can use any other kind of screw mechanism to position the magnet accurately.**
2. **Set up the apparatus as shown. Stick one of the magnets to the top of the block and the other to the bottom of the micrometer or screw.**
3. **BEFORE placing the micrometer in position in the clamp, press the 'TARE' or 'ZERO' button on the balance. This resets the balance reading to zero, compensating for the weight of the block and magnet.**
4. **Adjust the distance between the magnets using the boss and clamp until you *just* see a change in reading on the top-pan balance. If the reading increases, then the magnets are oriented to repel. If the reading decreases, the magnets are attracting each other.**
5. **Now use the apparatus to make measurements of the variation of the force between the magnets with distance.**
   - **What *range* of readings will you make?**
   - **What *interval* between readings will you use?** **(See *Reading a Vernier scale* on page 39.)**
6. **After taking one set of readings, flip one of the magnets around so that they are now interacting in the opposite way to before. Repeat your experiment, taking new readings.**

Results

Organize your readings in a suitable table, clearly showing the units of measurement.

Present your readings using a graph as before. Careful! Think carefully about your independent and dependent variables.

Interpret your results. **Identify** the pattern in the results. (See *Finding the fit* on page 42 to discover how to use a spreadsheet program to help with this.)

Conclusion

Summarize your results using this starter sentence:

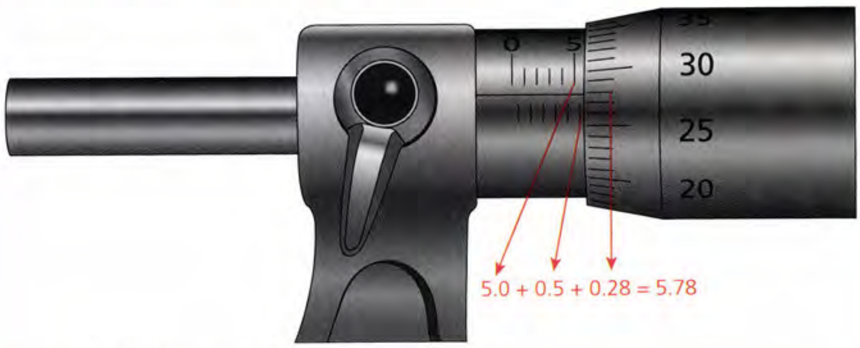
The force between two magnetic poles varies with distance in this way:

◆ Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion C: Processing and evaluating.

Reading a Vernier scale

A Vernier scale is a common method for reading quite precise measurements of distance. On the micrometer you will see two different scales.



■ **Figure 2.26** Vernier micrometer scale

The first (main) scale is on the barrel of the micrometer and measures in millimetres above the line, with gradations for 0.5 mm below the line. The second scale is on the rotating 'thimble' part and measures to an accuracy of 0.01 mm.

In the example shown in Figure 2.26, you would obtain the reading like this.

- Read the measurement on the barrel first. The edge of the thimble indicates the first part of the measurement on this scale. We can see the 5 mm mark, and we can also just see the next half-millimetre mark below the line. So the first part of the reading is 5.0 + 0.5 = 5.5 mm.
- Read the measurement on the barrel by looking for the gradation which is nearest to the centre line on the barrel. In this case the centre line of the barrel is closest to the line representing 0.28 mm.
- Add these measurements together for the total reading: 5.5 + 0.28 = 5.78 mm.

The newton gravitational force is properly known as the **weight** of an object.

weight = mass × gravitational field strength

$$W = mg$$

where g = 9.81 newtons per kilogram (N kg^{-1}) on Earth

Notice that the gravitational field strength, g, for the Earth is actually a little less than 10 newtons for every kilogram of mass.

Of course, we are used to thinking of our 'weight' in kilograms, however this is a little misleading. To a physicist, kilograms are a measure of **mass**, the amount of material in your body, and not of the gravitational force produced on it.

The different fundamental forces we experience do seem to behave in similar ways. We know that electrical and magnetic fields are very similar because magnetic fields are produced by the arrangement of electrons in certain kinds of atom, so scientists combine these into one force called **electromagnetic force**. Meanwhile, gravitation seems to share some properties of the other two (it is produced by the interaction between masses and its size depends on the multiplication of the masses) and it has the same $\frac{1}{r^2}$ relationship with distance as the force field fills the space around the mass. Yet gravitation does not – as far as we know – ever repel. Notice too the difference in the values of the constants in the equations. Electromagnetic forces tend to be *much* stronger over short ranges and gravitational forces are relatively weak; after all, it requires a mass the size of a planet to keep us down!

These intriguing similarities have led scientists to suspect there may be some other, underlying, mechanism which brings them all together; a 'unified' theory of force.

However, as we reduce our scale of measurement to the level of the nucleus, something goes wrong. Perhaps you noticed this problem already?

ACTIVITY: Comparing forces

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument

1 Copy and complete the table to summarize the properties of the forces you have explored. The column for electrical forces has been completed for you.

Properties	Electrical force	Magnetic force	Gravitational force
origin (caused by …)	electric charge		
SI unit of strength for origin	coulombs (C)		
values	positive (+) and negative (–)		
attracts?	yes		
repels?	yes		

Table 2.4 Properties of force fields

2 Interpret the information to compare and so evaluate the differences between the forces. Present your ideas using a visual Venn organizer with three interlocking circles.

In the circles, write the properties of the different forces from the table. If the forces share any properties, write those in the overlapping sections of the Venn circles.

Figures 2.27 and 2.28 show graphs for the variation of gravitational and electrical forces with distance.

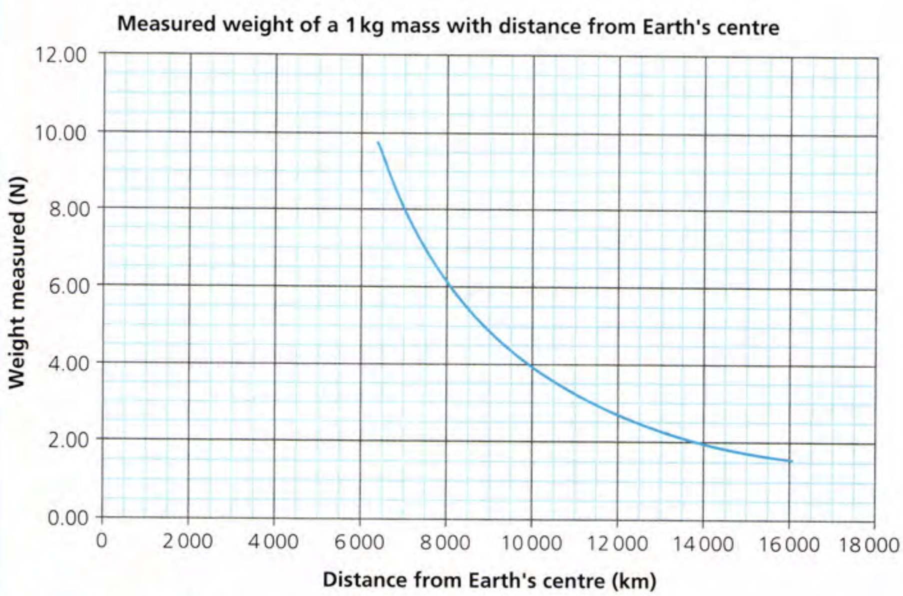
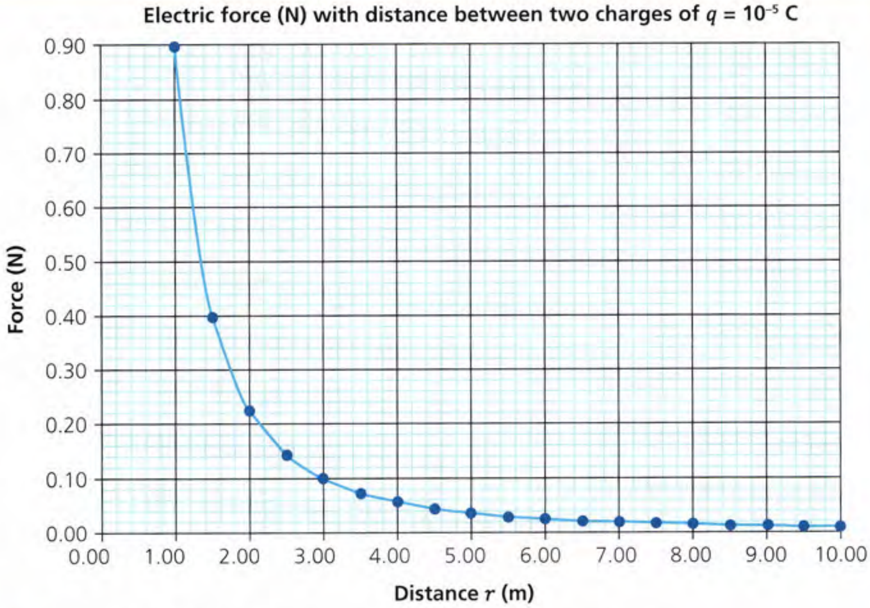


Figure 2.27 Weight of a 1 kg mass with distance from the Earth's centre



■ **Figure 2.28** Force between two charges with distance

3 **Compare these graphs with your results from the activity: *Feel the force – magnetism.* What do you notice about the way that all the forces vary with distance? Summarize your conclusions.**

The equations that describe the variation of gravitational and electrical forces are given below.

Newton's law of universal gravitation

$$F = G\frac{m_1 m_2}{r^2}$$

where F is the force between two masses, m_1 and m_2, separated by a distance r, and G is the *gravitational constant* = $6.67 \times 10^{-11}\,\mathrm{m^3\,kg^{-1}\,s^{-2}}$

Coulomb law of electrical force

$$F = k\frac{q_1 q_2}{r^2}$$

where F is the force between two charges, q_1 and q_2, separated by a distance r, and k is the *coulomb constant* = $8.99 \times 10^{9}\,\mathrm{N\,m^2\,C^{-2}}$ (in air)

4 **Compare the equations to each other and to the graphs. What do you notice?**

5 **Summarize your ideas about the forces produced by electrical, gravitational and magnetic fields.**

◆ Assessment opportunities

- In this activity, you have practised skills that are assessed using Criterion A: Knowing and understanding.

The protons in the nucleus hold a positive electrical charge, while the neutrons have no charge. The protons should be repelling each other and, since they are very close together indeed, this repulsion should be huge. Scientists could not explain why the nucleus of any atom bigger than hydrogen does not fly apart into its constituent nucleons. The only hypothesis they could propose was that there was *another* force acting *inside* the nucleus which was very strong, yet with very short range. Imaginatively, they named this the 'strong force'. Furthermore, investigation into the process of radioactive decay suggested that another force, less strong than the first, was acting; scientists called this the 'weak force'. Table 2.5 overleaf summarizes the known properties of all these fundamental forces.

Finding the fit

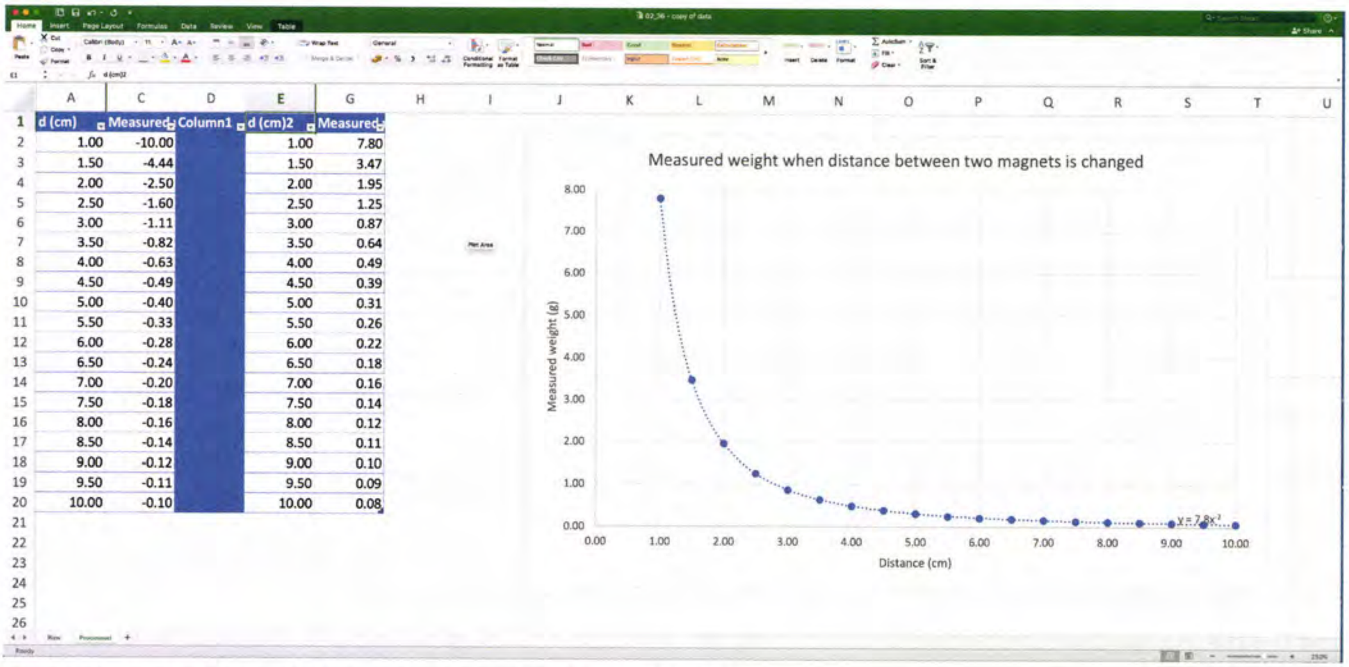
You can use a spreadsheet to plot the graph for your data (see Chapter 1 of *MYP Sciences by Concept 2* to refresh your memory). One way to find out the relationship between your variables is to use the 'trendline' function on the spreadsheet. The instructions opposite show how to do this in Microsoft Excel, but all spreadsheets will have a similar function. Alternatively, use the graph-plotting software recommended by your mathematics department!

Step 1: Once you have plotted the scatter graph, click on any of its points so that the whole curve is highlighted.

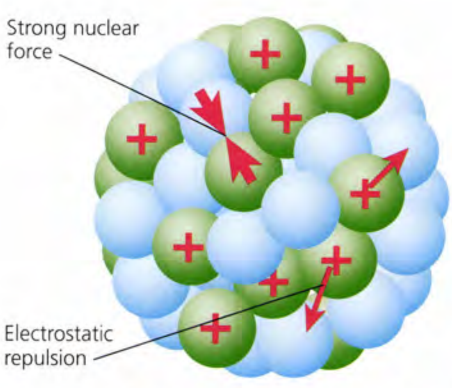
Step 2: Right-click on any of the dots. A menu appears. Select 'Add trendline'.

Step 3: In the right-hand panel, select the different trendline types until you find one that seems to fit the data well.

Step 4: To view the equation that describes this trendline, select 'Display equation on chart'.



■ **Figure 2.29** Screenshot of the spreadsheet in Microsoft Excel



■ **Figure 2.30** Forces inside the nucleus

Force	Relative strength (compared to strong nuclear = 1)	Distance of action/m
strong nuclear	1	<10^{-15} = less than size of a nucleus
electromagnetic	1/137 = 7.2×10^{-3}	infinite
weak	approximately 10^{-6}	10^{-18} = approximate size of a proton
gravity	6×10^{-39}	infinite

■ **Table 2.5**

What building blocks do scientists use to describe non-living matter?

CLASSIFYING THE PARTICLE ZOO

In 1961 US physicist Murray Gell-Mann (1929–) derived a classification system that used symmetry to suggest that nucleons and mesons might, in fact, all share another property. He suggested that the underlying component was even tinier particles, which he called 'quarks'. Gell-Mann's hypothesis was based on mathematical modelling, but in 1968 scientists at the Linear Accelerator at Stanford University, USA, bombarded nucleons with very high-energy electrons and the particle traces produced suggested that protons and neutrons did indeed have 'structure' *inside* them. This was taken as evidence of Gell-Mann's quarks.

Quarks are incredibly weird. While we may conceptualize them as tiny particles, they possess extraordinarily high energies and are held or 'contained' inside the tiny space of a single nucleon. They do not really behave like particles of matter as we might imagine them. Similar experiments at the HERA collider in Hamburg, Germany, by a team from Cornell University estimated that quark radii must be no larger than 0.43×10^{-18} m. At first it seemed that there were *two* kinds of quark, which were called 'up' and 'down', with electric charges of $+\frac{2}{3}e$ and $-\frac{1}{3}e$, respectively. This meant that to form protons and neutrons they had to combine in threes.

Nucleon	Charge/multiples of electron charge $e = 1.6 \times 10^{-19}$ C	Quark structure *u* = up, *d* = down
proton, *p*	$+1e$	*uud*
neutron, *n*	0	*udd*

■ **Table 2.6** Quark structure of nucleons

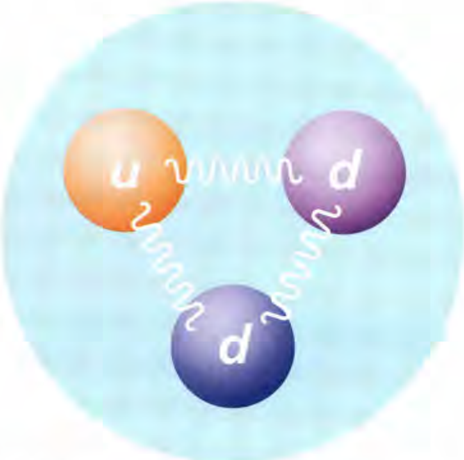
What was keeping the quarks in? Scientists realized that the strong force was responsible for holding the quarks together, but that this force field must be very different in properties from the other fundamental forces because it was confined to the scale of nuclei. It does not diminish with distance but rather *increases* with distance, similarly to the way an elastic band exerts a greater force the more it is stretched. Just as electromagnetic interactions are caused by a property we call 'charge', strong force interactions are given the attribute of 'colour'; nothing to do with the colours we observe, this is just a label for the property.

Links to: Language and literature

Poetry, literature, faith and the scientific imagination

Gell-Mann named his symmetrical particle scheme 'the eightfold way' in analogy with the importance of the number eight in the Buddhist faith. Similarly, he chose the name 'quarks' in reference to a scene in *Finnegans Wake* by James Joyce, when a barman makes a slip of the tongue and calls out 'Three quarks for Muster Mark!' instead of three *quarts*. In fact, both these discoveries were made almost simultaneously by others; the eightfold way by Yuval Ne'eman in Israel and the particle postulate by US physicist George Zweig. Zweig called his particles 'aces', but somehow Gell-Mann's quarks caught on! What role do other kinds of knowledge have as inspiration for new scientific ideas?

What other particles contain quarks? It turns out that mesons – the particles detected in the 1950s – exhibit similar structure to nucleons, but this time they only seemed to contain *two* quarks. Yet mesons are not detected with charge that has fractions of *e*. How can this be when we know that up and down quarks have charges that are multiple of $\frac{1}{3}e$? This, in turn, led scientists to postulate the existence of *antiquarks*, which are antimatter quarks with the same properties as their matter cousins but with the *opposite* charge.



■ **Figure 2.31** Nucleons are formed from quarks bound together by the strong force, which behaves like an elastic band!

ACTIVITY: Principal, I shrunk the science class! (the sequel)

ATL

- Creative-thinking skills: Consider multiple alternatives, including those that might be unlikely or impossible; Create original works and ideas; Use existing works and ideas in new ways
- Communication skills: Use appropriate forms of writing for different purposes and audiences
- Information literacy skills: Access information to be informed and inform others

Now that you have explored the Universe at different scales, return to the draft report you wrote at the beginning of this chapter.

Review your observations, and use this thinking routine to evaluate it:

I used to think …

Now I think …

What I would like to know now is …

Now finish your report, incorporating the new discoveries you have made.

Example mesons (there are many more …)	Charge	Quark structure u = up, d = down $\bar{u}$ = anti-up, $\bar{d}$ = anti-down
+ pion π^+	$+1e$	$u\,\bar{d}$
– pion π^-	$-1e$	$d\,\bar{u}$

■ **Table 2.7** Quark–antiquark structure of some mesons

What about electrons? Would they turn out to be made from something even smaller, such as quarks or antiquarks? In fact, not as far as we know; electrons appear to be fundamental and indivisible. They belong to a class of particles known as the **leptons** which also includes some other particles called muons and neutrinos.

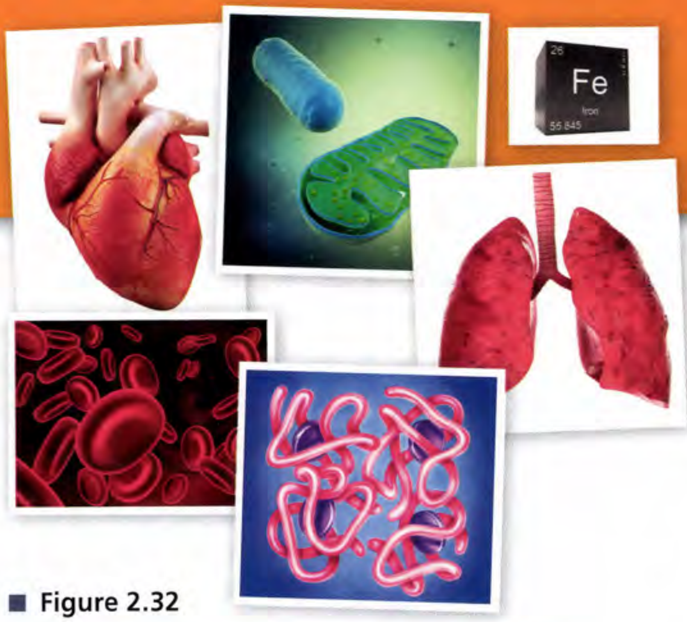
Quarks enabled scientists to establish a pattern to all the members of the 'particle zoo' which became known as the **Standard Model**.

<table>
<tr><td colspan="12">FERMIONS
(spin $s = \frac{1}{2}, \frac{3}{2}, \frac{5}{2}$)</td></tr>
<tr><td colspan="8">HADRONS
Consist of quarks and antiquarks</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">BARYONS
3 quarks</td><td colspan="4">MESONS
2 quarks</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">p</td><td colspan="2">n</td><td>π^+</td><td>π^+</td><td>K^+</td><td>many more …</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="8">QUARKS and antiquarks
Exist in three 'generations' according to energy state</td><td colspan="4">LEPTONS and antileptons
Fundamental particles</td></tr>
<tr><td colspan="2">u</td><td colspan="2">d</td><td colspan="2">$\bar{u}$</td><td colspan="2">$\bar{d}$</td><td>e</td><td>ν_e</td><td>$\overline{e}^+$</td><td>$\bar{\nu}_e$</td></tr>
<tr><td colspan="2">c</td><td colspan="2">s</td><td colspan="2">$\bar{c}$</td><td colspan="2">$\bar{s}$</td><td>μ^-</td><td>ν_μ</td><td>$\overline{\mu}^+$</td><td>$\bar{\nu}_\mu$</td></tr>
<tr><td colspan="2">t</td><td colspan="2">b</td><td colspan="2">$\bar{t}$</td><td colspan="2">$\bar{b}$</td><td>τ^-</td><td>ν_τ</td><td>$\overline{\tau}^+$</td><td>$\bar{\nu}_\tau$</td></tr>
<tr><td colspan="12">BOSONS
(spin s = 0, 1, 2, 3 …)</td></tr>
</table>

Strong force	Weak force	Electromagnetic force	*Gravity?*	Mass particle
Gluons g	$W^+\,W^-\,Z^0$	Photon γ	Graviton* G?	Higgs Boson H

* note that the graviton is a hypothetical boson for gravitational force and has not been detected

■ **Table 2.8** The Standard Model organizes the particle zoo into categories. The different categories of particle interact using different fundamental forces and are broadly classified according to a property named 'spin'. The fundamental forces are in turn transmitted by different 'force exchange' particles called *gauge bosons*.



■ **Figure 2.32**

SOME REVIEW PROBLEMS TO TRY

1 **Organize** the structures in Figure 2.32 on a size scale from the smallest size to the largest size (the images are not drawn to scale). Use scientific knowledge to support your answer.

2 **Describe** the relationship between the different levels of the structural organization in humans: cells, tissues, organs, organ systems, organism.

3 a **Deduce** the electron arrangements of the following elements:
   i helium
   ii oxygen
   iii potassium.
   b **Draw** the electron shell diagram for each of the elements in part (a).
   c Figure 2.33 shows the electron shell diagram a student drew of a fluorine atom. **Describe** why the diagram is incorrect.

■ **Figure 2.33**

   d Wherever you look, you will find very similar models of the atom. **Analyse** and **evaluate** how accurate this model is compared to the true structure of an atom, and how useful it is as a model.

Reflection

In this chapter we have looked at the scale of things and **organized** different structures from their biggest components to the smallest. We **compared** the scale of living and non-living things and inquired about the smallest particles that build them up. We **outlined** the similarities between the structural organization of plants and animals. We **summarized** the hierarchy of this structural organization and **discussed** the role of each structure to ensure the sustainability of organisms. We have **described** the structure of the atom, **defining** key terms such as atomic number and mass number, and **described** the sub-atomic particles in an atom and within nucleons. We **described** the arrangement of the electrons and **summarized** how forces act on matter of different types. We have used models and simulations to better understand the atom and **outlined** the work of key scientists in unfolding the mystery of the structure of the atom. Finally we have used analogies to **comment** on our understanding of the scales involved when dealing with individual atoms.

Use this table to reflect on your own learning in this chapter					
Questions we asked	Answers we found	Any further questions now?			
Factual					
Conceptual					
Debatable					
Approaches to learning you used in this chapter	Description – what new skills did you learn?	How well did you master the skills?			
		Novice	Learner	Practitioner	Expert
Learner profile attribute(s)	Reflect on the importance of being open-minded for your learning in this chapter				
Open-minded					

3 How do we organize the natural world?

We **develop our understanding** of the natural world by **discovering patterns** and **identifying relationships**, **organizing our knowledge in new ways**.

SEE–THINK–WONDER

Look at Figure 3.1. What do you **see**? What does it make you **think**? What does it make you **wonder**?

CONSIDER THESE QUESTIONS:

Factual: What is the periodic table? How are characteristics of living things used to classify them?

Conceptual: How do scientists use trends and patterns?

Debatable: To what extent does classification help or restrict our understanding of new information? How have technological advances affected our models of the world?

Now **share and compare** your thoughts and ideas with your partner or with the whole class.

IN THIS CHAPTER, WE WILL ...

- **Find out** how patterns in form enable scientists to identify relationships in the natural world.
- **Explore** how those patterns and relationships have enabled scientists to organize living and non-living matter in different ways.
- **Take action** to explore how classification is important in the worlds of medicine and pharmaceuticals.

These Approaches to Learning (ATL) skills will be useful ...

- Communication skills
- Collaboration skills
- Information literacy skills
- Critical-thinking skills
- Creative-thinking skills
- Transfer skills
- Media literacy skills

Assessment opportunities in this chapter:

The activities in this chapter will help you develop and evaluate your learning in these MYP Sciences learning objectives:

- **Criterion A:** Knowing and understanding
- **Criterion B:** Inquiring and designing
- **Criterion C:** Processing and evaluating
- **Criterion D:** Reflecting on the impacts of science

■ **Figure 3.1** Fractals show how patterns can help us understand complexity

KEY WORDS

category	formulae
classify	function
form	property
formula	

We will reflect on this learner profile attribute …

- Thinkers – how have the patterns and relationships that scientists discovered in nature changed the way we think about the world?

Did the image make you think of natural forms, perhaps a seashell or a plant? In fact Figure 3.1 is a computer-generated image of a special kind of mathematical function called a **fractal**. The image looks very complex, but is produced by repeating the same mathematical operation over and over again. The fact that fractals produce very complex patterns from relatively simple but recurring functions reflects the way in which the complexity of the natural world can be understood more easily when we identify underlying patterns and relationships. In this chapter, we will explore two very important scientific patterns that have enabled us to understand the complexity of living and non-living matter.

What is the periodic table?

Symbol	English name	Origin of symbol
Ag	silver	Latin *argentums*
Au	gold	Latin *aurum*
Cu	copper	Latin *cuprum*, from 'Cyprus'
Fe	iron	Latin *ferrum*
Hg	mercury	Greek *hydrargyrum* meaning 'silver water'
K	potassium	Arabic *qalay*, which in Latin is *kalium*
Na	sodium	Latin *natrium*
Pb	lead	Latin *plumbum*
Sb	antimony	Latin *stibium*
Sn	tin	Latin *stannum*
W	tungsten	German *wolfram*

■ **Table 3.1** Elements with symbols that are not consistent with their English names

THE MODERN PERIODIC TABLE

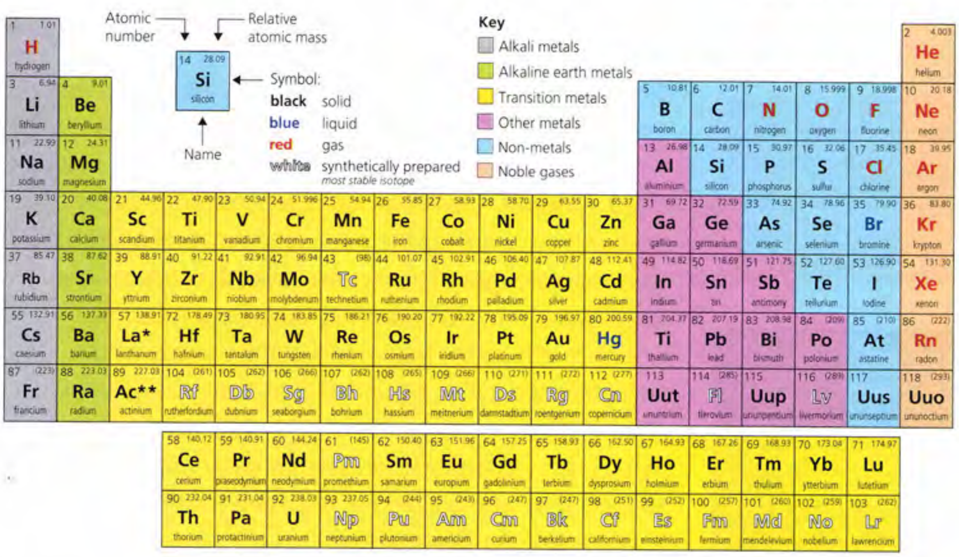
The modern periodic table is a tabular arrangement of the elements from which all matter is created, organized by increasing atomic number, Z. Each element is represented by a chemical symbol; rows of elements are called periods, while columns are called groups.

Using symbols

John Dalton was the first scientist to use symbols to represent the elements (Figure 3.3), although earlier mystical thinkers, now called **alchemists**, used a system of astrological symbols to describe the few substances they knew. Dalton understood that atoms could combine only in whole number ratios. By using symbols to represent the individual atoms in a substance, he could represent compounds as combinations of the symbols of the elements that comprised them, essentially coming up with what we now call 'chemical formulae'.

The main disadvantage of Dalton's symbols was that there was no logical order to them, which made them very hard to remember. In 1813–14, a new set of symbols was published by the Swedish scientist Jöns Jakob Berzelius. Inspired by Carl Linnaeus' classification system for living things, Berzelius gave each of the 47 elements known at the time a symbol based on the element's Latin name. He also went on to derive symbols for compounds. The system was hated by Dalton and initially rejected by the scientific community but was accepted by the mid-1800s and is still largely in use today.

An element's symbol may consist of one uppercase letter or two letters, uppercase for the first and lowercase for the second. While the symbols are based on the element's Latin name, it is not unusual for the symbol to also represent the English name as the English language has roots in Latin. There are, however, a few exceptions, as shown in Table 3.1.



■ **Figure 3.2** The modern periodic table (* and ** La and Ac are displayed in group 3 but belong to the lanthanoid and actinoid groups at the bottom of the table, respectively)

■ **Figure 3.3** Dalton's 36 symbols of the elements, as presented in *A New System of Chemical Philosophy*, 1805

Many element names find their origin in ancient myths including Greek and Roman gods, and a number of names have specific meanings when translated from the classical languages of Greek and Latin. This is because in the eighteenth and nineteenth centuries, science was considered more of a hobby, and therefore only practised by people from the upper classes of society who were educated in these languages.

ACTIVITY: Elemental games

■ ATL

- Communication: Use and interpret a range of discipline-specific terms and symbols; Use intercultural understanding to interpret communication
- Creative-thinking skills: Use brainstorming and visual diagrams to generate new ideas and inquiries; Make unexpected or unusual connections between objects and/or ideas

In this activity you will familiarize yourself with some of the elements in the periodic table and their symbols.

1. **Identify** elements that have been named after:
   a. parts of the Solar System
   b. countries or continents
   c. places
   d. scientists.
2. Use the following website to **identify** three elements whose names are from mythical beings: www2.ucdsb.on.ca/tiss/stretton/database/element_origins.html
3. Use the same website to find the meanings of the names bromine, dysprosium and technetium, and then find out a little about each element to **explain** why they were given these particular names.
4. In June 2016, the last four elements in the periodic table were assigned names. Research the origin of their names and **explain** how they conform to IUPAC guidelines for naming new elements, set out in the blue box below.
5. Challenge yourself to write a small sentence or phrase with element symbols, for example: tellurium, actinium, hydrogen, erbium, sulfur, potassium, nobelium, tungsten, nitrogen, oxygen, thorium, iodine, nitrogen = TeAcHErS KNoW NOThIN.

◆ Assessment opportunities

In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

▼ Links to: Language and literature

Language acquisition

The symbols of the elements were a new international scientific language. As you carry on through MYP Sciences, you too will become more and more familiar with this language. If you speak multiple languages you are likely to recognize the symbols of some of the elements and even be able to translate the meanings of some element names.

IUPAC guidelines

The guidelines for the naming of elements can be found at:

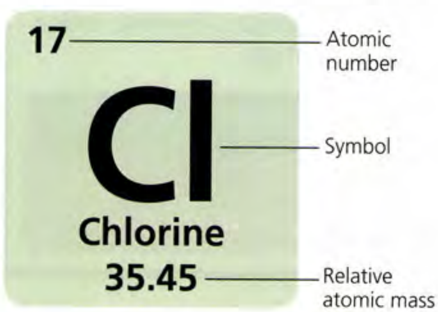
https://iupac.org/iupac-is-naming-the-four-new-elements-nihonium-moscovium-tennessine-and-oganesson/

Exploring the periodic table

You can explore the elements of the periodic table further using the many interactive periodic tables available online: search **royal society chemistry periodic table**, **TED periodic videos** and **interactive periodic table** to further explore its properties.

In Chapter 2 we discussed how elements are made up of identical atoms and that atoms themselves consist of protons, neutrons and electrons. The number of each sub-atomic particle present in the atom of any element can be determined simply by looking at the periodic table.

Select any element in the periodic table and have a look at the information provided for it more closely. You will notice its symbol, its name and two numbers, which are different except in the case of hydrogen where they are both 1. The smaller of the two numbers is always the atomic number, or proton number; this is also equal to the number of electrons present in an atom. The larger number represents the mass of the atom (protons + neutrons). You have learnt that to calculate the number of neutrons, you subtract the proton number from the mass number; but hang on a minute, most of the larger numbers in the periodic table are decimals! That means that we would have 'bits' of neutrons, which can't be possible.



■ **Figure 3.4** Chlorine, as shown in the periodic table

Atoms of a particular element can exist with different numbers of neutrons. Chlorine (element 17), for example, can exist with 17 protons, 17 electrons and 18 neutrons, giving it a mass number of 35, or with 17 protons, 17 electrons and 20 neutrons, giving it a mass number of 37. The atoms with a mass of 35 and 37 are **isotopes** of the element chlorine. Isotopes are atoms of the same element (so with the same proton number) with a different number of neutrons, hence different mass number. In order to account for the natural existence of a mixture of isotopes of an element, the larger number in the periodic table is the average mass of all of the isotopes of the element, taking their natural abundance into consideration. It is called the **relative atomic mass (RAM)**, shown by the symbol A_r.

The mass of each element is compared to a standard – the mass of one-twelfth of the mass of an atom of the carbon-12 isotope. So if helium has a mass of 4, its mass is $\frac{4}{12}$ of the mass of a carbon-12 isotope.

The first 92 elements in the periodic table are known as natural elements. This is because all of the elements up to and including uranium were created in stars in a process called **nucleosynthesis**. This process will be explored further in Chapter 10. The remaining elements, referred to as **transuranic** elements, are all extremely unstable as they decay radioactively and are usually synthesized in a laboratory.

EXTENSION

Find out more about how and why scientists came to choose carbon-12 as their reference atom for relative atomic mass.

HOW IS THE PERIODIC TABLE ORGANIZED?

Creating our modern periodic table

The periodic table you will most likely see displayed in your school laboratory is not the only periodic table that exists. No matter what the particular arrangement of elements chosen for a particular periodic table, they all have one thing in common. The clue is in the name ...

In this section we will look at how we arrived at the structure we are familiar with today and why it is significant.

ACTIVITY: Re-enacting the development of the periodic table

ATL

- Transfer skills: Inquire in different contexts to gain a different perspective
- Communication skills: Use a variety of media to communicate with a range of audiences; Read critically and for comprehension; Paraphrase accurately and concisely
- Collaboration skills: Delegate and share responsibility for decision-making; Help others to succeed; Encourage others to contribute; Give and receive meaningful feedback

Your task today is to work in groups to **create** a 3-minute TV programme about the development of the periodic table that is suitable for an audience of students who are one year younger than yourselves.

The roles

Each member of the group will take on a role.
The roles are:

1. **Interviewer**
2. **John Dalton (1766–1844)**
3. **Johann Döbereiner (1780–1849)**
4. **John Newlands (1837–98)**
5. **Dmitri Mendeleev (1834–1907)**
6. **Paul-Émile Lecoq de Boisbaudran (1838–1912)**

How to begin

- **Decide which role each group member will take on.**
- **Research the interviewees together to find out how their work contributed to the development of the periodic table. Identify key points that should come across in the interview and turn these into one or two questions that the interviewer can ask. Create flashcards with the answers that each scientist would provide to these questions.**
- **Work with the interviewer so that they understand what they need to ask each interviewee, making sure you explain the significance of the question with regards to the development of the structure of the periodic table.**
- **Think about how you can make your presentation resemble an actual TV programme as closely as possible and about how you can make it interesting to watch.**
- **After each presentation, give meaningful feedback to the group that presented, identifying two aspects of their presentation that you enjoyed and one that could be improved.**

Assessment opportunities

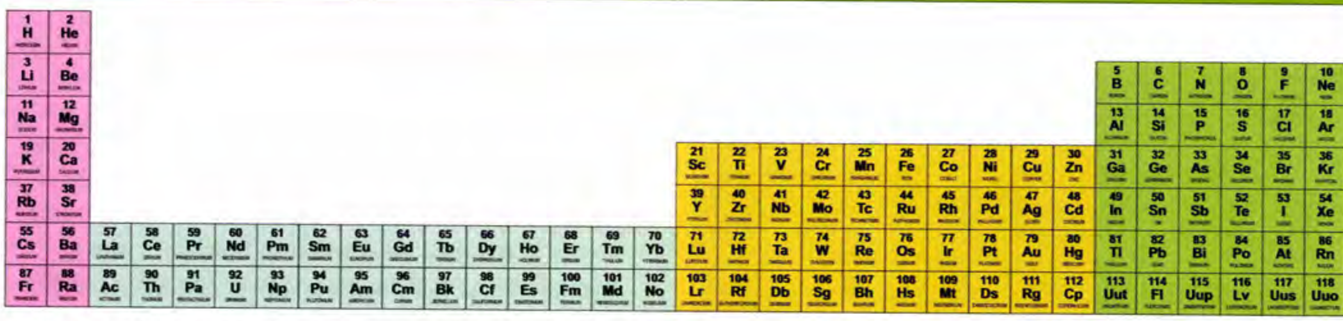
- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding and Criterion D: Reflecting on the impacts of science.

MEET A SCIENTIST: DMITRI MENDELEEV

Mendeleev is the most celebrated scientist when it comes to the periodic table. He excelled at the university of St Petersburg; he also worked in Paris and Heidelberg (the latter under Bunsen – of the Bunsen burner), where his work on the elements really took off and led to the development of the periodic table. But it is worth mentioning that in 1869 when Mendeleev published his periodic table, another chemist, Julius Lothar Meyer (who had also worked under Bunsen), published his own independently; in fact, the two scientists shared a prestigious prize called the Davy Medal in 1882.

There was no doubt how **knowledgeable** Mendeleev was when it came to the elements, which fuelled the self-confidence and self-belief needed to not only predict the existence of undiscovered elements, but even to predict their properties. On the other hand, his work did not lack mistakes and a huge amount of work took place between Mendeleev's 1869 periodic table and the one we have today. Later on in his life, Mendeleev's arrogance led to his refusal to believe in atoms, as well as other things that couldn't be seen like electrons and radioactivity.

Figure 3.5 A monument to Dmitri Mendeleev, with his 1869 periodic table on the wall behind, in St Petersburg, Russia



■ **Figure 3.6** The long form periodic table. It is worth noting that the final resting place of La and Ac is currently under debate; while traditionally displayed in group 3, under Sc and Y, more recent debate has stipulated that the whole lanthanoid and actinoid group should come before group 3, and that this actually consists of the elements Sc, Y, Lu and Lr.

The modern periodic table is based on the 1869 periodic table of Dmitri Mendeleev. While Mendeleev's table arranged the elements in order of their atomic mass, the modern periodic table is based on increasing atomic number. Arranged in this way, elements in the same group have similar general properties and, moving from left to right across the periodic table, changes in the properties of the elements can be seen. The names of the key groups in the periodic table in Figure 3.2 are:

- group 1 – alkali metals
- group 2 – alkaline earth metals
- group 17 – halogens
- group 18 – noble gases
- the elements in the rectangular block that sits between group 2 and group 13 are called the transition metals
- the two rows at the bottom of the periodic table are called the lanthanoids and actinoids, respectively. These should sit in the top part of the periodic table but this would make the table long and less easy to use so they tend to be removed and kept separate. A 'long' periodic table is shown in Figure 3.6.

The majority of elements are metals (found on the left and in the centre of the periodic table). Other elements are classified as non-metals (on the right, with the exception of hydrogen, which is either placed on the left or separate to the other elements in the centre) and metalloids (forming a staircase between the metals and non-metals). Metals can be distinguished from non-metals by their physical properties. These are summarized in Table 3.2.

The metalloids show physical properties of both the metals and non-metals.

Physical properties of metals	Physical properties of non-metals
solids (except for mercury which is a liquid at room temperature)	solids or gases (except for bromine which is a liquid at room temperature)
shiny	solids are dull
good conductors of heat and electricity	non-conductors of heat and electricity
malleable (can be hammered into shape without breaking)	solids are brittle
ductile (can be drawn into long thin wires)	
usually hard but can vary	solids are soft
hard metals are sonorous (make a ringing sound when struck)	
usually high melting and boiling points but can vary	low melting and boiling points

■ **Table 3.2** Summary of the differences in the physical properties of metals and non-metals

■ **Figure 3.7** Some common metals

EXTENSION: GOING FURTHER

As we saw in Table 3.2, non-metals exist in either the gaseous or solid state at **standard ambient temperature and pressure (SATP)** (25 °C and 100 kPa). Hydrogen is a gas at SATP and a gas in space, so can you imagine the existence of a black flowing river of liquid hydrogen? While hydrogen exists in the gaseous form here on Earth, in the extreme conditions on Jupiter, there is evidence that it could exist in an entirely different state. Find out more here: **https://science.nasa.gov/science-news/science-at-nasa/2011/09aug_juno3**

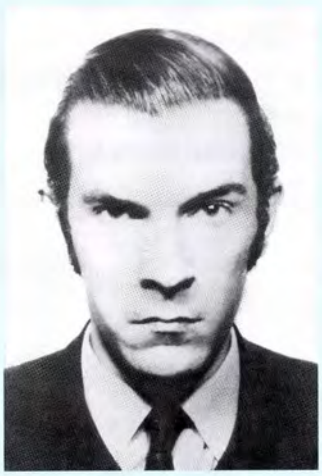
Periodic table alter egos – what other information are they hiding?

■ **Figure 3.8** Copper has antiseptic properties and was used by the ancient Egyptians and Greeks to store water. It is now the metal of choice to create air conditioning wires.

■ **Figure 3.9** Titanium is used to make the parts for hip replacements because it bonds to our cells as if it were bone and our immune system does not attack or reject it.

■ **Figure 3.10** Tantalum is a metal that is mined and used to make mobile phones. In Chapter 12, you will find out more about how it is linked to the civil war in the Democratic Republic of the Congo.

■ **Figure 3.11** Cadmium is found underneath zinc in the periodic table and therefore displays similar properties. Our bodies are unable to distinguish between the elements and happily mop it up. But cadmium softens the bones to such a degree that they can snap when touched, leading to a disease called 'itai-itai' or 'ouch ouch' disease.



■ **Figure 3.12** Read about Graham Frederick Young, a British serial killer who used thallium to kill his victims, by searching for **Bismuth: A gentleman among scoundrels**.

■ **Figure 3.13** Alexander Litvinenko lost all his hair and his organs started to fail days after being poisoned by the element polonium, which led to his death a few days later.

How do scientists use trends and patterns?

EXPLANATION GAME

I notice that the atomic radius of group 1 metals increases going down the group.

Why is it this way?

Hint

Some of the terms that were used to describe the change in atomic radius across a period will be useful here.

Periodicity

In this section we are going to look more closely at our periodic table, in order to gain a better understanding of the significance of the arrangement of the elements and how this leads to periodic trends (trends that occur at regular intervals). **Periodicity** is the study of these trends and patterns arising from the arrangement of the elements in the periodic table.

Across a period

As we move across the periodic table from left to right, there is a clear change from metallic to non-metallic character in the elements. This is best seen in period 3, sodium to argon. The metals, sodium, magnesium and aluminium, are separated from the non-metals, phosphorus, sulfur, chlorine and argon, by the element silicon. Silicon is a metalloid, showing the properties of both metals and non-metals.

A further change going across the periodic table is a decrease in **atomic radius**. The radius of an atom depends on two competing factors, one attractive and one repulsive.

- The **nuclear charge** is the attraction between the positively charged protons and the negatively charged electrons. The greater the number of positive protons present in the nucleus of an atom, the greater the attraction, so the valence electrons are drawn inwards.
- The **shielding/screening** effect is the repulsion between the negatively charged electrons. The greater the number of completed shells of electrons, the more the attractive charge of the protons is reduced, allowing the valence electrons to move further away from the nucleus.
- The **effective nuclear charge** is the difference between the attractive force (nuclear charge) and the repulsive force (shielding effect).

As you move from left to right across a period, the attractive force (nuclear charge) increases as a proton is being added to the nucleus each time. However, because each additional electron is being added to the same shell as the previous one, there is no increase in the repulsion or shielding effect of the valence electrons. The result is that the effective nuclear charge increases, drawing the valence electrons closer to the nucleus and reducing the size of the atomic radius.

Group chemistry

When talking about elements in the periodic table, we usually refer to elements of a particular group. You can almost imagine that the elements within a group are close relatives of each other, like siblings in one big family. They share similar traits that make it clear they belong to the same family, but each sibling has their own character. Let's find out more about these 'families'.

ACTIVITY: Alkali metals and halogens (demonstrations)

ATL

- Information literacy skills: Collect, record and verify data
- Critical-thinking skills: Draw reasonable conclusions and generalizations; Identify trends and forecast possibilities

Demonstration: reaction of alkali metals with air and water

You will be observing the reactions of the alkali metals lithium, sodium and potassium with air (oxygen) and water in order to **identify** similarities in their physical and chemical properties, and highlight some trends and patterns within the group.

Safety: The demonstrator must wear safety goggles or a face shield and students must be at least 2m away and wear safety goggles. Lithium, sodium and potassium are all corrosive and highly flammable, so the demonstrator must wear gloves and only very small pieces of the metals should be added to water. A scalpel should be used to cut pieces approximately 5mm, 4mm and 3mm for lithium, sodium and potassium, respectively, from the larger pieces in the jars of oil, and any remaining metal returned to the jar immediately. Universal indicator can also include flammable substances.

Alternatively, you can watch this video: https://youtu.be/0KonBvfnzdo

1. **Draw** a suitable table into which you can record your observations.
2. **Describe** the appearance of the alkali metals and the ease with which they can be cut with a knife.
3. Observe what happens when the alkali metals are left exposed to air and **describe** your observations in your table.
4. **Deduce** a general word equation for the reaction of alkali metals with oxygen.
5. Observe what happens when the alkali metals are added to water and **describe** your observations in your table. What happens when universal indicator is added to the resulting solution?
6. **Deduce** a general word equation for the reaction of alkali metals with water.
7. **Outline** the similarities in the metals lithium, sodium and potassium.
8. **Describe** how the reactivity of the metals changes going down the group.
9. Use your observations to **suggest** how you would expect rubidium and caesium to react with water.

Demonstration: displacement reactions of the halogens

You will be observing the reactions of chlorine water, bromine water and iodine, with solutions of the halogen salts, sodium chloride, sodium bromide and sodium iodide, in order to **identify** trends and patterns within the group.

Safety: Safety goggles should be worn by the demonstrator and students. Chlorine water and bromine water are harmful; chlorine gas, which can escape during the demonstration, is toxic. The solutions of chlorine water and bromine water should be diluted to 0.1 per cent to minimize the production of chlorine and bromine fumes but still achieve a colour change; a 0.1 M iodine solution can be used. Stoppered test tubes should be used.

Alternatively you can watch this video of the reactions of the halogens with the halogen salts: https://youtu.be/HW2jRyQ3dzo

1. **Draw** a suitable table into which you can record your observations.
2. **State** the initial colours of the halogens in your table.
3. Observe what happens when the halogens are added to the salt solutions of the other halogens and **describe** your observations in your table.
4. Where a reaction was observed, **deduce** a word equation.
5. **Describe** how the reactivity of the halogens changes going down the group.
6. Fluorine is extremely reactive so cannot be used in the lab and astatine is a dangerous and highly radioactive rare element so is not well explored. However, we can use observations and patterns to make assumptions about some of their properties. **Suggest** what the colours of fluorine and astatine might be. **Suggest** how you would expect each of them to react with a solution of sodium chloride, sodium bromide and sodium iodide.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding and Criterion C: Processing and evaluating.

■ **Figure 3.15** The halogens in gas jars: fluorine, chlorine, bromine and iodine

Hydrogen gas is one of the products of the reaction of the alkali metals with water. The test for hydrogen gas is called the 'squeaky pop' test; if a lighted splint burns with a squeaky pop, it confirms the production of hydrogen gas. Can you write a word equation for this reaction?

Alkali metal compounds are used widely in manufacturing and industry. Sodium chloride is table salt, sodium bicarbonate is used in baking, and one of the main ingredients in gunpowder is sodium nitrite. Other compounds of sodium are used in the paper and pulp industry, while sodium carbonate removes sulfur dioxide from emission stacks. Compounds of potassium are found in the manufacturing of fertilizers as well as in detergents, explosives and in the photographic industry.

ALKALI METALS (GROUP 1)

The naturally occurring group 1 metals are all light-grey or silvery but do not share all the typical physical properties of metals; they are soft (can be cut with a knife), are not dense (they float on water) and also have relatively low melting and boiling points, which decrease going down the group. However, it is these common characteristics that result in them being grouped together. Chemically, they are highly reactive and have to be stored in oil to prevent them from reacting with the oxygen or water vapour in the air, therefore they are never found as pure elements in nature. They also react with the element sulfur and with the halogens. Adding them to water makes hydrogen and an alkaline solution (the metal hydroxide) which is where they get their group name from. Their reactivity increases going down the group. The final element in the group, francium, barely exists in nature and is extremely radioactive, so is only found in laboratories where it can be made.

■ **Figure 3.14** The alkali metals need to be stored in oil to prevent them from reacting with the oxygen in the air

HALOGENS

The group 17 non-metals are all coloured substances (getting progressively darker from pale yellow to yellow-green to red-brown to deep purple), poisonous and have a very strong smell. They have low boiling points and show a change of state from gases (fluorine and chlorine) to liquid (bromine) to solid (iodine) going down the group. The halogens exist as **diatomic** molecules and dissolve in water to form strong acids. They are extremely reactive, with reactivity decreasing down the group. The earlier demonstration proved this, showing that a more reactive halogen was able to displace a less reactive halogen from its solution. This is called a displacement reaction. As discussed above, the halogens react directly with metals, in particular alkali metals, to form salts called halides.

Halogens are used as bleaching agents as they can remove colour; chlorine, for example, is used to make white paper. They are also disinfectants; chlorine is added to drinking water and to swimming pools to kill bacteria. When chlorine is dissolved in sodium hydroxide it forms sodium chlorate (I) which is found in domestic bleach. Fluorides are added to water and toothpaste to reduce tooth decay. Bromine is used to to make plastics and pesticides, as well as sedatives.

DISCUSS

What will happen to the atomic radius of group 17 elements going down the group?

DISCUSS

Why do the noble gases exist as **monatomic** atoms? Why was the group previously called group 0?

Iodine is used in antiseptics (it is less strong than a disinfectant and can be added to the skin) for sterilizing wounds. It is also a vital ion in our diet as it is used to make the hormone thyroxine which controls the body's metabolic rate.

Links to: Language and literature

Exploring science through literature allows us to describe science in a new language and experience it from a different perspective.

Use this website to find the poem *Dulce et decorum est* by Wilfred Owen, which was published after he died during the First World War: **www.wilfredowen.org.uk/poetry/dulce-et-decorum-est**

Aimed at people who thought war was noble and glorious, it describes the true horrors of war, and in particular the effects of the use of chlorine gas which was used for the first time as a chemical weapon in this conflict (find more on the uses of gases in war in Chapter 11).

Links to: Individuals and societies

Science has played a significant role in many historical events that are explored through the subject of Individuals and societies. Whether it be civil wars in order to obtain natural resources, or the use of ammunition and chemicals in global wars, in the last century governments spent an incredible amount of money on enlisting the help of scientists. Some scientists have knowingly contributed to warfare, while for others their work has been used in ways they could not even imagine. What responsibility do scientists have for the consequences of their discoveries? We will be exploring this topic further in Chapters 10 and 11.

NOBLE GASES

The final group in the periodic table, the noble gases (group 18), are all present in the Earth's atmosphere with argon occurring in the greatest proportion (about 0.9 per cent). Helium is the second most abundant gas in our Universe, after hydrogen. The noble gases are colourless, odourless, tasteless and non-flammable. Their full shells and resistance to bonding make them extremely unreactive or **inert** (though more recently it has been shown that, on occasion, they can form compounds under extreme conditions). This is the reason why they are the most recently discovered group of elements and why this whole group of elements was left out of Mendeleev's periodic table.

The uses of the noble gases are centred around their properties. Helium is used in balloons because it is less dense than air and in spacecraft as it is unreactive. It is also used in deep-sea diving to reduce the proportions of oxygen and nitrogen to below those in air, which reduces the narcosis effect of nitrogen. All of the noble gases glow when an electric charge is passed through them, so they are commonly used in advertising signs. Argon is the gas used to fill traditional hot **filament** light bulbs; the hot filament (thin metal wire) would normally react with any gas present but by surrounding it with an unreactive gas this is prevented. Krypton, along with neon and xenon, is used in lasers.

Figure 3.16 (a) Noble gas elements are used in advertising, (b) helium is used in balloons

THINK–PAIR–SHARE

Individually, consider whether it is a coincidence that the least reactive group, the noble gases, is found between the two most reactive groups, the alkali metals and the halogens.

With a partner, **compare** and **contrast** the physical and chemical properties of group 1, group 17 and group 18 elements.

As a class, **discuss** which group you feel is the most useful, making reference to the use of the elements in your everyday lives.

TRANSITION METALS

The transition metals sit in a block in the middle of the periodic table. Most of the important metals that we rely on are found within this section of the periodic table, including iron, copper, silver and gold.

DISCUSS

The general properties of metals that we described earlier on in this chapter are very typical properties of the transition metals. Make a list of these key properties or review your learning from earlier if you need a reminder.

The transition metals are different from the metals of group 1 and group 2 in two main ways: they are nowhere near as reactive, which is what makes them so much more useful, and they form coloured compounds. This property can be used decoratively; for example the colours in stained glass are often created using transition metals. Figure 3.17 shows images of some transition metal compounds. Transition metals also have high densities and high melting and boiling points and are often used as catalysts (Chapter 10) to speed up chemical reactions.

EXTENSION: GOING FURTHER

Zinc is not actually classified as a transition metal. Understanding the reason behind this is beyond the scope of this book, however if you can't wait until DP Chemistry, carry out some research to try to find out why. It will require you to rethink the electron arrangements of the elements.

Figure 3.18 summarizes key trends going down groups and across periods in the periodic table.

PATTERNS IN REACTIVITY

We have seen that there is a direct link between the chemical properties of an element and its position in the periodic table. Why do elements in the same group react similarly? Why does the reactivity of metals increase going down the group? How would the reactivity change from group 1 to group 2? Why does the reactivity of the non-metals decrease going down the group? All of these clear patterns can be explained by understanding the driving force behind reactions, and to do this we need to revisit electron arrangements.

■ **Figure 3.17** Transition metal compounds: (a) copper (II) sulfate, (b) potassium permanganate, (c) cobalt (II) chloride

ACTIVITY: Patterns in reactivity

ATL

- Communication skills: Make inferences and draw conclusions
- Creative-thinking skills: Apply existing knowledge to generate new ideas, products or processes

Identifying trends in the reactivity of metals

1. **List** the symbols of the metals lithium, sodium and potassium and **state** their electron arrangements.
2. **List** the symbols of the metals beryllium, magnesium and calcium and **state** their electron arrangements.
3. **Describe** any patterns you observe in the electron arrangements of the metals in the two groups.
4. According to the octet rule, atoms of elements 6–20 tend to combine in a way that results in their atoms having eight electrons in their valence (outer) shell, thereby achieving a full outer shell. This is because full shells make the atom electronically stable. **Suggest** how the electron arrangement of the element will change when each of the metals above reacts.
5. **Suggest** reasons why the reactivity of metals increases going down the group.
6. **Suggest** how the reactivity of the metals changes moving from group 1 to group 2, justifying your answer.

Identifying trends in the reactivity of non-metals

1. **List** the symbols of the non-metals fluorine and chlorine and **state** their electron arrangements.
2. **List** the symbols of the non-metals oxygen and sulfur and **state** their electron arrangements.
3. **Describe** any patterns you observe in the electron arrangements of the non-metals in the two groups.
4. **Suggest** how the electron arrangement of the element will change when each of the non-metals above reacts, taking the octet rule into consideration.
5. **Suggest** reasons why the reactivity of non-metals decreases going down the group.
6. **Suggest** how the reactivity changes moving from group 16 to group 17.
7. **Explain** why the noble gases are completely unreactive.

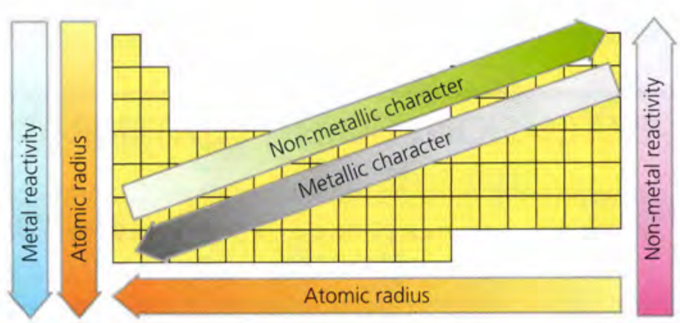
Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

LINKING POSITION IN THE PERIODIC TABLE AND ELECTRON ARRANGEMENT

The activity *Patterns in reactivity* has shown that elements in the same group of the periodic table have the same number of valence electrons. Further, for the elements in groups 1–2 and 13–18 (the main group elements), the number of valence electrons can be linked to the element's position in the periodic table – to the group number:

- for the metals: number of valence electrons = group number
- for the non-metals: number of valence electrons = group number – 10.



■ **Figure 3.18** Trends in the periodic table

The number of shells of electrons an atom has can also be linked to its position in the periodic table as the number of shells is the element's period number.

FORMING IONS

When metals react, they lose electrons in order to have complete shells. When electrons are lost, the resulting particle, an ion, has a positive charge and is known as a **cation**. The number of electrons lost is equal to the positive charge on the ion.

When non-metals react, they gain electrons in order to complete their shells. When electrons are gained, the resulting particle, an ion, has a negative charge and is known as an **anion**. The number of electrons gained is equal to the negative charge on the ion.

The chemical properties of an element depend on the number of valence electrons it has. As elements in the same group have the same number of valence electrons, they will have similar chemical properties.

For metals, the ease with which the valence electrons are lost is what determines the reactivity; the more easily they are lost, the more reactive the metal. For non-metals, the ease with which electrons are gained to complete the valence shell is what determines reactivity; the more easily electrons can be gained, the more reactive the non-metal.

The ease with which the valence electrons can be lost or gained depends on the two competing factors: attraction between the protons and electrons (nuclear charge) and repulsion between the negatively charged electrons (the shielding effect).

■ **Figure 3.19** Remember CATions are PAWsitively charged

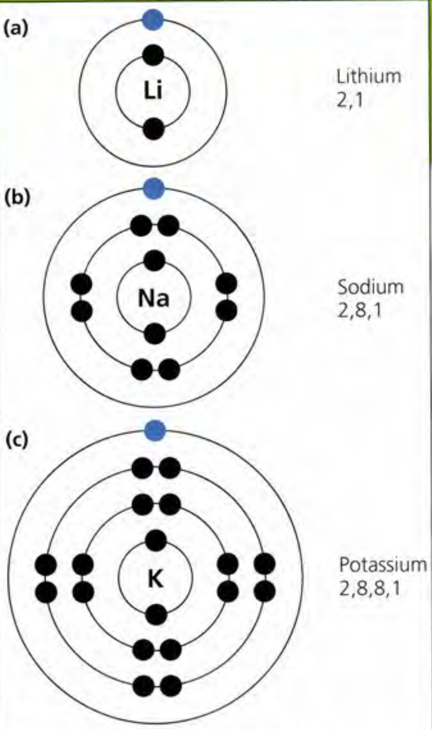
EXTENSION: GOING FURTHER

Return to the *Build an atom* simulation (Chapter 2, page 29). Use the information on your periodic table to create a neutral atom for all of the elements from hydrogen to neon, each time experimenting by adding or removing electrons until an ion is formed with full shells. Record the overall charge on each of the ions formed. Compare this to the element's group number. Does this agree with the rule on page 59?

EXPLANATION GAME

I notice that the reactivity of group 1 metals increases going down the group. Why is it this way?

I notice that the reactivity of group 17 non-metals decreases going down the group. Why is it this way?



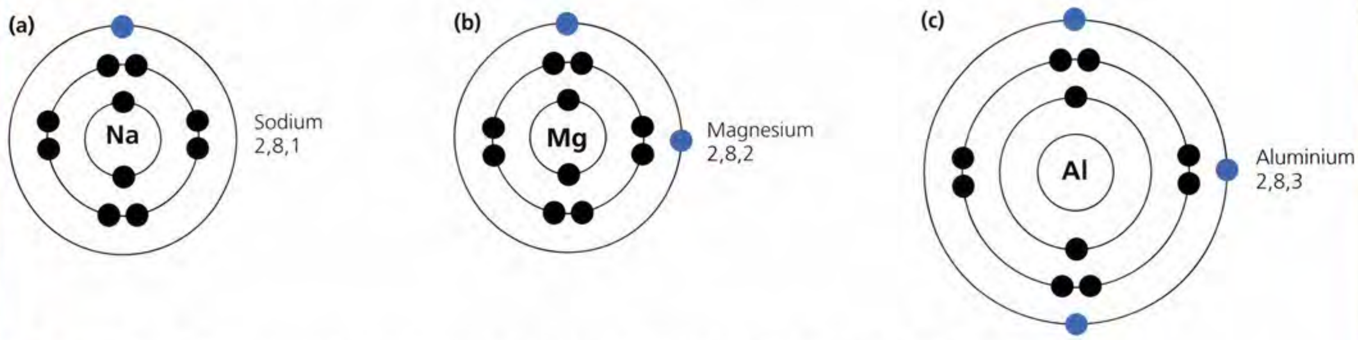
■ **Figure 3.20** The electron shell diagrams of (a) lithium, (b) sodium, (c) potassium

As you go down a group, there are more protons in the nucleus which increases the nuclear charge and therefore the attraction of the valence electrons. However, each time you go down the group, you add a full shell of electrons which increases the repulsion between the electrons and thus the shielding effect between the nucleus and the valence electrons. The increasing shielding effect has a greater impact than the increase in the nuclear charge, which means that the further down the group you go, the attraction between the nucleus and the valence electrons is weaker. In the case of metals, it means the valence electrons are more easily lost and the metals are more reactive. In the case of non-metals, the pattern is reversed as further down the group, weaker attraction means it is harder to gain electrons, so the non-metals become less reactive.

The trend in reactivity of both the metals and non-metals can be linked to the trend in atomic radius, which also depends on the competing effect of nuclear charge and shielding. The further away from the nucleus that the valence electrons are, the more easily they are lost, or the less easily they are gained. So as you go down a group and the atom gets larger, the more reactive it is if it is a metal and the less reactive it is if it is a non-metal.

CONNECT–EXTEND–CHALLENGE

Figure 3.21 shows the electron shell diagrams for sodium, magnesium and aluminium. Place the metals in order of reactivity, explaining why you have decided on this particular order.



■ **Figure 3.21** The electron shell diagrams of (a) sodium, (b) magnesium, (c) aluminium

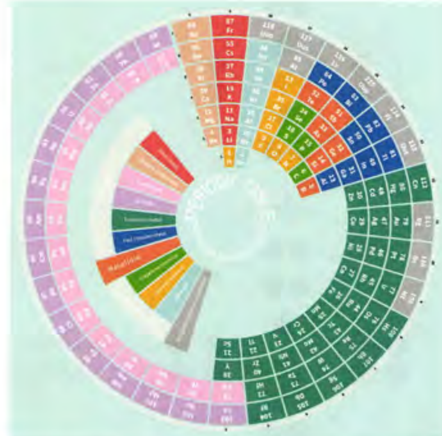
How are the ideas and information presented **connected** to what you already knew?

What new ideas did you come up with that **extended** or pushed your thinking in new directions?

What is still **challenging** or confusing for you to get your mind around?

What questions, wonderings or puzzles do you now have?

To what extent does classification help or restrict our understanding of new information?

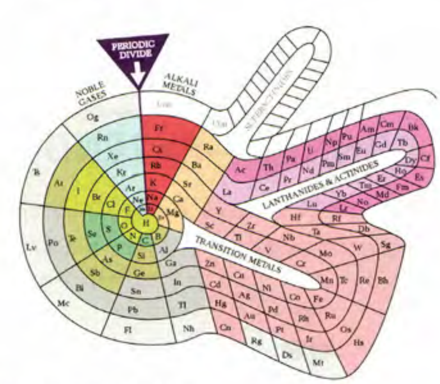


■ **Figure 3.22** Charles Janet's left-step periodic table in a spiral version (1929)

THE PERIODIC TABLE

Mendeleev's periodic table opened a door to a new level of understanding of the elements and of chemistry. It made links which were previously unknown and allowed predictions to be made about both the physical and chemical properties of undiscovered elements. Accurate predictions about the properties of elements can be made just by looking at their position in the periodic table and we use our knowledge of these properties for new inventions (for example rare earth metals are used in alternative technologies for new ways to make energy).

So why was Mendeleev's classification system more successful than the attempts of other scientists? A classification system needs to have some flexibility so as not to restrict our understanding of new information. Newlands and Döbereiner had failed in their attempts to classify the elements, as they did not possess the open-mindedness of Mendeleev, who acknowledged that he might not have all of the information that he needed to create a complete periodic table at the time.



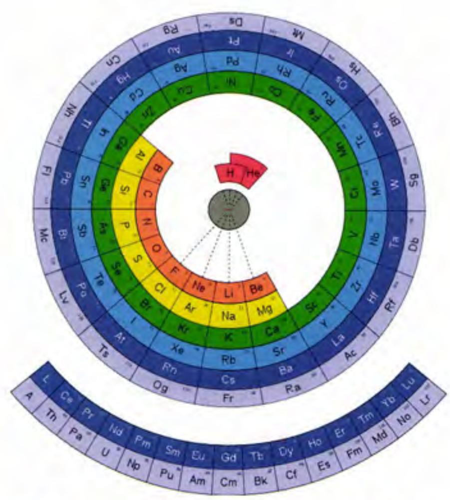
■ **Figure 3.23** Theodor Benfey's spiral periodic table (1964)

But is this version of the periodic table the best there is? Consider the following questions:

- Where should hydrogen be placed in the periodic table? Should it be placed above the group 1 alkali metals as it is in many periodic tables?
- Does helium deserve to be in group 18, as it only has two electrons in its outer shell while the rest have eight?
- Does the removal of the lanthanoids and actinoids aid or inhibit our understanding of the changing properties of the heavier elements?

There has been much controversy concerning the placement of lanthanum, the first of the lanthanoid elements, and actinium, the first of the actinoid elements. Typically, they have been placed in group 3, underneath scandium and yttrium, but, as mentioned earlier on in this chapter, more recently, lutetium and lawrencium have taken their place in the bottom of group 3 and lanthanum and actinium have been moved to the two rows that sit beneath the periodic table with the rest of the lanthanoids and actinoids.

There have been hundreds of alternative periodic tables suggested. (Mendeleev alone put forward about 30.) Figures 3.22–3.24 show just a few.



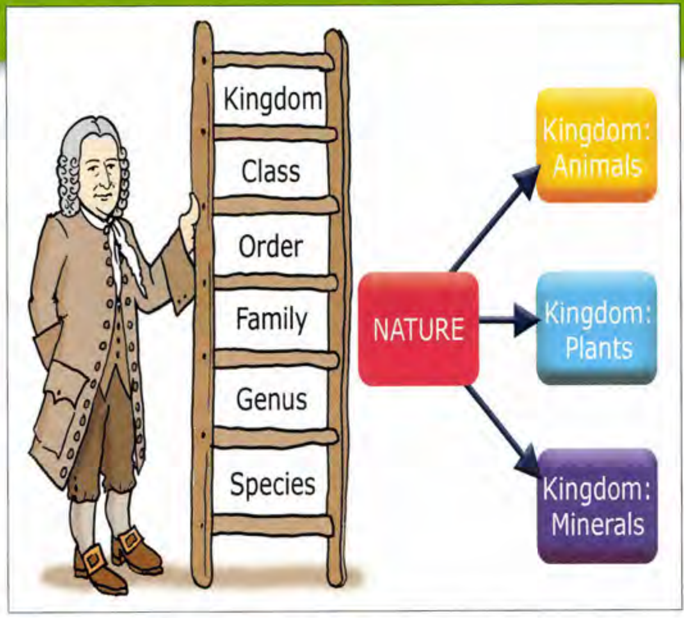
■ **Figure 3.24** A circular periodic table

We have seen how identification of *pattern* and of *form* has enabled scientists to classify non-living matter in terms of the *relationships* between elements. Now we will consider how the same concept can be applied to living matter.

How are characteristics of living things used to classify them?

WHAT MAKES YOU SAY THAT?

Look for pictures of a great grey owl, a red fox and a long-nosed bat. Which of these animals is the odd one out? What makes you say that? **Discuss** your answer with the rest of your class.



■ **Figure 3.25** Linnaeus' classification of nature (right). Further lower level categories were introduced (left). 'Minerals Kingdom' has since been abandoned.

Imagine you are asked to tidy a room full of clothes and objects in no particular order. Instinctively, you would probably start to group these items into categories based on their similarities and differences. While you may choose a certain way of organizing these items, such as by type of material or colour, someone else might decide to organize them by size or usefulness. There is a huge amount of diversity in nature; no one knows the exact number of different living things that ever existed on Earth. Organizing them is what scientists tried to do using observations of similarities and differences in key characteristics. The science of classifying living things is called **taxonomy**. As in our room example, scientists do not always agree on certain details when grouping living things. The most influential scientist whose classification system and ideas are still being used nowadays is Carl Linnaeus (1707–78). He is called the 'father of modern taxonomy'. In his publications, he described his system of naming living things and organizing them into hierarchical groups.

Let's use the example of the teaching groups in a particular school. Your school might include three smaller schools (e.g: primary, secondary and college). Each of these will be divided into further sections, for example the secondary school might be divided into upper and lower school, then each will be subdivided into classes and so on until you reach the level of individual students! Similarly, Linnaeus classified nature by first splitting it into three **kingdoms**: animals, plants and minerals. He then introduced lower-level categories such as class, order, genus and species to group living things. These categories enabled Linnaeus to create a **nomenclature** for naming each individual species. His system is called the **binomial** system since it gives each living organism a name composed of two parts. As many people have a forename and a family name, so the lion will be called *Panthera leo*, for example.

This universal system allows scientists, regardless of their language, to avoid any confusion when talking about a particular organism. The first part of the name indicates the genus and the second part indicates the species. A genus is a group of similar species; a species is a group of organisms that share similar characteristics and can mate to make fertile organisms of the same species. Humans who currently live on Earth all belong to the same species, *Homo sapiens*, but other species of humans such as *Homo neanderthalensis* have existed and there is evidence that they interbred with modern humans but became extinct.

Latin or ancient Greek names are used to describe taxonomic groups or species. It is an international convention that the genus starts with an uppercase letter and the species with a lower case letter. They should both be written in *italic* when printed or underlined when handwritten.

As mentioned, two individuals belonging to different species cannot normally **interbreed**. If they do, their offspring are usually infertile and unable to reproduce. For example animals called mules are the offspring of a male donkey and a female horse. Because horses and donkeys are different species, mules are infertile and acquire a number of chromosomes that does not allow them to reproduce. Table 3.3 on page 65 shows how humans and onions are classified following a Linnaeus-inspired system of classification.

How have technological advances affected our models of the world?

Traditional classifying methods rely largely on observations of **morphological**, functional and anatomical characteristics of living things. Advances in technology meant that taxonomists had more powerful tools to enable them to look at living things in a different way. DNA sequencing techniques allow scientists to map out and compare the genomes of living organisms to find relationships between species that may have been considered distant relatives in the past. These findings have resulted in many changes in the traditional classification systems. Some species have been moved from one group to another and some categories or levels of classification have been introduced or changed. For example, we moved from the three kingdoms suggested by Linnaeus to five then six kingdoms. Higher classification groups called **domains** or **superkingdoms** have been created. The two superkingdoms are **Prokaryota** (which include bacteria) that have cells with no defined nucleus and **Eukaryota** which include all organisms that have cells with a defined nucleus and more complex structures. Eukaryota were then divided into four kingdoms: plants, animals, fungi and protista. In the 1990s, based on bacterial DNA studies and analysis, a scientist called Carl Woese suggested that there should be a third group separated from Prokaryota called **Archaea** because of the significant differences between archaebacteria and eubacteria. This resulted in what is now known as the three-domain system (Bacteria, Archaebacteria and Eukaryota). However, many scientists disagreed with this new rearrangement and continued to use the two domain system with Archaebacteria becoming a new kingdom separated from Bacteria.

These new scientific and technical developments mean that in addition to morphological and anatomical differences or similarities between living things, scientists now take into account the evolutionary history of the species they study. This approach is called **phylogenetics**. Therefore, when grouping species, we should not only look at **analogous features**, such as the presence of wings in birds and insects or the body shape of sharks and dolphins (which could simply be related to function rather than anatomy or origin), but also consider **homologous features** which indicate a common evolutionary origin. These considerations have given rise to **cladistic classification**. Cladistic classification traces the characteristics of organisms back to the most recent ancestor and scientists sometimes use **clades** rather than the traditional Linnaean divisions of class or phylum to describe groups of organisms.

It is now relatively easy to access online information about the latest agreed classification of all known species on Earth. Numerous databases are available to the public such as the ITIS (Integrated Taxonomic Information System) and 'Catalogue of Life' (CoL). As of April 2017, the CoL had 1.7 million species classified out of the 1.9 million species known to science (including extinct species). Can you imagine how Linnaeus would feel having such information at the tips of his fingers?

ACTIVITY: Who am I?

ATL

- Information literacy skills: Access information to be informed and inform others
- Media literacy skills: Locate, organize and use information from a variety of sources and media

In this activity, you will work in groups of 4–5 students and access various online sources to find the classification of organisms of your choice. You will then use the information to **construct** a quiz for the rest of the class.

- As a group, **select** five living organisms (preferably belonging to different kingdoms such as animals, plants, etc.) then **search** for their classification. Enter the search term catalogue of life then input the name of the organism you are searching for. If you don't find the classification, it could be because the database does not recognize the common name you used. In that case enter the common name in your browser followed by scientific name. When you find the scientific name of your organism, enter it in the database to find its full classification from domain to species. Use the empty column labelled 'Mystery organism' in Table 3.3 to **classify** your chosen organism.
- Add more columns for all of your chosen organisms as needed. Once done, use the classification of these organisms to **create** a quiz called 'Who am I?'. For example, **state** 'I belong to the superkingdom of Eukaryota, I am from the kingdom Animalia, I belong to the class of Mammalia …' and so on until you reach the genus and the species. Take turns with the rest of the groups, scoring points for each group that gets the correct answer then reveal the answers at the end.
- To make this activity even more interesting, you could add more hints in the form of unique characteristics about the organism in question to help your classmates in their guess.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

	ONION *Allium cepa*	HUMAN *Homo sapiens*	Mystery organism
SUPERKINGDOM	Eukaryota	Eukaryota	
KINGDOM	Plantae	Animalia	
PHYLUM	Tracheophyta	Chordata	
CLASS	Liliopsida	Mammalia	
ORDER	Asparagales	Primates	
FAMILY	Amaryllidaceae	Hominidae	
GENUS	*Allium*	*Homo*	
SPECIES	*cepa*	*sapiens*	

Table 3.3 Classification of humans and onions using the Catalogue of Life database

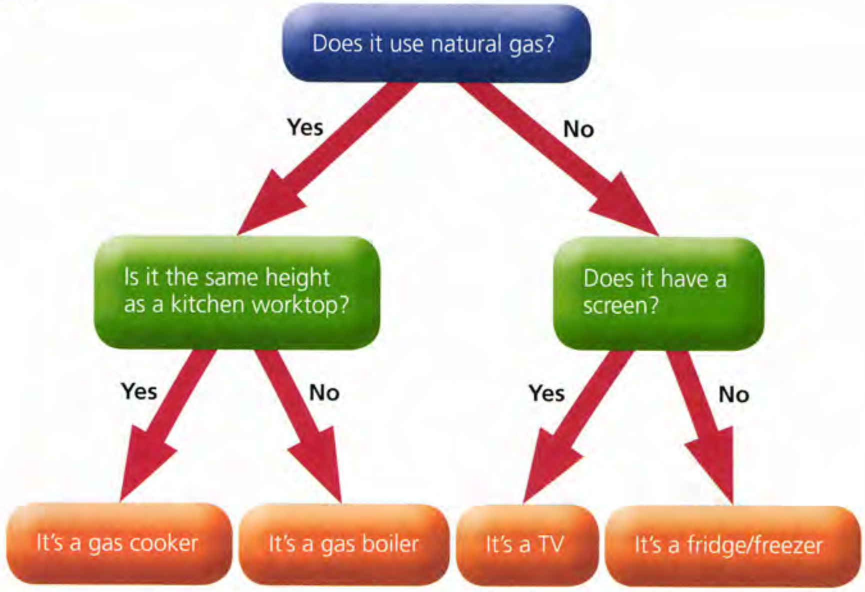
EXTENSION

Traditional taxonomy techniques are time consuming and difficult to use when scientists wish to quickly identify the species living in a particular habitat. Find out more about the exciting work of the scientists in the British Natural History Museum, who are using cutting edge technology to help them overcome what they called 'the taxonomic barrier': **www.nhm.ac.uk/our-science/our-work/biodiversity/breaking-the-taxonomic-barrier.html**

ACTIVITY: Plant detectives!

ATL

- Communication skills: Use and interpret a range of discipline-specific terms and symbols; Organize and depict information logically; Make inferences and draw conclusions
- Creative-thinking skills: Apply existing knowledge to generate new ideas, products or processes
- Collaboration skills: Give and receive meaningful feedback
- Information literacy skills: Collect and analyse data to identify solutions and make informed decisions



■ **Figure 3.26** A simple dichotomous key to help identify household appliances

Imagine that you and your friend are nature explorers and your adventure landed you on an island with a variety of plants that you have never seen before. In your adventure bag you only have a camera, a magnifying glass, a pen and some paper. How would you **identify** these plants?

Scientists use what is called a key, more specifically a **dichotomous key**, to identify living things.

Look at the example given in Figure 3.26. This shows a very simple dichotomous key to identify household appliances. The same key can be written in a different way as shown in Table 3.4.

Description/question	Answers
1. Does it use natural gas?	Yes – Go to Question 2 No – Go to Question 3
2. Is it the same height as a kitchen worktop?	Yes – It's a gas cooker No – It's a gas boiler
3. Does it have a screen?	Yes – It's a TV No – It's a fridge/freezer

■ **Table 3.4** Simple dichotomous key to identify household appliances

You can learn more by looking at other examples. Search **examples of dichotomous keys of plants, animals, insects** in your browser.

Work in groups of two to three students.

Part 1

Use the characteristics of some groups of plants to **design** a simple dichotomous key that will help you **classify** them into the suggested phyla and classes. (According to the Catalogue of Life, the plant kingdom contains eight phyla in total but we chose two for simplicity.)

Use this information to **construct** one type of key as suggested in Table 3.4 or Figure 3.26:

- **Phylum *Bryophyta* (mosses): plants with simple leaves and stems; small in size; no roots; have hairy structures called rhizoids instead; reproduce by spores stored in capsules**
- **Phylum *Tracheophyta* (vascular plants): land plants which contain transport systems with phloem to conduct products of photosynthesis throughout the plant and xylem containing lignin to transport water and minerals**

We will consider the following classes in the phylum Tracheophyta:

- **Class of *Liliopsida*: flowering plants; seeds only contain one embryonic leaf or cotyledon; leaves are narrow and linear with parallel veins; the leaves usually form a sheathing around the plant stem at its base; examples are rice, wheat, maize, sugar cane, onions and grasses**
- **Class of *Pinopsida*: most are evergreen, cone-bearing trees; they can grow very tall, up to 100 metres or more; leaves can be long, thin and resemble needles or can have a scaly structure; examples are pine trees, cedars and yew trees**

- Class of *Magnoliopsida*: **flowering plants; seeds contain two embryonic leaves; leaves are flat and vary in size but have reticulate veins branching from a central vein; examples include geranium plants, apple trees, lettuce and nettle plants**

Part 2

Once you have constructed your key, swap it with that of another group of students. Collect some plants from your school environment and bring them back to the classroom. Use the borrowed key to **classify** the plants you collected by **examining** them carefully using a magnifying glass if necessary.

Organize the data into a suitable form, perhaps as a table with a specimen or a picture glued next to the classification. **Evaluate** the efficiency of your key and that of your friends in classifying plants.

Suggest improvements to your friends' key. Ask for their feedback to improve your own key.

Describe what information you would need to **identify** which lower ranking groups the plants belong to, such as the family, the genus and the species.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion B: Inquiring and designing and Criterion C: Processing and evaluating.

Take action: Why classify?

ATL

- Information literacy skills: Access information to be informed and inform others; Make connections between various sources of information; Evaluate and select information sources and digital tools based on their appropriateness to specific tasks
- Critical-thinking skills: Gather and organize relevant information to formulate an argument

Figure 3.27 Why taxonomy matters!

! Having a unified approach to classifying living things makes communication between scientists and other communities easier. However, the importance of taxonomy goes beyond its use as a language of biodiversity.

! Your task is to write an article for a science magazine to debate an idea that was discussed in a previous issue in which they claimed that taxonomy is now 'old fashioned'.

! To begin, watch this video or search taxonomy, discover, nhm: **www.nhm.ac.uk/discover/naming-nature-putting-life-in-order.html**

! In your article:

- **describe** and **explain** how taxonomy helps in the specific area or example you chose, focusing on the scientific facts
- **discuss** and **evaluate** the implications of using taxonomy in the area you chose and other possible areas linked to society, the economy and the environment
- **apply** scientific language and use visuals to support your arguments
- **document** all of the sources using a recognized referencing and citation system.

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.


(a) Siberian tiger, *Panthera tigris altaica*


(b) Domestic cat, *Felis catus*


(c) Lion, *Panthera leo*


(d) Bengali tiger, *Panthera tigris tigris*


(e) European gray wolf, *Canis lupus*


(f) Dog, *Canis lupus familiaris*

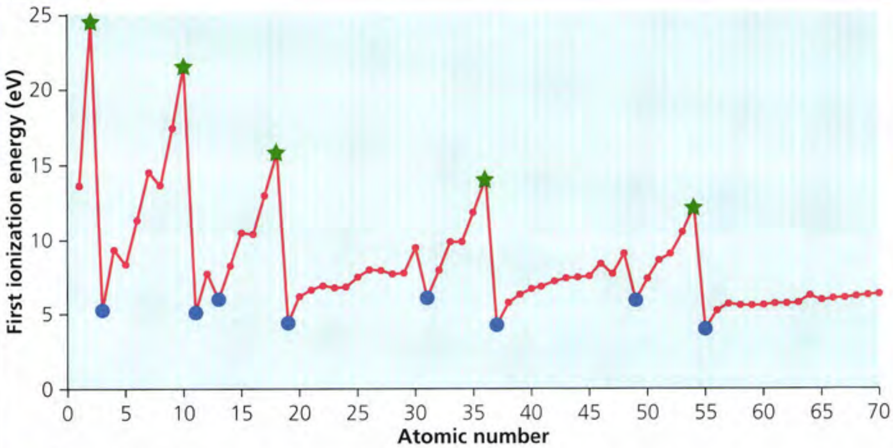
■ **Figure 3.28** Animals with their common and scientific names

SOME REVIEW PROBLEMS TO TRY

1 The scientific and the common names of some animals are shown in Figure 3.28.
   - a **State** how many species of animals there are in the pictures and indicate which animals belong to the same species. **Justify** your answer.
   - b **State** which of these animals belong to the same genus. **Justify** your answer.
   - c **Suggest** how many families of animals are represented by the animals in these pictures. Which animals belong to the same family? **Justify** your answer.

2 Using the pictures of animals from Figure 3.28:
   - a **State** which animals' names are composed of three parts rather than the usual two in the binomial system.
   - b **Suggest** a reason for the need to add a third part to the scientific name of the animals you mentioned in the previous question.
   - c **Suggest** a name for the taxonomic group that comes at a lower rank than the taxonomic group of species.
   - d **Apply** your understanding of the definition of a species to **suggest** which of these animals could mate and produce fertile offspring. **Justify** your answer.
   - e The animal kingdom is divided into 34 phyla according to the CoL. One of these is the phylum of Chordata (known as vertebrates). Traditionally we know that vertebrates are made up of five groups (mammals, birds, reptiles, amphibians and fish). In the CoL classification, these five groups only make up five of 14 classes in the phylum of Chordata. **Suggest** which class the animals in Figure 3.28 belong to and **outline** the characteristics that you relied on in your classification.

3
   - a Consider the following pairs: potassium and rubidium, magnesium and sulfur, argon and chlorine, oxygen and selenium. **State** which pairs will undergo similar reactions.
   - b **Outline** why this is the case.
   - c The element astatine (At), which sits below iodine in the periodic table, has very little currently known about it. Using your knowledge of periodic trends, **predict** some of its physical properties (state at room temperature, colour, atomic size), whether it is monatomic or diatomic and how you would expect it to react compared to the other elements in its group.
   - d Figure 3.29 shows a graph of atomic number against first ionization energy. The ionization energy tells us how much energy is needed to remove an electron from an atom in order to form an ion with a charge of 1+. Use your periodic table to **identify** which elements are at the peaks (shown by a star) and which are at the troughs (shown by a circle) and **suggest** an explanation as to why this is the case.



■ **Figure 3.29** Graph of atomic number against first ionization energy

Reflection

In this chapter we have explored the ways in which patterns in form can be used to identify relationships in nature, and used those relationships to invent new ways to organize and understand nature. We have **described** what the periodic table is and how each element is represented. We have **outlined** the work of different scientists who contributed to its development and **identified** trends and patterns that result from this. We have **described** the way metallic properties change across the table and **described** the main properties and uses of group 1, 17 and 18 elements. We **observed** the chemical reactions of alkali metals and halogens and used these observations and the electron arrangements of the elements to **explain** how reactivity changes going down groups. We have **defined** isotopes and ions and **explained** the relationship between the electron arrangement of an atom and the periodic table. We have **compared** the arrangement of the modern periodic table against alternative versions. Finally, we have **analysed** how living things are **classified** and **discussed** how traditional classifications have changed because of new technological advances.

Use this table to reflect on your own learning in this chapter					
Questions we asked	Answers we found	Any further questions now?			
Factual					
Conceptual					
Debatable					
Approaches to learning you used in this chapter	Description – what new skills did you learn?	How well did you master the skills?			
		Novice	Learner	Practitioner	Expert
Learner profile attribute(s)	Reflect on the importance of being a good thinker for your learning in this chapter				
Thinkers					