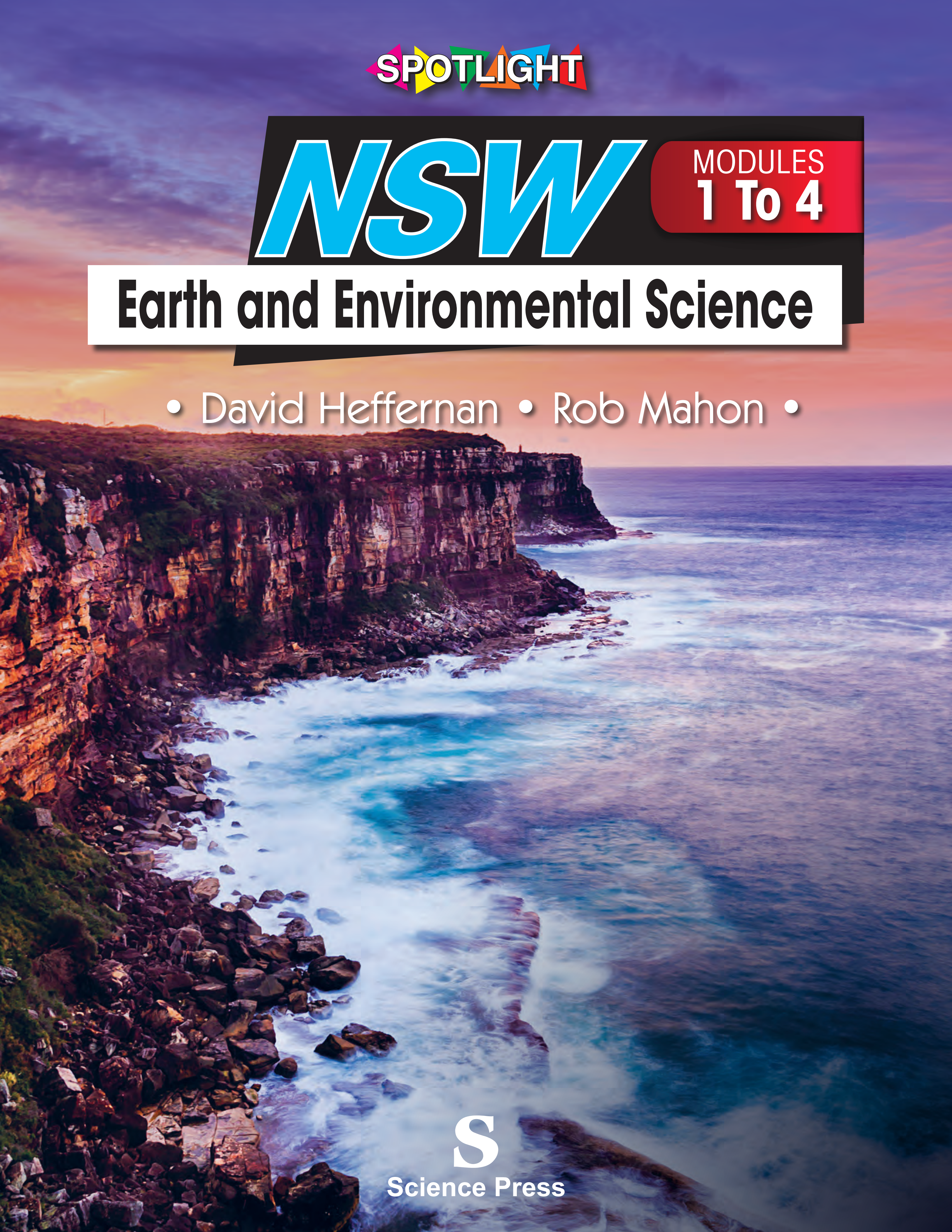
SPOTLIGHT

NSW

MODULES 1 To 4

Earth and Environmental Science

• David Heffernan • Rob Mahon •



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Chapter vocabulary links

At the start of each chapter a QR link to a vocabulary list for that chapter has been included. These take the user to a Quizlet study set, which allows students to interact with the new vocabulary for this chapter in a variety of ways. At the top of the study set are a number of tabs to select from. These are explained below.

Note: Students can study either the full set of terms or they can select specific words to revise by selecting the star symbol next to each term.

Flashcards: The ideal starting point when being introduced to new terminology. The definition is shown and the student tries to guess the correct word (which is revealed by clicking/tapping on the card). Note that you can customise the settings to suit yourself.

Learn: Once you have been introduced to the terminology, practise typing in the terms when prompted. This helps with improving your spelling of these terms.

Match and gravity: These are single player games that challenge your recall of the terminology in different ways.

Live: This is an online team game using the vocabulary. Watch the introductory video, then play this during class.

Test: This is by far the most valuable interactive feature of Quizlet. This will autogenerate a test in a variety of question styles. You can include all terms or only the terms you select. It will then correct your answers and provide feedback. *Note:* The most valuable learning will come from from studying the terms you answered incorrectly, then immediately generate another test. You can keep doing this until you regularly score 100% in these tests.

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Contents

Words to Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Put to use in a particular situation.

assess Make a judgement about the value of something.

calculate Find a numerical answer.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Estimate, measure or note how things are similar or different.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

create Originate or bring into existence.

deduce Reach a conclusion from given information.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Talk or write about a topic, taking into account different issues or ideas.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Make something clear or easy to understand.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

hypothesise Suggest an explanation for a group of facts or phenomena.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers.

measure Find a value for a quantity.

outline Give a brief account or summary.

plan Use strategies to develop a series of steps or processes.

predict Give an expected result.

propose Put forward a plan or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

relate Tell or report about happenings, events or circumstances.

represent Use words, images or symbols to convey meaning.

select Choose in preference to another or others.

sequence Arrange in order.

show Give the steps in a calculation or derivation.

sketch Make a quick, rough drawing of something.

solve Work out the answer to a problem.

state Give a specific name, value or other brief answer.

suggest Put forward an idea for consideration.

summarise Give a brief statement of the main points.

synthesise Combine various elements to make a whole.

Chapter 1

STRUCTURE OF THE EARTH: THE EARLY GEOSPHERE, ATMOSPHERE AND HYDROSPHERE

Chapter 1 Quizlet
http://qr.w69b.com/g/rbF5H3U1G

1.1 Formation of the Earth

In the aeons after the **Big Bang**, as the Universe was flying apart, stars formed and clumped together into galaxies due to their combined gravitational force. In the outer arms of the Milky Way galaxy there were massive clouds of gas and dust (which we can still see today; Figure 1.1). Much of this matter is hydrogen that formed during the early Universe, while some of it is heavier elements formed in the cores of earlier giant stars. These giant stars had long since exploded and the elements had been scattered. These include carbon, oxygen, silicon and iron. It was in a dust cloud such as this that our Solar System began to form around 5 billion years ago.

Introduction to Earth science
http://qr.w69b.com/g/s7bBx9dTi

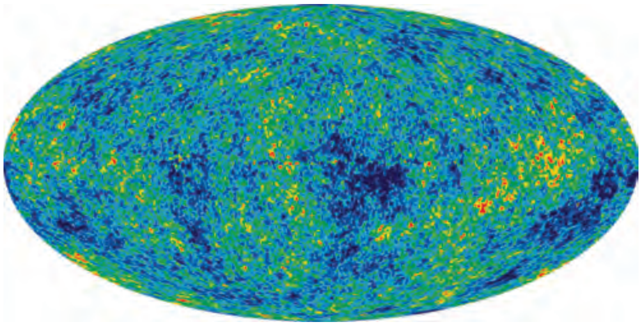


Figure 1.1 The Universe This image was constructed using 5 years of precise mapping of the cosmic microwave background radiation in every direction. What this shows us is the faint but measurable heat traces left over from the Big Bang. (NASA)

The protoplanetary disc

For some reason, perhaps due to a shock wave resulting from a nearby supernova, an area of dust and gas measuring light years across began to contract. Within this **protoplanetary disc**, fine particles began to clump together and the whole cloud began to rotate at a faster rate (Figure 1.2). Eventually, most of the material was located in a central sphere with a wide disc of material extending around its equator.

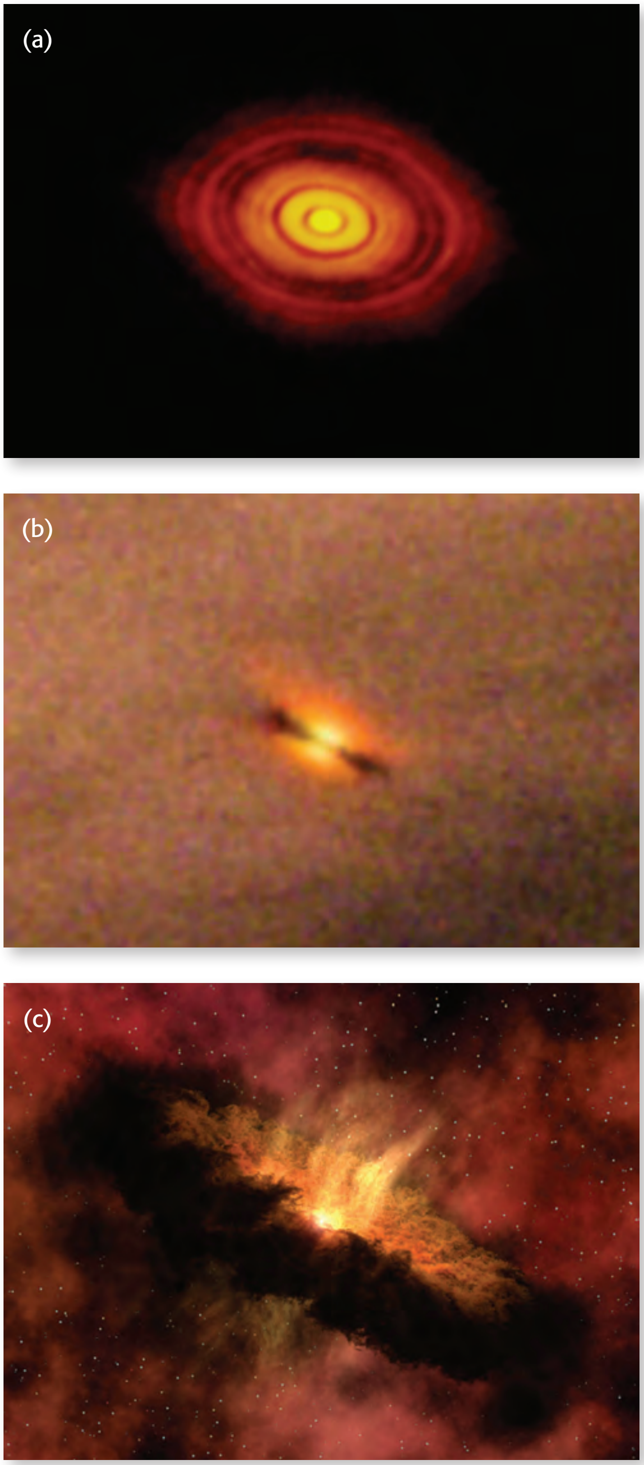


Figure 1.2 Protoplanetary disc (a) A protoplanetary disc image as seen from above through the Atacama Large Millimeter/submillimeter Array (ALMA). (b) A protoplanetary disc as seen from the side. (NASA) (c) An artist's impression of a protoplanetary disc using the above images. The centre region eventually ignites as a true star while the surrounding disc of debris forms the protoplanets. (NASA)

ACTIVITY 1.1 EXPERIMENT: ICE SKATING AND THE FORMATION OF THE SOLAR SYSTEM

What does ice skating have in common with the formation of the Solar System? Both are good examples of what is known as the conservation of angular momentum. In both cases, as widespread arms are pulled towards the centre of a rotating body, the speed of rotation changes.

Aim: To simulate the change in rotational speed of the Solar System as it contracted.

Hypotheses

As the arms of a rotating object pull in, the object will … (select one):

- Rotate slower.
- Rotate faster.
- Rotate at the same rate.

Adding mass to the arms as they are pulled in will … (select one):

- Magnify the effect.
- Reduce the effect.
- Have no influence on the effect.

Apparatus: One × swivel chair, 2 × 2 kg masses or similar (e.g. bricks).

Risk assessment: Low. Remove obstacles within 2 metres of chair. To avoid motion sickness, change students or alternate the direction you spin each time.

Method

1. Have one student sit on the swivel chair with arms raised sideways and legs pointing out straight.
2. Spin them firmly. After a few spins the student should then pull their arms and legs inwards back towards their body. Describe what happens. If unsure, try it yourself or ask the student in the chair to describe what they felt.
3. Repeat the experiment at a slower speed. Does the same thing happen?
4. Repeat the experiment, but this time begin with arms and legs pulled in at the start and extend them outwards after a few spins. Record what happens.

5. Repeat the experiment (both pulling in and extending out) while holding masses in your hands. Record whether or not this affects the result.
6. Which causes the greatest change to the rate of spin; pulling in your arms or pulling in your legs? Infer a reason for this difference and test your hypothesis. Write this up as a separate practical report.
7. Search the internet for video of the world record figure skating spin. Who holds the record, how fast did they spin and what did they do with their arms and free leg to achieve it?
8. Whilst on the internet, search for the best short video you can find which illustrates the formation of the Solar System. Save this to your files.

Earth science overview
http://qr.w69b.com/g/q2SXXOPsI

Due to the huge internal pressures caused by its collapse, the central protoplanetary sphere became very hot and began to glow, forming a **protostar**. Debris within the disc around the protostar gathered into numerous large clumps or **protoplanets** by the process of **accretion** – the gathering together of small bodies into larger ones by gravity (Figure 1.3). Accretion is the underlying process responsible for the initial formation of the Solar System and the associated changes that occurred. These protoplanets numbered in the hundreds if not thousands. They would 'vacuum' up and concentrate most of the dust in the disc surrounding the protostar that was to become our Sun.

Gravitational squeezing caused temperatures and pressures within the protostar to increase to enormous levels. When pressure and temperature reached the critical temperature of tens of millions of degrees, hydrogen atoms – the most abundant component of the protostar – began to fuse together to make helium atoms. This **nuclear fusion reaction** releases huge amounts of energy in the process. It follows Einstein's famous equation $E = mc^2$. This equation states that energy (E) = mass (m) multiplied by the speed of light squared (c^2). The speed of light squared is a huge number, so in effect this equation means that even small amounts of matter can be converted into very large amounts of energy. As it undergoes constant nuclear fusion reactions our Sun loses 4 tonnes in mass every second.

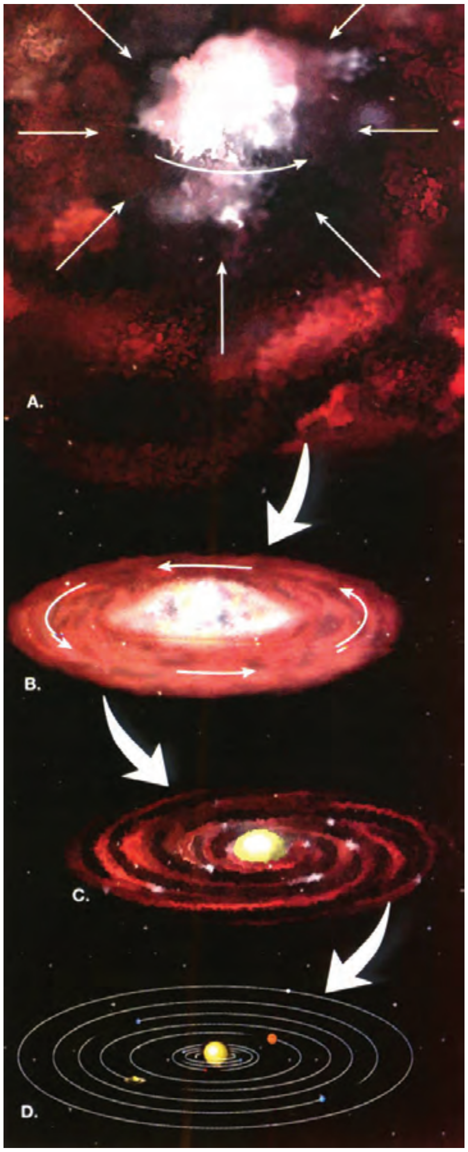


Figure 1.3 Formation of the Solar System The Earth and other planets are the result of the accretion of dust and gases orbiting the Sun.

When fusion reactions started, the protostar ignited like a massive and sustained nuclear bomb, becoming a **true star**. Further collapse was prevented by these nuclear fusion reactions in the core of the Sun pushing outwards against gravity. The ignition of our Sun blew away much of the surrounding material, including most of the gases around the inner planets. This is why the inner planets of our Solar System are small and rocky while the outer planets are gas giants (they were far enough away from the Sun to avoid being blasted so strongly). The ignition of fusion reactions within the Sun marks the moment of 'birth' for our entire Solar System, and it occurred around 4.6 billion years ago.

The formation of the Earth

Even though the planets were forming by accretion of dust particles at the same time as the Sun was forming, it would be a mistake to think that the planets were 'born' as we know them today at the same time as the Sun exploded to life. The infant Solar System would have contained hundreds of small protoplanets with overlapping orbits. At this time the Solar System would have resembled a giant smash up derby.

These protoplanets would have been constantly bombarded with meteorites as they swept into each other or cleared their orbits free of debris. This bombardment increased each planet's size and mass. In the case of the rocky planets such as our own Earth, it also heated its rocks to melting point. The gases released from these molten rocks would form Earth's first atmosphere. Below the surface, heavier metallic elements sank deep into the liquid Earth, while the lighter elements floated at the surface like volcanic froth.

Eventually, the planets as we know them today were the 'winners' of the protoplanetary smash up derby. As the planets settled into stable orbits and swept the space around them free of debris, they experienced decreasing meteorite impacts and began to cool.

Earth's formation
http://qr.w69b.com/g/qmzhX0MF2

ACTIVITY 1.2
HAPPY BIRTHDAY EARTH!

Eighteenth birthdays are a special occasion in our society. They mark the transition from the age of childhood to the age of adulthood. They are often accompanied with embarrassing childhood photos or videos and speeches remembering the key moments of the person's life to date.

You are to organise a presentation of the key events (described previously in this chapter) which led to the formation of a solid Earth with land and ocean. It should include pictures with descriptions, stories or anecdotes (either written or spoken). Don't just restate the science content as told in this text. Deliver your story as though the Earth is your best friend and that you are doing a slideshow at Earth's 18th birthday party.

The formation of the Moon

Our Moon is believed to have been born out of one colossal impact between the Earth and another protoplanet the size of Mars (Figure 1.4). Huge amounts of debris exploded into space; much of it falling back to Earth and some of it coalescing to form the Moon. This theory accounts for the fact that Moon rocks seem to have formed 100 million years after the Earth did. It also explains the fact that although Moon rocks have a similar chemical composition to Earth rocks, they are deficient in iron. If the Mars sized meteorite hit the Earth with an off centre blow, Earth's core (where most of the heavy molten iron had accumulated) would have remained intact.

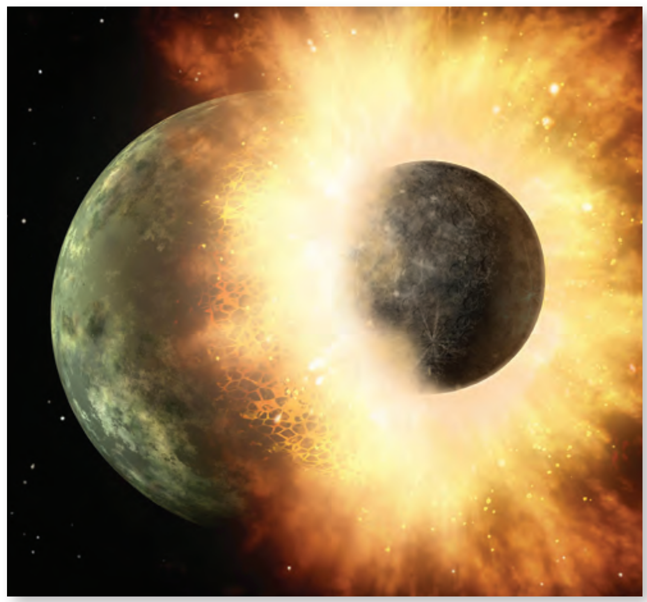


Figure 1.4 Formation of the Moon Artist's impression of the collision that led to the formation of our Moon. (NASA)

ACTIVITY 1.3
THE MAKING OF THE MOON

Search online for an animation, applet or video on the formation of the Moon. Save screen shots to show a sequence of steps starting with 'Earth and protoplanet on collision course' and ending with 'Moon fully formed and in orbit around Earth'.

How the atmosphere formed

The majority of life forms on Earth today have evolved to be well adapted to the current atmosphere, specifically to the high levels of oxygen. However if oxygen loving organisms, such as humans, were exposed to the Earth's *original* atmosphere, they would die quickly (Figure 1.5). This would be the result of not only a lack of oxygen but also high concentrations of poisonous gases, like ammonia and carbon monoxide.

Earth's original atmosphere

The original source of the gases that made up Earth's original atmosphere was the planet itself. The process is called **outgassing**. The molten rocks of the young, hot Earth released a mixture of gases, just as volcanoes still do today. Some of these gases remain in the atmosphere to this day; others were quickly removed by a variety of processes. While their relative proportions are uncertain, the main gases of the original atmosphere seem to have been nitrogen (N_2), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4) and water vapour (H_2O).

Figure 1.5 Life on Earth Current life forms like whales could not survive in the Earth's original atmosphere.

Earth's current atmosphere

Careful measurement and chemical analysis have allowed scientists to determine the proportions of gases that make up the atmosphere. Those for dry air are found in Table 1.1. Water vapour, which is not listed with the others because of its variability, ranges between 0.1 and 3 per cent.

Figure 1.6 Limestone This limestone was formed in ancient seas.

Where did the original atmospheric gases go?

- **Nitrogen.** Most of the original atmospheric nitrogen remains in the air to this day because it is unreactive, although some of it cycles through the biosphere as part of the nitrogen cycle.
- **Carbon monoxide** and **carbon dioxide.** The early atmosphere contained 100 to 1000 times as much carbon dioxide as it does now. These gases were mostly combined with calcium and magnesium dissolved in sea water, creating insoluble carbonate sediments that formed carbonate rocks, such as limestone (Figure 1.6). High levels of carbon dioxide early on might have acted as a greenhouse blanket for the Earth while the young Sun was much weaker than it currently is.
- **Hydrogen.** Being so light, hydrogen vented from molten rocks was lost into space.
- **Water vapour.** As the Earth cooled after its formation, most of this water vapour condensed and fell as rain, filling the ocean basins.
- **Methane.** A reaction between methane and oxygen produces carbon dioxide and water. Trace amounts of oxygen would have been produced as intense ultraviolet rays split atmospheric molecules apart.

Table 1.1 Atmospheric chemistry.

Gas	Formula	Proportion
Nitrogen	N_2	78.1%
Oxygen	O_2	20.9%
Argon	Ar	0.93%
Carbon dioxide	CO_2	0.04% (increasing)
Others	Ne, He, CH_4	0.03%

Where did the current atmospheric gases come from?

- **Nitrogen** remains from the original atmosphere.
- **Oxygen** was produced as 'waste' during photosynthesis by green plants. At high altitudes, ultraviolet rays split oxygen molecules, forming ozone (O_3). This ozone layer blocks most of the Sun's damaging ultraviolet rays, making life on land possible.
- **Argon** is an inert gas formed by the radioactive decay of some elements within the mantle. It is then released as a volcanic gas.
- **Carbon dioxide** is added to the air by volcanic eruptions, the weathering of carbonate rocks and the respiration of living things. It is also removed by a variety of processes and cycled throughout the lithosphere, hydrosphere and biosphere as well as the atmosphere.
- **Water vapour.** Water is continually being cycled throughout the lithosphere, hydrosphere and biosphere, as well as the atmosphere. Most of the water on Earth today was vented from molten rocks, with meteorites providing additional quantities.

ACTIVITY 1.4
CHANGING ATMOSPHERE

1. Compare the composition of the Earth's original and current atmospheres. *Note*: Compare means to discuss similarities and differences.
2. Construct a pie chart to show the proportions of gases in today's atmosphere. Figure 1.7 is provided as an example. Pie charts represent portions of a whole as segments of a circle, like slices of a pie. To convert a percentage (out of 100 per cent) into an angle of a circle (out of 360 degrees), simply multiply the percentage by 3.6. For example, how much of the pie chart should 50 per cent take up? The answer is $50 \times 3.6 = 180$ degrees, or half the pie chart.

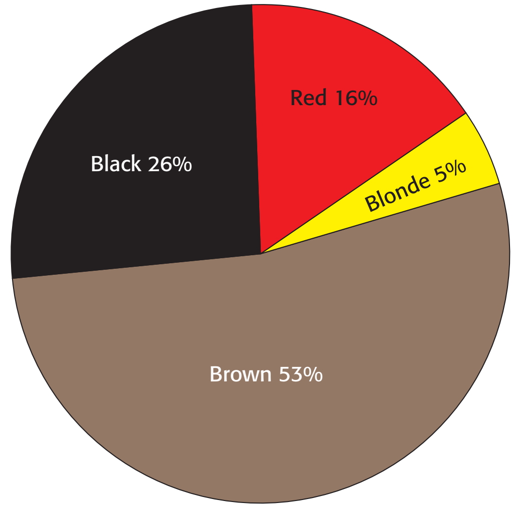


Figure 1.7 Pie charts The percentage of students with various hair colours is represented as segments of a circle.

Origin of Earth's water

Scientists still do not know for sure the origins of water on the Earth (Figure 1.8). There are a number of possibilities. One involves icy bodies from space. Studies of asteroids show that some contain water. Perhaps in the early stages of the formation of the Earth, water arrived as these bodies bombarded the surface.

Another possibility is volcanic outgassing. We know that present day volcanoes produce large amounts of water. After the Earth cooled enough the abundant water vapour in the atmosphere (released from the molten rock) was able to condense and form thick clouds. Rain fell heavily (probably for many centuries) and continued until oceans covered the low lying areas and most of the planet's surface.

Figure 1.8 Planet water How did we get the oceans around us?

SCIENCE SKILLS

1. **Identify** means to recognise and name. You may need to recognise an image or a verbal statement. For example, **identify** the source of water produced by the Earth.

   Answer:

   Water was produced during volcanic eruptions of the early Earth.

2. **Describe** means to provide characteristics and features. Be as thorough as the word limit will allow, making sure you concentrate on the most important points. You do not have to explain or interpret. For example, **describe** the origin of argon that we find in the Earth's atmosphere.

   Answer:

   Argon is an inert gas formed by the radioactive decay of some elements within the Earth's mantle. It is then released during volcanic eruptions.

3. **Explain** means to relate cause and effect; to make the relationships between things evident; to provide why and/or how. You need to clarify and interpret the material you present. Where appropriate, give reasons for differences of opinions or results, and try to analyse causes. For example, **explain** the role of gravity in the formation of the Earth.

   Answer:

   Gravity has two roles in the formation of the Earth. Firstly, gravity is important in the accretion of matter during the formation of the solar system. A disc of matter gathers around the protosun. Matter in this disc forms into clumps that grow to become a protoplanet. Meteorite bombardment helps increase the new planet's size as well as heating the rocks to melting point. This releases gases from rocks that would form the first atmosphere.

   Secondly, gravity then causes heavier metallic elements sink deep into the liquid Earth, while lighter elements floated at the surface. This early differentiation of material within the Earth is preserved in its layered internal structure.

4. **Outline** means to sketch in general terms, indicate the main features of something. You emphasise the structure or arrangement, omitting minor details. Outlines are often in point form. For example, **outline** the origin of the oceans.

   Answer:

   - The source of the oceans is not completely understood.
   - Some may have come from meteorites that bombarded the early Earth.
   - Some may have come from outgassing as water vapour is produced during volcanic eruptions.

TO THINK ABOUT

Set 1

1. **Explain** the role of supernovae in the formation of a protoplanetary disc.
2. **Describe** the formation of a protostar.
3. **Outline** the role of accretion in the formation of protoplanets.
4. **Describe** the source of energy in a star.
5. **Describe** the transition of a protostar to a true star.

Set 2

6. **Outline** the stages in the formation of the Earth.
7. **Describe** the formation of the Moon.
8. **Describe** what happens during a smash up derby. **Explain** how this provides an analogy for the formation of the planets.
9. **Explain** the origins of the atmosphere.
10. **Identify** a gas that was present in the Earth's original atmosphere but is no longer present. **Explain** where this gas has gone.

1.2 Investigating the structure of the Earth

'My soul can find no staircase to Heaven unless it be through Earth's loveliness.'

Michelangelo: Renaissance Artist

'It suddenly struck me that that tiny pea, pretty and blue, was the Earth. I put up my thumb and shut one eye, and my thumb blotted out the planet Earth. I didn't feel like a giant. I felt very, very small.'

Neil Armstrong: Astronaut

Working out what is in the heavens around us is relatively easy. Space is empty, and we can therefore see through it and even travel through it with relative ease. The Earth is not empty or hollow; it is full of rock and minerals and mysteries (Figure 1.9). It is a strange fact that we know more details about the galaxy spreading for light years around us than we do about what lies a few dozen kilometres below our feet. Space offers us boundless opportunities to observe and measure data to inform our theories about what processes are shaping the Universe.

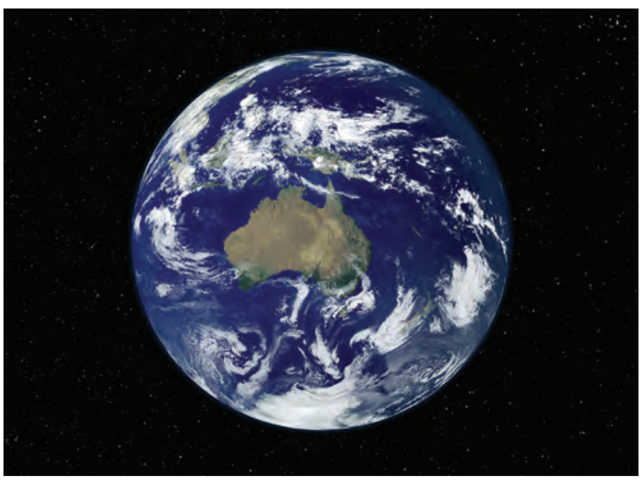


Figure 1.9 Earth from space What is inside our Earth? (NASA)

In contrast, humans have never succeeded in digging through the thin surface crust of the Earth. We have relied on weak spots and gaps in this crust that allow us to catch an occasional glimpse of what lies beneath. An alien world of magma and movement that appears to be totally removed from our experience of conditions on the surface.

It's what's inside that matters

Most primary school students can recall the fact that the Earth has a layered internal structure. The obvious question is … how do we know this if we have never been there?

ACTIVITY 1.5
THE EARTH REVEALED

This group activity is designed to give you a clearer perspective of the internal layered structure of Earth. It also gives you practice in scale drawing. Your group is to calculate the measurements needed to draw an accurate scale drawing of the Earth's internal structure. Your wedge shaped diagram will represent a segment of the Earth from the centre of the core to the crust.

Apparatus

- Sheet of butchers paper at least 1.2 m long
- String 1.2 m long
- Pencil
- Coloured textas/chalk/crayons
- Sticky tape
- 1 m ruler

Risk assessment: Low.

Method

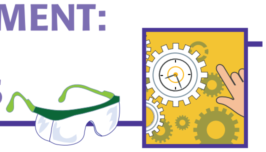
1. Make a dot at the bottom centre of a cut/torn edge of the butchers paper. This will represent the centre of the Earth and it is the reference point that your measurements are to be made from.
2. Use the metre ruler to draw angled lines exactly 1 m long forming a large 'V' (the dot is at the base).
3. Use the data in Table 1.2 to mark the distances from the centre of the Earth that each layer starts/finishes, e.g. make a mark 195 mm up each line to mark the boundary between the inner and outer core. Mark these exact distances on each line of your 'V'.
4. To join the measurements on each side with a smooth curve, tape one end of your string to your pencil (near the tip) and fix the other to the bottom of your 'V'. Adjust the string to the correct length, pull tight and swing the pencil across the diagram.

5. The height of the International Space Station (ISS) orbit has been included to give a perspective of scale in this diagram.
6. Use colours to identify your different layers. Select colours that indicate cool for the crust, hot for the mantle and increasingly hot for deeper layers.
7. Add labels and the temperatures of each layer (research). Once you finish Activity 1.6 include the densities you calculated for each layer to this poster.

Table 1.2 Earth structure.

Layer	Thickness (km)	String length for a 1 metre radius scale drawing (mm)
Inner core	1250	195
Outer core	2200	539
Mantle	2900	992
Lithosphere	50 (av.)	1000
Space Station orbit	400	1048

ACTIVITY 1.6 EXPERIMENT: MIXING FLUIDS OF DIFFERENT DENSITIES



Density is a measure of how much mass something has compared with how much space (volume) it takes up. Like solids, liquids have a variety of densities. Their density is calculated using the following formula.

$$\text{Density (g/cm}^3\text{)} = \frac{\text{mass (g)}}{\text{volume (cm}^3\text{)}}$$

When determining the mass of any liquid, the mass of the container holding the liquid must be subtracted from your calculations.

Aim: To calculate the density of different liquids and to observe their behaviour when mixed.

Hypothesis: Write your prediction about what you think will happen when low density liquids are mixed with higher density liquid.

Risk assessment: Medium. Glycerine and copper sulfate can be mild irritants. Avoid skin contact and wear safety goggles.

Apparatus

- Beaker containing copper sulfate solution
- Beaker containing glycerine
- Beaker containing vegetable oil
- 1 × 20 mL measuring cylinder
- 3 × 10 mL measuring cylinders
- Beam or electronic balance
- 3 × disposable pipettes

Method

1. Accurately measure the mass of a 10 mL measuring cylinder. Label this as measuring cylinder 1 and record its mass in your copy of Table 1.3.
2. Using the pipette, add exactly 5 mL of glycerine into measuring cylinder 1. *Note*: 1 mL = 1 cm^3.
3. Use the balance again to calculate the new mass of measuring cylinder 1. Record this in your results table.
4. Using fresh pipettes, repeat steps 1 to 3 using copper sulfate solution (measuring cylinder 2) and vegetable oil (measuring cylinder 3). *Note*: do not assume that all similar measuring cylinders have the same mass.
5. When the mass and volume of all three liquids have been measured, calculate the following.
   (a) The mass of the liquids by subtracting the initial measuring cylinder mass from that of the cylinder with liquid.
   (b) The density of each liquid by using the formula given above.
6. Pour the vegetable oil into the 20 mL measuring cylinder. Tilt the 20 mL measuring cylinder at an angle and slowly pour the glycerine into it. When this has settled, slowly pour the copper sulfate into the 20 mL cylinder in the same way.
7. Let the liquids settle and draw what you observe. Label each liquid and its calculated density.

Results: Complete Table 1.3.

Conclusion: Complete this conclusion by selecting one of the underlined words: When liquids of different densities are mixed, the denser liquids settle above/below/between the less dense liquids.

Discussion: What implications do these results have to the formation of Earth's interior structure?

Table 1.3 Fluid density results table.

Liquid	Mass (g)			Volume (cm^3)	Density (g/cm^3)
	Measuring cylinder	Measuring cylinder plus liquid	Liquid		
Glycerine					
Copper sulfate					
Vegetable oil					

Gravity and differentiation

Put simply, **gravity** is the force of attraction between two masses. This force is greater when the masses are larger and closer together. For example, a person experiences less gravity on the Moon than on Earth because the Moon has less mass. Gravity plays a fundamental underlying role in many of Earth's processes, including the water cycle, plate tectonics and differentiation.

Differentiation is the process whereby a mixture of fluids with different densities organises itself into layers (Figure 1.10). The densest layer will be on the bottom and the least dense will be on the top. This process is driven by gravity and it is the reason for the different layers that are believed to be inside Earth.

Figure 1.10 Differentiation Produces layering effects in cocktails.

Figure 1.3 illustrates the Earth and other planets forming as the result of accretion of material orbiting the Sun. As Earth grew in size and mass, its gravity also grew and attracted a hail of meteorites. This period of meteorite bombardment melted the rocks of the young Earth and allowed the molten ingredients to differentiate according to density. The densest materials, such as iron and nickel, sank to the centre under the pull of gravity while the less dense materials, such as oxides and sulfides, were pushed to the surface.

As the Earth swept its orbit free of large debris, the meteorite strikes reduced in size and frequency. This allowed the surface of our planet to cool enough for a thin crust of rock to form over the hot interior. The interior remains hot to this day because the radioactive decay of some elements acts as an additional heat to boost the inner furnace that would otherwise have slowly cooled over time.

Differentiation
http://qr.w69b.com/g/qmzhX0MF2

Internal layered structure

The early differentiation of material within the Earth is preserved in its layered internal structure. Scientists have never drilled through the crust, yet they can infer what lies deep beneath it. These inferences are based on calculations of Earth's mass, on observations of the behaviour of **seismic (earthquake) waves** as they travel through the Earth (Figure 1.11) and on the analysis of meteorites that have preserved the original ingredients of the Solar System.

Earth's mass can be calculated by carefully measuring its gravitational pull and factoring in Earth's diameter. If Earth's interior consisted of rocks with similar densities to those in its crust, its gravity should be considerably less than it is. The only way to account for this sizeable difference is if the rocks within Earth's interior are much denser than those on the surface.

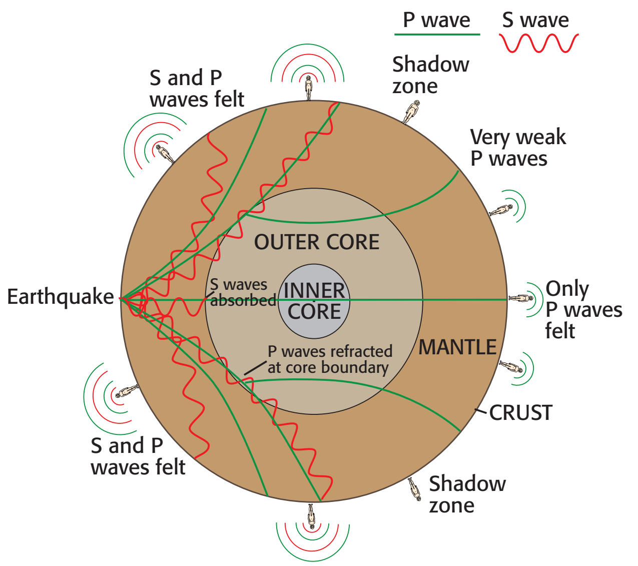


Figure 1.11 Seismic waves The structure of Earth's interior can be inferred from the behaviour of seismic waves as they pass through the planet.

Seismic waves produced by earthquakes provide geologists with the best tool for indirectly observing the Earth's interior. Whenever an earthquake occurs, it releases different types of waves which travel at different speeds and in different ways. The slowest of these waves (**L waves** or Love waves) move along the Earth's surface only. The other two types (**primary** or **P waves** and **secondary** or **S waves**) can move through the deeper layers of the Earth. P waves are compression waves that can travel through both solids and liquids. S waves are transverse waves and can travel through solids but not through liquids. By measuring speed changes as well as direction changes caused by reflection and refraction of the waves, geologists can determine the internal structure of the Earth.

We know that the upper mantle is partly molten at about 100 kilometres deep because both P and S waves slow down at this depth (Figure 1.12). We know that density and pressure increase with depth in the mantle because the velocity of both P and S waves increases with depth (waves travel faster through denser material). We know that the boundary between the mantle and the outer core is about 2900 kilometres in depth and that the outer core is a dense liquid. This can be determined because S waves are stopped at this depth (they cannot travel through liquids) and P waves are slowed and bent. A surge in the velocity of P waves at a depth of 5100 kilometres indicates a solid and even denser inner core. These results are supported by faint echoes of P waves being reflected back to the surface from the changes at these depths.

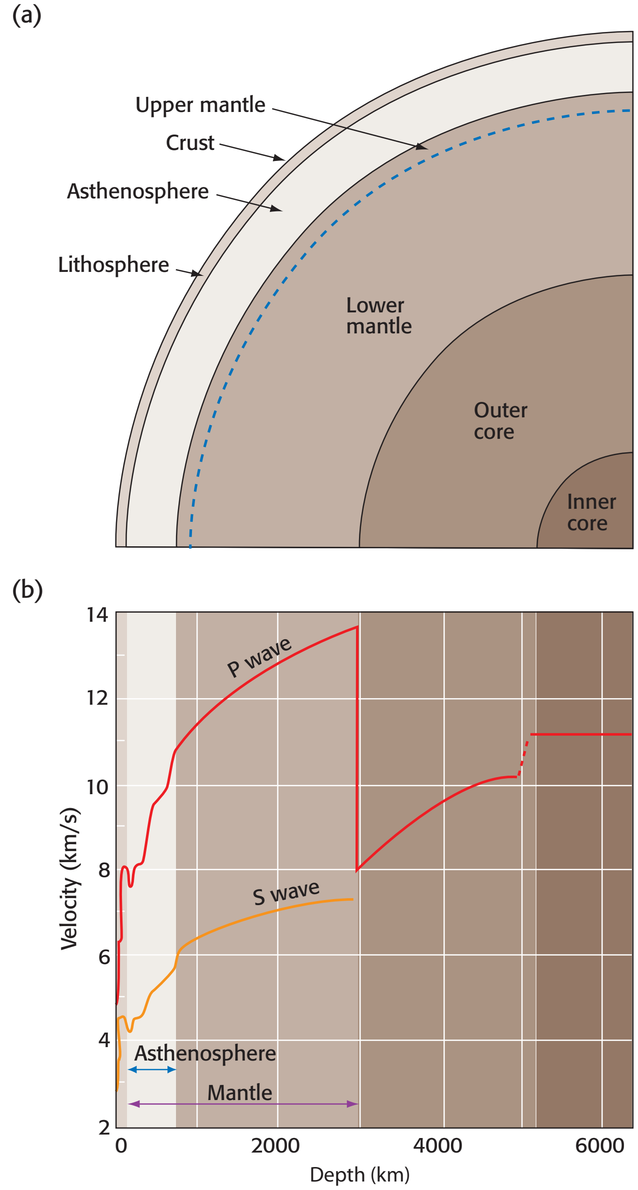


Figure 1.12 Earth's internal layered structure (a) The layered structure of Earth – the crust is very thin at this scale. (b) Changes in the speed of seismic waves helped geologists to determine the internal structure of the Earth.

Meteorites

The oldest crustal rocks yet found are from Western Australia and date back to about 4.2 billion years. The regular processes which break down and recycle rocks have destroyed the first rocks that formed on our planet. However, these ancient Australian samples are not the oldest rocks found by geologists (Figure 1.13).

Meteorites were made from the same ingredients at the same time as the Earth and the rest of the Solar System. Therefore, analysis of the physical and chemical composition of meteorites allows scientists to read our planet's original recipe (Table 1.4). Most meteorites are much like ordinary Earth stones, but are a little denser. A small percentage of meteorites contain abundant heavy metals, such as iron, nickel and iridium. When you compare the overall density of the Earth (5.5 g/cm^3) with the lower density of stony meteorites (chondrites, 3.3 g/cm^3), we must explain why the overall density is so high. There is no problem if the centre of the Earth is made of iron/nickel similar to the iron meteorites (4 to 8 g/cm^3). This data confirms what has been found during seismic studies. The inference can be made that these dense materials were part of the early Earth, but melting and differentiation has caused them to sink out of sight to the deep interior.

Figure 1.13 Antarctica offers a treasure trove for meteorite hunters Ice flowing over buried mountain ranges pushes the dark meteorites to the surface where they can be easily spotted. These meteorites are samples of the original ingredients from which the Earth was built. (Royal Belgian Institute)

ACTIVITY 1.7 EXPERIMENT: ROCK DENSITY

Rocks are made up of minerals that have specific chemical and physical properties. Minerals are classified according to their chemical make-up and physical characteristics. Density is one of these physical characteristics.

Aim: To determine and compare the densities of materials that represent different layers of the Earth.

Table 1.4 Meteorites.

Type	Percentage of all found (%)	Average density (g/cm^3)	Appearance and composition
Stony	63	3.3	Generally have a dark grey or black surface due to melting and a lighter grey interior. Mainly silicate minerals they contain small round structures.
Carbonaceous	3	2.4	Contain traces of organic compounds.
Enstatite	1	3.6	Contain small amounts of the mineral enstatite (magnesium silicate).
Achondrites	3	3.1	Similar to stony meteorites but they do not contain the small round internal structures.
Stony-iron	1	4.5	Mixture of iron and nickel with silicate material.
Iron	4	7.5	Composed of iron-nickel alloys.
Unclassified	25		

Risk assessment: Low. Slide or lower the materials into the measuring cylinders to avoid breakages.

Apparatus

- Beam or electronic balance
- Measuring cylinder
- Cotton thread or similar
- Paper towels
- Small specimens of these rocks (able to fit in a measuring cylinder):
  - Granite and/or rhyolite (representing the continental crust)
  - Basalt and/or gabbro (representing the oceanic crust)
  - Haematite or an iron bolt (representing the core)
  - Peridotite or olivine (representing the mantle)

Method

1. Select the rock that is to represent continental crust (granite or rhyolite). Measure and record its mass in your copy of Table 1.5.
2. Half fill the measuring cylinder with water and make an accurate reading of water volume in cubic centimetres (cm^3). Record this. (Note that 1 mL = 1 cm^3.)
3. Carefully slide the rock into the angled measuring cylinder or lower the rock into the water using thread until it is fully submerged. Record the new volume reading.
4. The volume of the rock can be calculated by subtracting the original volume from the second volume reading. Calculate and record the volume of the rock.
5. Repeat these steps with rocks representing:
   (a) Oceanic crust, such as basalt or gabbro.
   (b) The mantle, such as peridotite or olivine.
   (c) The core, such as haematite or the iron bolt. (*Note*: Haematite is not formed in Earth's core but is rich in iron, which is a major component of the core.)
6. Calculate the density of each rock by using the formula used in the last activity.
7. Copy a diagram of the Earth's structure into your notebook (Activity 1.8 or Figure 1.12 (a)). Label the densities you have determined and where they are located.

Results

Table 1.5 Rock density.

Rock used	Region of Earth represented	Mass (g)	Volume (cm^3)	Density (g/cm^3)
	Continental crust			
	Oceanic crust			
	Mantle			
	Core			

Conclusion: Write a sentence that summarises the observed trend of density in comparison to depth.

Our Earth was once a molten ball of materials gathered together by the accretion of dust in the disc around a young star. The last two activities illustrate how the denser materials, such as iron and nickel, would naturally have sunk to the core while the less dense materials, like granite and basalt, would naturally have risen to the surface. This explains the indirect observation that Earth has a layered internal structure, with denser materials closest to the core and the lighter materials nearer the surface.

ACTIVITY 1.8
CHEMICAL COMPOSITION OF THE EARTH

Cumulative bar charts are a type of graph that shows the proportions of things making up a whole, similar to pie charts. For example, a cumulative bar chart showing the proportion of flavours in Neapolitan ice cream might look like Figure 1.14. Bar charts must be accurately measured and may be vertical (like Figure 1.14) or horizontal.

1. Use the data in Table 1.6 to construct two cumulative bar charts: one for the relative abundance of elements in the entire Earth; the other for the relative abundance of elements in the Earth's crust.
2. Use a spreadsheet program of your choice to graph this data (Table 1.6). Copy the graph type that you think best illustrates these results into your notes.

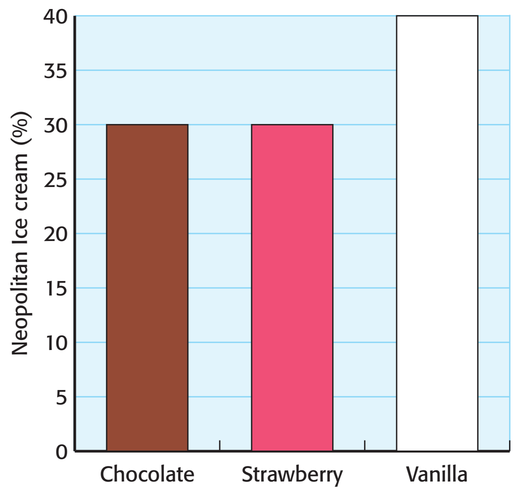


Figure 1.14 Cumulative bar chart The proportion of flavours in Neapolitan Ice cream.

3. Iron is the most abundant element in the Earth, yet it is only present in relatively small amounts in the crust.

(a) Where is the rest of the Earth's iron?

(b) Account for this uneven distribution.

4. With specific reference to two other elements, account for their high or low abundance in the crust.

Table 1.6 Relative abundance of elements.

Element	Abundance in whole of Earth (%)	Abundance in crust (%)
Iron	35	6
Oxygen	30	46
Silicon	15	28
Magnesium	13	4
Nickel	2.4	0.009
Sulfur	1.9	0.04
Calcium	1.1	2.4
Aluminium	1.1	8
Potassium	0.16	2.3
Sodium	-	2.1
Other	0.5	1.2

SCIENCE SKILLS

1. **Define** means to state meaning and identify essential qualities. You may need to state the limitations of the definition, and may need to state multiple meanings. For example, **define** the term meteorite.

Answer:

A piece of rock or metal that has fallen to the Earth's surface from outer space as a meteor.

2. The Flat Earth Society 'is dedicated to unravelling the true mysteries of the Universe and demonstrating that the Earth is flat and that Round Earth doctrine is little more than an elaborate hoax.'

(a) **Outline** at least one piece of evidence that the Flat Earth Society uses to show that the Earth is flat and not roughly a sphere.

(b) **Describe** how the Flat Earth Society accounts for the visit of astronauts to the Moon.

(c) How good are the claims made by the Flat Earth Society? **Explain** your answer.

3. Using Table 1.6, construct a bar graph to show the relative abundance of the top eight elements in the Earth's crust.

TO THINK ABOUT

Set 1

1. **Explain** why it is easier to study outer space than it is to study inner space – inside the Earth.

2. **Outline** the role of gravity in the formation of the Earth.

3. **Describe** the difference between L waves and S and P seismic waves.

4. **Explain** why Earth's rocks become more dense with depth.

5. **Explain** how scientists are able to describe Earth's interior when it has never been directly observed.

Set 2

6. **Describe** how meteorites can help understand the formation of the Earth.

7. What is differentiation? **Describe** an experiment that can simulate the differentiation of the early Earth.

8. Some elements in the Earth's crust are underrepresented in the crust compared to deeper down, while others are overrepresented in the crust compared to deeper down. **Explain** this uneven distribution.

9. **Define** the term density. **Describe** how the density of rock samples can be accurately determined.

10. **Draw** a labelled diagram of the Earth in cross-section.

1.3 Structure of the Earth

An attempt to drill as deep as possible through the Earth's crust was undertaken by Russian scientists on the Kola Peninsula (Figure 1.15). Beginning in 1970 they were able to drill a borehole to a depth of 12 262 metres by 1989. The deepest drill hole in Australia only gets to around 3000 metres. The Kola borehole only reached around one third of the way to the bottom of the continental crust (estimated at 35 km thick in that location). As you can see, we need other techniques such as seismic wave analysis to determine the inner structure of the Earth.

Answers

Chapter 1 Structure Of the Earth, the Early Geosphere, Atmosphere and Hydrosphere

1.1 Formation of the Earth

1. Hydrogen has been converted into heavier elements inside massive stars. When these explode in a supernova, the new material is scattered far and wide. A shock wave resulting from such a supernova can cause an area of dust and gas measuring light years across to begin to contract forming a protoplanetary disc.
2. Within a protoplanetary disc, fine particles began to clump together and the whole cloud began to rotate at a faster rate. Eventually, most of the material is located in a central sphere with a wide disc extending around its equator. Due to the huge internal pressures caused by its collapse, the central protoplanetary sphere became very hot and glows dimly, forming a protostar.
3. • Accretion is the gathering together of small bodies into larger ones by gravity.
   • Debris within the disc around a protostar gathers into numerous large clumps or protoplanets by the process of accretion.
   • The protoplanets attract any remaining dust in the disc around the central star.
4. Energy is produced in stars by nuclear fusion. Lighter atoms of hydrogen are heated by the collapsing protostar so they are travelling fast enough to fuse together forming helium. In the process, energy is released.
5. Once a fusion reactions starts, a protostar ignites like a massive and sustained nuclear bomb, becoming a true star. Further collapse is prevented by these nuclear fusion reactions in the core of the Sun pushing outwards against gravity.
6. • The infant Solar System would have contained hundreds of small protoplanets with overlapping orbits.
   • The protoplanets would have been constantly bombarded with meteorites as they swept into each other or cleared their orbits free of debris.
   • This bombardment not only increased the Earth's size and mass but also heated its rocks to melting point.
   • The gases released from these molten rocks would form Earth's first atmosphere.
   • Below the surface, differentiation occurs when heavier metallic elements sink deep into the liquid Earth, while the lighter elements floated at the surface like volcanic froth. This forms the layered structure we know today.
7. The Moon is believed to have been formed by one colossal impact between the Earth and another protoplanet the size of Mars. Huge amounts of debris exploded into space, much of it falling back to Earth and some of it coalescing to form the Moon.
8. During a smash up derby, cars race around a track and try to push other cars out of the way by colliding with them. Sometimes they become entangled and cannot be separated. In a vaguely similar way, the protoplanets around the protostar will collide and sometimes coalesce.
9. The molten rocks of the young, hot Earth released a mixture of gases, just as volcanoes still do today. Some of these gases remain in the atmosphere to this day; others were quickly removed by a variety of processes. While their relative proportions are uncertain, the main gases of the original atmosphere seem to have been nitrogen (N_2), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4) and water vapour (H_2O).
10. Hydrogen gas was present in the original atmosphere. Because these hydrogen atoms are so small, gravity is not sufficient to hold them and they drift off into outer space.

1.2 Investigating the structure of the Earth

1. Since most of outer space is a vacuum, it is transparent to light from which we can gain much information. However, the Earth is solid and it takes an enormous amount of effort to drill even a few kilometres.
2. • Gravity is a force of attraction between masses.
   • Since outer space is a vacuum, even a weak force of gravity can cause masses of rock to move towards each other.
   • Once pieces of rock had formed a small mass, it could attract more and more and gradually grow in size.
   • Gravity acts on outer layers of the Earth compressing rocks deeper down making them denser.
3. L waves are transverse waves generated during earthquakes and explosions that travel over the surface of the Earth. S and P waves are also generated during earthquakes and explosions but can travel through the Earth revealing its structure.
4. Gravity acts on outer layers of the Earth compressing rocks deeper down making them denser.
5. The structure of the Earth's interior can be determined from seismic waves generated by earthquakes or by explosions and other means. P waves are compression waves that can travel through both solids and liquids. S waves are transverse waves and can travel through solids but not through liquids. By measuring speed changes as well as reflection and refraction of the waves, geologists can determine the internal structure of the Earth.
6. Meteorites were formed at the same time as the planets allowing us to determine the Earth's original chemical composition. As well, their chemical composition has not been changed by weathering caused by water or air. Many meteorites contain abundant heavy metals, such as iron, nickel and iridium. The inference can be made that these dense materials were part of the early Earth, but melting and differentiation has caused them to sink out of sight to the deep interior.