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Executive Preview

Marine Science

for Cambridge International AS & A Level

MULTI-COMPONENT SAMPLE

Matthew Parkin, Jules Robson & Paul Roobottom

Brighter Thinking
Better Learning

Welcome to the new editions of our Cambridge International AS & A Level Marine Science resources providing everything that you need to effectively teach the Cambridge AS & A level Marine Science (9693) syllabus, for examination from 2022.

This new series has been designed around extensive research interviews and lesson observations with teachers and students around the world following the course. As a result of this research, some changes have been made to the new series, with the aim of solving and supporting your biggest classroom challenges and developing your students' passion and excitement for the wonders of the underwater world.

As practical work and the scientific method are an essential part of the revised syllabus, we have included all of the core practical activities in the coursebook, with helpful support and suggestions in this teacher's resource. We have also added a practical skills chapter to the coursebook, introducing students to experimental planning, presenting data and evaluating experimental methods, with examples and questions. We hope this will be a useful introduction and reference point for students.

We have introduced a workbook to the series for the first time, which is split into two sections. The first section includes exercises and exam-style questions for each topic and the second section includes 27 exciting practical activities to develop your students' investigative skills. Support notes and sample data for these activities are provided in this teacher's resource.

As we develop new resources, we ensure that we are keeping up to date with best practice in pedagogies. For this new series we have added new features to the coursebook, such as engaging projects to develop students' collaborative skills and self-evaluation checklists at the end of each chapter for students to track their progress and take control of their own learning.

Finally, we have updated the teacher's resource to make it as useful and relevant as possible to your day-to-day teaching needs. From teaching activity, assessment and homework ideas, to how to tackle common misconceptions in each topic, to support with running practical activities, we hope that this handy resource will inspire you, support you and save you much-needed time.

We're very pleased to share with you draft chapters from our forthcoming *Cambridge International AS & A Level Marine Science Coursebook, Teacher's Resource* and *Workbook*. We hope you enjoy looking through them and considering how they will support you and your students.

If you would like more information or have any questions, please contact your local sales representative: **cambridge.org/education/find-your-sales-consultant**

Gemma Coleman
Commissioning Editor for Marine Science
Cambridge University Press

Brighter Thinking
Better Learning

Hello, my name is Matthew Parkin and I am one of the authors for the new second edition of the *Cambridge International AS & A Level Marine Science* series. I am an experienced teacher, trainer and examiner. Meeting fellow professionals in different countries is a very enriching experience and has really helped to give me a feel for what learners and teachers want from published resources. I am sure that you will be aware that the syllabus (9693) has been revised both in terms of content and assessment for first examination in 2022. These changes reflect the global interest in the subject, which is highly valued by universities and employers all around the world. Please do take a look at the full syllabus document at cambridgeinternational.org. It gives me great pleasure to introduce this second edition of the marine science series that has been written to guide both students and teachers through the revised syllabus.

To help prepare both you and your students, we have:

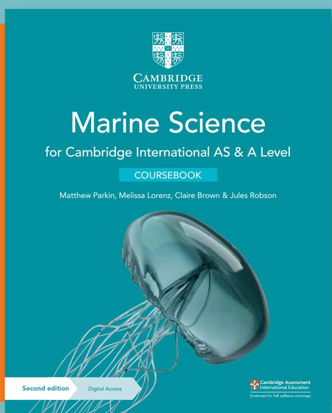
- Included detailed coverage of all areas of the revised syllabus
- Included glossaries of key scientific vocabulary that students need to know
- Provided details of all the new core practicals in the coursebook including sample data
- Added additional practicals, along with ways of developing practical and investigative skills in the workbook
- Provided questions within each chapter of the coursebook to help students develop their knowledge
- Added further exercises to help students develop data analysis skills and their knowledge in the workbook
- Included exam-style questions in both the coursebook and workbook and accompanying mark schemes in the teacher's resource
- Included up-to-date, relevant and interesting case studies to help develop students' understanding and thinking skills
- Added all the mathematical skills, including statistical tests, which students need to understand in the coursebook. The workbook includes many more opportunities to develop these skills and takes students through all the necessary steps
- Added opportunities for students to carry out mini research projects in each chapter of the coursebook
- Fully updated the teacher's resource containing teaching ideas, worksheets, revision materials, maths skills and specific guidance on practical skills with sample data for when practicals cannot be carried out

All the authors for this series are experienced teachers of biology and marine science and have an excellent understanding of how students learn. The development of the syllabus is very exciting and this excellent series of resources should really help you and your students to get to grips with all the changes. We wish you and your students every success.

Kind regards,
Matthew D Parkin
Author of *Cambridge International AS & A Level Marine Science (2nd edition)*

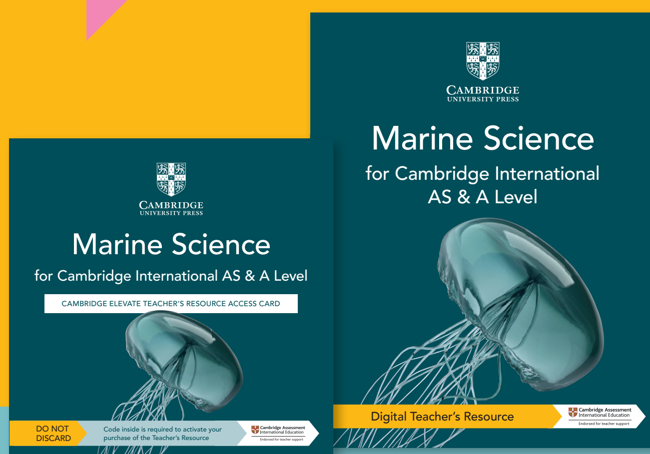
How to use this series

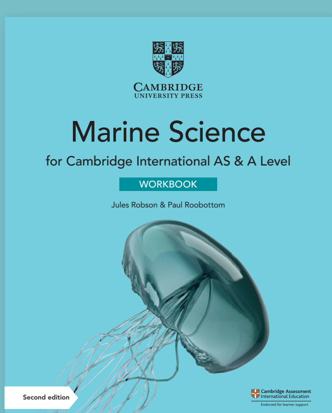
This suite of resources supports students and teachers following the Cambridge International AS & A Level Marine Science syllabus (9693). All of the books in the series work together to help students develop the necessary knowledge and scientifi c skills required for this subject.



The coursebook covers the full Cambridge International AS & A Level Marine Science syllabus (9693), with the chapter structure following the syllabus order. Each chapter includes exercises to develop problem-solving skills; practical activities to help students develop investigative skills; and international case studies and projects to illustrate phenomena in real-world situations. There is a new practical skills chapter that introduces students to experimental planning, presenting data and evaluating experimental methods, with examples and questions.

The teacher's resource supports and unlocks the projects, questions and practical activities in the coursebook, as well as providing detailed lesson ideas and plans. It includes support notes for the practical activities in the workbook and coursebook and sample data for the workbook practical activities. It also contains answers to all questions in the coursebook and workbook.





The workbook contains engaging exercises and exam-style questions to develop scientific skills such as problem-solving, handling and applying information, and mathematical skills for science. It also contains practical activities for each syllabus topic area, to support students' investigative skills, including planning experiments and data exercises.

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Marine Science

for Cambridge International AS & A Level

COURSEBOOK

Matthew Parkin, Melissa Lorenz, Claire Brown & Jules Robson

Second edition

Digital Access

Cambridge Assessment International Education
Endorsed for full syllabus coverage

Contents

How to use this book

Throughout this book, you will notice lots of different features that will help your learning. These are explained below. This book is divided into separate AS Level and A Level chapters. If you are studying AS Level Marine Science, you will use Chapters 1-5. If you are studying A Level Marine Science, you will need Chapters 6-9.

LEARNING INTENTIONS

These set the scene for each chapter, help with navigation through the coursebook and indicate the important concepts in each topic.

BEFORE YOU START

This contains questions and activities on the topic knowledge that you will need before starting a chapter.

PRACTICAL ACTIVITIES

Practical activities give you the opportunity to test out the theory that you have learnt in a chapter and investigate a topic for yourself.

COMMAND WORDS

Command words that appear in the syllabus and might be used in exams are highlighted in the exam-style questions when they are first introduced. In the margin, you will find the Cambridge International definition and some further explanation on the meaning of these words.

Test yourself

Test yourself questions appear at the end of each section in a chapter. These give you the chance to check that you have understood the topic that you have just read about.

REFLECTION

Reflection questions follow on after each practical activity. These ask you to look back on the practical and encourage you to think about your learning.

SCIENCE IN CONTEXT

This feature presents real-world examples and applications of the content in a chapter, encouraging you to look further into topics. There are discussion questions at the end which look at some of the benefits or problems of these applications.

KEY WORDS

Key vocabulary is highlighted in the text when it is first introduced. Definitions are then given in the margin, which explain the meanings of these words and phrases. You will also find definitions of these words in the Glossary at the back of this book.

PROJECT

Projects give you the opportunity to work collaboratively with other students. Your group will explore a particular question or topic, and will then present the outcome via various creative methods. Afterwards, you can reflect on or assess the project with the 'Thinking about your project' questions.

CASE STUDY

Case studies take an in-depth look at a topic in the chapter and present it in a real-world setting. This will help you to discuss issues relating to this topic.

MATHS SKILLS

Maths skills contain background information, worked examples and practice questions that will help you to develop the mathematical awareness that is needed for your Marine Science course.

EXAM-STYLE QUESTIONS

Questions at the end of each chapter provide more demanding exam-style questions, some of which may require you to use your knowledge from previous chapters.

SELF-EVALUATION

At the end of each chapter, you will find 'I can' statements which match the learning outcomes at the beginning of the chapter. You might find it helpful to rate how confident you are for each of these statements when you are revising. You should revisit any topics that you rated 'Needs more work' or 'Almost there'.

I can	See topic...	Needs more work	Almost there	Ready to move on

EXTENDED CASE STUDY

Each chapter is followed by a longer case study, which illustrates a more complex topic in a real-world setting. This will help you to think about this topic and discuss issues relating to it in more depth.

Practical Skills chapter

This chapter contains some additional features to support your learning.

A Level content

If you are studying A Level Marine Science, you will find that any relevant content beyond AS Level in this chapter is highlighted in blue font.

EXAMPLES

You will find examples throughout this chapter that present practical activities that you may encounter as part of your Marine Science course. These conclude with 'Now you try' questions that encourage you to think about various aspects of the practical for yourself.

SUMMARY

At the end of each section in this chapter, you will find a summary. This list summarises the steps that you should take to complete some of the key skills relating to practical activities.

Chapter 1
Water

LEARNING INTENTIONS

In this chapter you will learn how to:

- use the kinetic particle theory to explain the changes of state in water, between solid, liquid and gas
- describe how the structure of atoms leads to the formation of different bonds such as covalent, ionic, and hydrogen bonds
- explain how hydrogen bonding provides special properties to water
- explain the terms solute, solvent, solution and solubility in order to apply these terms to the dissolution of substances in the ocean
- explain the impacts of physical factors, such as temperature and salinity and pressure, on the solubility of salts and gases in seawater
- explain how run off, precipitation and evaporation impact the salinity of seawater
- describe the pH scale and techniques used to measure pH in water
- explain the effects on the density of seawater caused by water temperature, pressure and salinity
- state why ice floats and explain why this is important as a thermal insulator and habitat to marine organisms
- describe how temperature and salinity gradients form in water columns to produce ocean layers and how subsequent mixing of these layers may occur.

BEFORE YOU START

- With a partner discuss your understanding of the term 'atom'. Sketch a labelled diagram to show what you understand atoms to be made from. Compare your drawing to others in class and review with your teacher.
- We use water to clean clothes, dishes and our own bodies. Discuss with a partner why water is so good for cleaning.
- Write one or two questions about what affects the density of seawater on a sticky note and post them on the board. With your class, compare and organise your questions into topics for discussion.

THE STUDY OF SEAWATER

When beginning your studies in marine science it helps to gain a scientific understanding of the properties of seawater. After all, 71% of our planet is covered in water and the vast majority of that water (about 97%) is held in the oceans. Some people may think that seawater is simply saltwater – they may think that, if you add some table salt to a glass of water, you can recreate seawater that is suitable for fish and other organisms to live in. But this is not true.

Seawater is a complex mix of chemicals. In fact, nearly every **element** in the Periodic Table has been located, usually combined with other elements as many different **compounds**, within the ocean's vast waters. Water itself is made from hydrogen and oxygen; it interacts with all the other substances dissolved or immersed in it. These substances interact with the water **molecules** to support life in our oceans. The concentrations of these elements and their compounds determine what organisms are capable of living within different marine ecosystems, and how they will survive.

It is imperative, then, to know how these substances interact together and how water molecules function to support life. To begin that study, we must look to the **atom** and build our way up from there.

Questions

1. Do you agree that starting with the simplest form and working up is the best way to begin? Why or why not?
2. Which of our senses can we use to try to determine what is in a sample of seawater? How reliable are these senses and can you suggest other methods or equipment to determine what is in the sample of seawater?

KEY WORDS

element: a substance that cannot be chemically broken down into a simpler substance

compound: a substance containing two or more elements chemically bonded together

molecule: a group of atoms covalently bonded together

atom: The smallest particle an element can be divided into and still be the same substance

1.1 Particle theory and bonding

An atom is the smallest particle that an element that be separated into and still be the same substance. Atoms are the particles found in everything around and within us.

Atomic movement

The **kinetic particle theory (particle theory)** describes all matter as a collection of particles that are in constant, random motion, even if those movements are only small vibrations. The amount of movement a particle has is determined by the amount of energy it has. The chair you are sitting on, the water you are drinking, and the air you are breathing are all examples of many particles that have joined together to create materials. Matter generally exists in three states: solid, liquid, or gas (Figure 1.1). As energy is transferred away from, or transferred to, these molecules, the state of matter may change as the movement of the *molecules* within the matter changes.

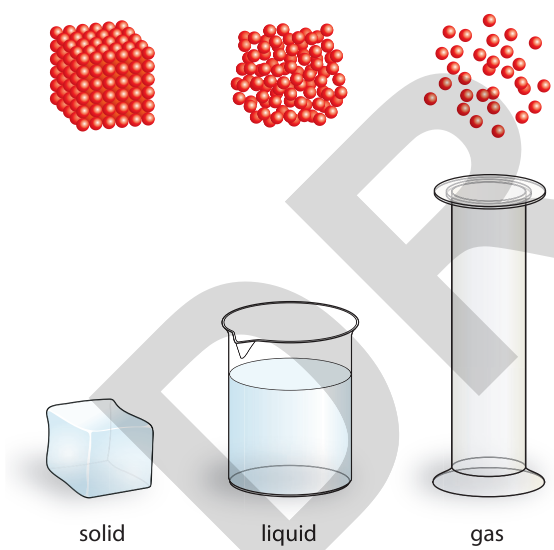


Figure 1.1: The states of matter and the arrangement of their particles.

Water molecules can be used to demonstrate this theory. When liquid water cools down, the movement of the water molecules slows until they arrange in a regular structure called a lattice. The molecules become fixed in position in this lattice resulting in a solid (ice) forming. As more molecules join the lattice the ice crystals grow larger.

When ice is heated the water molecules are given more energy, resulting in them vibrating faster until the forces holding the molecules together start to break. The water molecules nearest the outer surfaces of the ice crystals break free and are able to flow away from the crystals, taking the shape of the container they are in. The water molecules are closely packed to each other in a liquid but able to move freely past each other; this explains why liquids can take the shape of their container but cannot be compressed – they are already very close to each other.

When liquid water is heated the particles gain more energy, making them move faster and slightly further from each other. Some of the collisions between water molecules transfer enough energy for molecules at the upper surface to escape the forces attracting them to other molecules, and they can evaporate into the air above. This process is essential to the water cycle and occurs faster as the surface water becomes warmer. When water approaches its boiling temperature (100 °C at 1 atmosphere pressure), all the water molecules have enough energy to break the forces holding them together and water rapidly evaporates (boils). **Water vapour** is the term given to gaseous water (both from evaporation and boiling).

A brief understanding of atoms

Atoms are made of three smaller particles that, depending on their numbers, give the atom its characteristics (or properties). These subatomic particles are **protons**, **neutrons** and **electrons**. Protons are positively charged, neutrons are neutral (they have no

KEY WORDS

kinetic particle theory (particle theory): the theory of how particles (such as atoms and molecules) move in relation to each other and the amount of energy within the system

water vapour: gaseous phase / state of water; produced when liquid water evaporates or boils

protons: positively charged subatomic particles contained within the nucleus of an atom

neutrons: neutral subatomic particles contained within the nucleus of an atom

electrons: negatively charged subatomic particles that orbit the nucleus of an atom electrical charge), and electrons are negatively charged. An atom has an equal number of electrons and protons, so they are neutral.

Protons, neutrons, and electrons are arranged within the atom to provide stability and structure (see Figure 1.2). At the centre of the atom is the **nucleus**. The nucleus is made of the neutrons and protons. Electrons move around the nucleus in orbits called **shells**. These shells vary in size and distance from the nucleus depending on how many electrons are present. The first shell nearest the nucleus can hold two electrons. This is the only shell present in both hydrogen and helium. The next two shells hold up to eight electrons. Atoms are at their most stable when their outermost shell containing electrons is full.

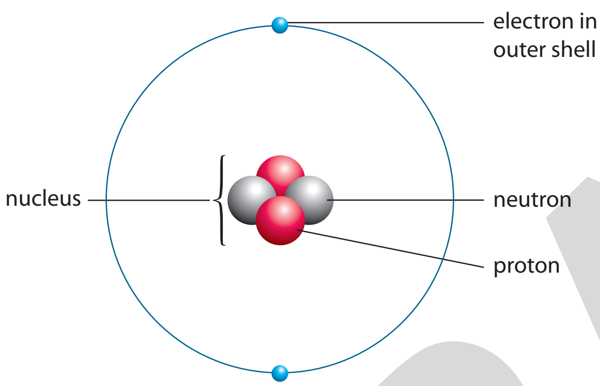


Figure 1.2: The atomic structure of helium showing the relative positions of the protons, neutrons and electrons.

The periodic table you might see hanging on the wall in many science classes lists all the known types of atoms. These different types of atoms are called elements. An element is made of atoms that have a specific number of protons. This **atomic number** never varies and helps us to identify the characteristics of elements. Seawater is a mixture of different elements and compounds. Examples of elements we find in the ocean include carbon, hydrogen and oxygen.

Bonding properties of atoms

When individual atoms come together to form different substances, they form **bonds**. A substance with a specific ratio of different elements bonded together, such as water, is called a compound. A water molecule is two atoms of hydrogen bonded to one atom of oxygen. Water molecules always have a 2[H]:1[O] ratio. A compound's properties can be very different from those of the elements that it is made of. For instance, at room temperature, both hydrogen and oxygen are gases which require very low temperatures and high pressures to become liquid. When combined in a 2H:1O ratio, however, water can be formed, which is liquid at room temperature. The new characteristics a compound develops through bonding are called **emergent properties**.

The type of bond formed between the atoms of a compound will also play a part in the emergent properties of the compound. There are three major categories of bonds that we will discuss: **covalent bonds**, **ionic bonds** and **hydrogen bonds**. All three bond types play a major role in how the ocean works and how organisms can make the ocean their home.

Covalent bonds

A covalent bond forms when two atoms share a pair of electrons. Covalent bonding occurs in most non-metal elements, and in compounds formed between non-metals.

Because the atoms are sharing the electrons, both atoms have complete outer shells. This sharing of electrons also makes this type of bond between atoms one of the strongest, requiring a large amount of energy to break.

KEY WORDS

nucleus: the positively charged central core of an atom that is made of protons and neutrons

shells: each of a set of orbitals around the nucleus of an atom that can be occupied by electrons

atomic number: the number of protons contained in the nucleus of an atom

bond: a strong force of attraction holding atoms together in a substance

emergent properties: characteristics that are present within a compound or molecule of two or more different elements that those elements do not possess on their own

covalent bond: chemical bond that involves the sharing of electron pairs between atoms

ionic bond: chemical bond that involves the attraction between two oppositely charged ions

hydrogen bond: a weak bond between two molecules due to the electrostatic attraction between a hydrogen atom in one molecule and an atom of oxygen, nitrogen or fluorine in the other molecule

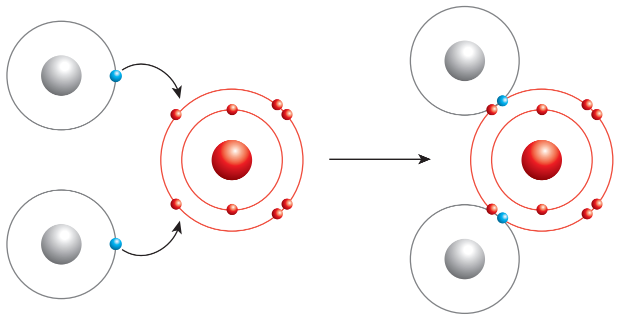


Figure 1.3: The formation of the covalent bonds in water molecules. The red atoms represent the oxygen molecules and the blue atoms represent the hydrogen atoms.

Compounds with covalent bonds are able to exist as a solid, liquid or gas at room temperature and normal atmospheric pressure. Therefore, it should come as no surprise that water is one of the most prevalent covalent compounds on our planet. Each water molecule contains two covalent bonds connecting the oxygen atom to each of the hydrogen atoms (Figure 1.3). These bonds form when an oxygen atom, which only has six electrons in its outermost shell, reacts with two hydrogen atoms, with only one electron each. The hydrogen atoms share their individual electrons with the oxygen atom. The shared electrons orbit around the atoms connected in the bond, filling the outer shells of the oxygen and the hydrogen. Many compounds in seawater have covalent bonds (Figure 1.4).

Carbon dioxide, needed by plants for photosynthesis, and oxygen, needed by organisms for respiration, also use covalent bonds to hold their atoms together. Speaking of photosynthesis, the glucose produced through photosynthesis is also a covalently bonded carbohydrate. This is important because a lot of energy is stored in the covalent bonds that join molecules, making glucose a useful molecule for holding chemical energy. In ecosystems where photosynthesis is not possible, some bacteria use the process of chemosynthesis to break apart the covalent bonds within the molecule sulfur dioxide in order to obtain the energy needed for survival (see Chapter 7). In each instance, these atoms are sharing one or more pairs of electrons creating strong chemical bonds.

Ionic bonds

An **ion** is an atom that has gained or lost an electron from its outer shell. This change in the number of electrons gives the atom an electrical charge. An electron will move from one atom, which results in either filled or empty outer electron shells. If an atom loses an electron, the ion created will have a positive charge because the protons in the nucleus (positive charge) now outnumber the electrons in the outer shell (negative charge). If an atom gains an electron, the ion created will be negatively charged due to an excess of electrons compared to protons.

KEY WORD

ion: an atom or molecule that has lost or gained one or more electrons creating an electrical charge

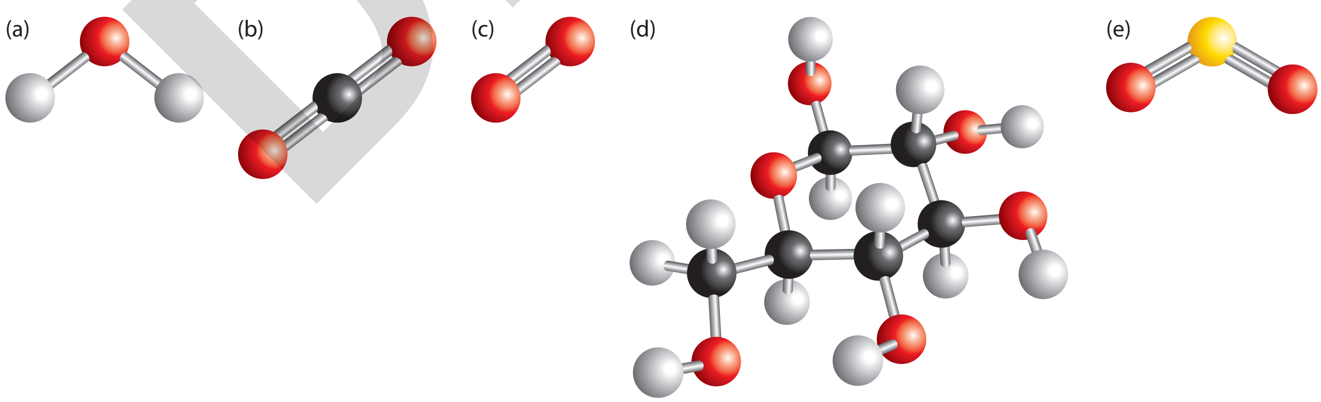


Figure 1.4: Common covalently bonded molecules in seawater: (a) water (H_2O); (b) carbon dioxide (CO_2); (c) oxygen (O_2); (d) glucose ($C_6H_{12}O_6$); and (e) sulfur dioxide (SO_2).

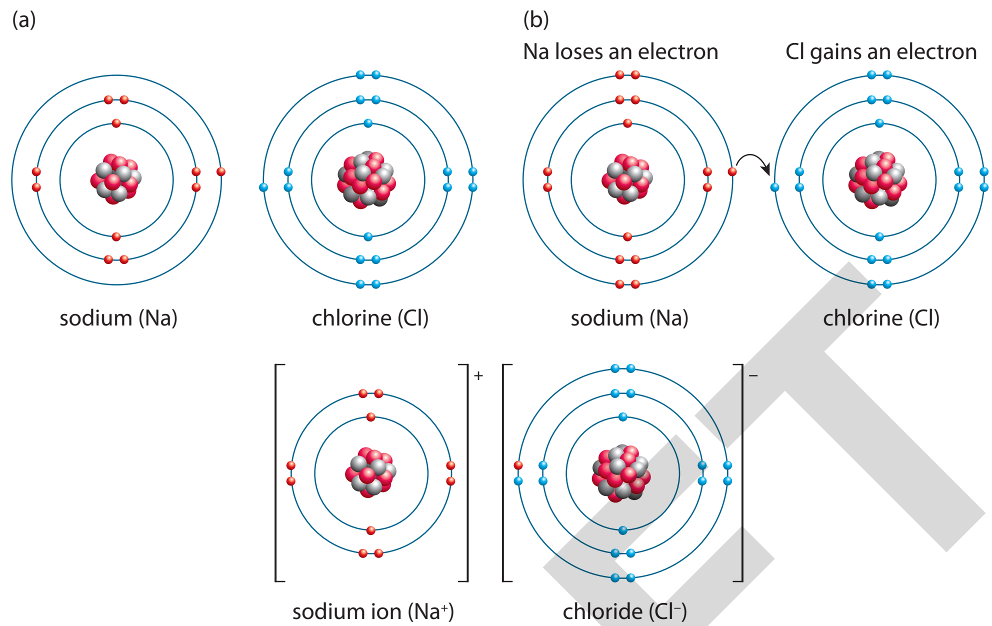


Figure 1.5: The formation of an ionic bond between sodium and chloride atoms.

So, how do ionic bonds form? When an ion loses an electron, its positive charge is attracted to the newly formed negative ion that gained its electron. This electrostatic attraction causes an ionic bond to form.

The process of forming an ionic bond is seen in Figure 1.5. In step (a) sodium and chloride both have incomplete outer shells, with sodium having a single electron and chloride having seven. In step (b) sodium's single electron breaks away and moves to complete chloride's outer shell, making both ions more stable in the process. In step (c) sodium has a positive charge, chloride has a negative charge. The electrostatic attraction between the positive sodium ions and negative chloride ions creates an ionic bond.

It is important to remember that many atoms of sodium and chlorine react together in this way, and the resulting positive and negative ions can create solids that have a three-dimensional ionic lattice structure, a small part of which is shown in Figure 1.6.

Salts are made from ions, which are very important compounds in our oceans. There are many types of salts found in the ocean including sodium chloride (NaCl), calcium carbonate ($CaCO_3$), and magnesium sulfate ($MgSO_4$). These salts are all formed using ionic bonds. Chemical diagrams of the ions in these salts can be found in Figure 1.7.

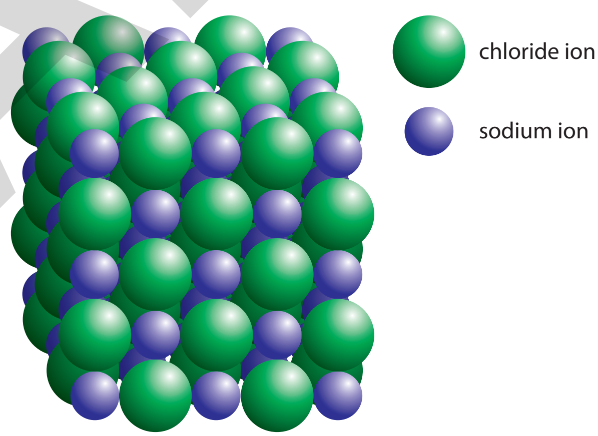


Figure 1.6: Ionic lattice structure of sodium and chloride ions.

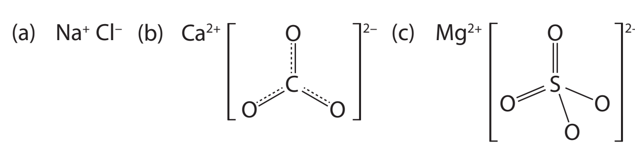


Figure 1.7: Chemical diagrams of sodium chloride (a), calcium carbonate (b), and magnesium sulfate (c).

Hydrogen bonding

A hydrogen bond is a weaker bond that can occur between molecules containing a hydrogen atom bonded to an atom of oxygen, nitrogen or fluorine. Water is an example of such a molecule, as it has two hydrogen atoms bonded to an atom of oxygen. When creating this covalent bond, the oxygen and hydrogen atoms share electrons unequally. The oxygen atom has a much stronger attraction to the bonding pair of electrons between oxygen and hydrogen, resulting in these being pulled closer to the oxygen atom than the hydrogen atom. This unequal sharing causes a partial charge on the atoms involved in the bond: the hydrogen atoms are partially positive (δ+), and the oxygen atom is partially negative (δ−). When molecules have a partial charge on each end as water does, they are referred to as **polar**. Due to this polarity, the more positive hydrogen atoms of one water molecule will be attracted to the more negative oxygen atoms of a nearby water molecule (Figure 1.8) creating a dipole – a molecule with a separation of partial positive and negative charges.

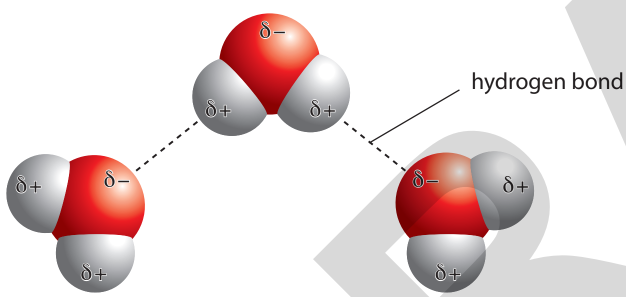


Figure 1.8: Hydrogen bonding in water.

While hydrogen bonds are easily broken, they have an incredible impact on the properties of water due to the sheer number of water molecules found within a single droplet of water and therefore lots of hydrogen bonds are always occurring between these molecules. One of the reasons seawater is unique is because of the many different elements and compounds that can be found within it. This exceptional variety is due to water's properties as a **solvent**. A solvent is a material capable of dissolving other substances. The partial charges on the water molecule allow water to interact with charged ions from many ionic compounds as well as many covalent substances including glucose and gases from the atmosphere. The partial charges on the water molecule allow it to form bonds with an unusual number of substances, making water one of the best solvents on the planet. In fact, water is often referred to as the universal solvent. More information regarding water's solvent capabilities can be found in Section 1.2.

The **density** of water is also impacted by hydrogen bonds. As previously mentioned, as the energy within matter lowers, so too does the movement of the individual particles making up that matter. So, as water nears its freezing point (0 °C), the water molecules slow their movement and gather closely together allowing the hydrogen bonds to become stronger. The hydrogen bonds then help keep the water molecules at perfectly symmetrical distances from each other, forming a crystal lattice-like shape. The shape formed upon freezing actually spreads the molecules out further than they were just prior to freezing. Because fewer water molecules can fit into the same space, the density of solid ice is actually less than that of liquid water. Water is one of the few substances on earth that can claim a solid state that is less dense than the liquid. More information on water density and the impacts of temperature can be found in Section 1.3.

The **specific heat capacity**, the amount of heat required to change one kilogram of mass by one degree Celsius, is yet another property of water that relates to its hydrogen bonding properties. Water has one of the highest specific heat capacities due to the number of hydrogen bonds holding the molecules together. This property allows water to act as a great temperature buffer and helps moderate our planet's climate. The size of our oceans allows them to hold a great deal of heat before they actually change temperature creating mild climates along coastlines worldwide.

KEY WORDS

polar: when opposite sides of a molecule have contrasting partial electrical charges

solvent: a substance which is able to dissolve other substances

density: a measure of the mass of a defined volume of water

specific heat capacity: the heat required to raise the temperature of the unit mass of a given substance by one degree Celsius

Test yourself

1. Sketch a hydrogen bond between two water molecules. Label the nucleus, electrons, protons, neutrons and bond.
2. How do compounds differ from elements?
3. What determines the number of covalent bonds that an atom can form?
4. How will you remember the differences between the different types of bonds?

1.2 Solubility in water

As we saw in Section 1.1, a solvent is a material capable of dissolving other substances and water is one of the greatest solvents on earth. The substance that is dissolved by a solvent is called a **solute**. There are many solutes in seawater, such as sodium chloride, carbon dioxide, oxygen and calcium carbonate. The mixture of solutes and solvent is referred to as a **solution**.

Understanding solubility

Solubility refers to the extent to which a particular solute, such as sodium chloride, can be dissolved in a solvent, such as water. This combination then creates a solution, such as seawater. In general, sodium chloride and other soluble salts dissolve easily into water through **dissolution** of ions. This is a result of the polarity of the water molecule and its ability to interact with ions from ionic substances. As we saw in Section 1.1, sodium chloride is an ionic compound formed through the attraction of sodium ions to chloride ions after the transfer of an electron from sodium to chlorine. The change in distribution of electrons gives both atoms an electrostatic charge that water molecules are attracted to. When placed in water, the sodium and chloride ions are easily dissolved when their ionic bonds are broken by the water molecules. At this point, the partially positive hydrogen ends of the water molecules will surround the negatively charged chloride ions and the partially negative oxygen ends of the water molecules will surround the positively charged sodium ions (Figure 1.9).

Solubility can be impacted by physical factors within the seawater, particularly temperature. Repeated studies have found that as the temperature of seawater rises, the rate of dissolution of salts increases as well. This is because as water heats up, the individual water molecules move faster. This movement helps mix the ions into the water making it easier for water molecules

KEY WORDS

solute: a solid that dissolves in a solvent

solution: a mixture of a solute dissolved in a solvent

solubility: the ability of a solute to dissolve within a solvent (such as water)

dissolution: the process of being dissolved

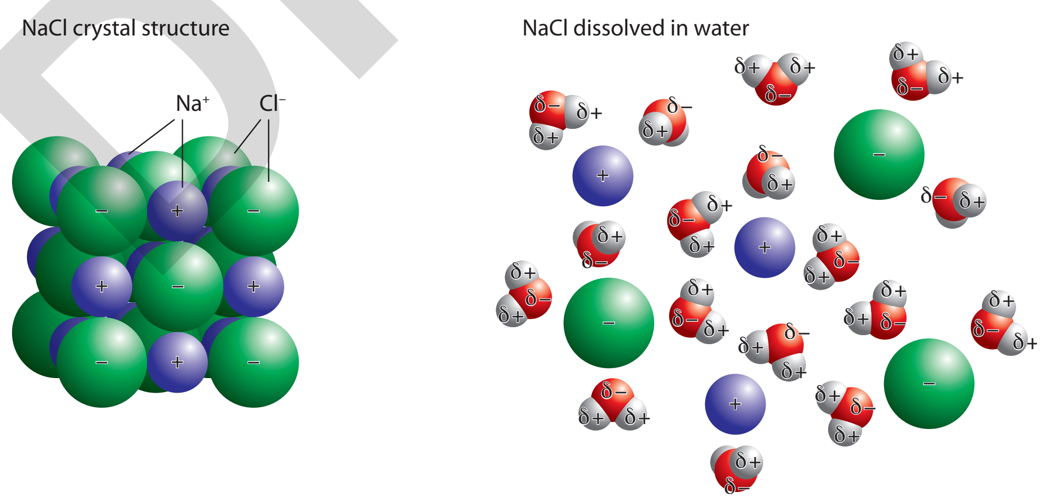


Figure 1.9: A comparison of sodium chloride solid molecular structure and its dissolved structure in water.

to break the ionic bonds and surround the positive and negative ions that are left. So, the warmer the water, the saltier it can be.

Salinity

When studying the chemistry of the ocean, traditionally you start by looking at the **salinity** of seawater. Salinity is a measure of the concentration of dissolved salts in seawater. The unit used for salinity is parts per thousand (ppt or ‰). This unit was originally derived using the traditional method for discovering the salinity of a solution called total dissolved solids (TDS). Using this method, scientists would boil 1000 g of seawater until all of the water present had evaporated. The solutes left behind, usually ions called salts, were then weighed, making them the 'parts' that make up 1000 g of water. After hundreds of years of water samples, scientists now know that the average salinity of the open ocean is 35 ppt.

While 35 ppt is the average salinity of ocean water, the actual salinity at any given location does vary locally thanks to the water cycle. **Precipitation** (for example, rain or snow) lowers the salinity of a body of water by diluting the salt in the seawater with incoming fresh water. After it rains, the water will flow over or into the Earth's surface. Eventually, most of this water, as part of the hydrological cycle, finds its way to the oceans as **run-off**, either directly by first flowing into a river, or through flows of groundwater (water moving through soil and porous rocks). In areas of ocean with fresh-water run-off, the salinity may be much lower than the open ocean. This lower salinity is caused by the addition of fresh water, rather than the removal of salts. It is important to note that as run-off flows over city streets or through farmers' fields, it dissolves many substances and carries them along. These substances could include vital nutrients, pesticides, fertilisers, oils and other pollutants capable of changing the salinity or quality of the water it is entering as well.

Evaporation will cause salinity levels to rise due to the removal of water from the solution rather than the addition of salts. It is important to note that only water is removed through evaporation; all solutes are left behind. Salinity higher than 35 ppt is often found in regions with above-average evaporation rates and a limited fresh-water inflow. When the salts are even more concentrated, the water is described as **hypersaline**. The most hypersaline environment in the world is Don Juan Pond in Antarctica. Scientists refer to this region as the McMurdo Dry Valleys due to the lack of precipitation in the area. That lack of rain and snow causes this pond to have a salinity of 440 ppt, which is twelve times saltier than the ocean. The salinity is so high that even in −50 °C weather, the pond does not freeze (Figure 1.10). For more information about the freezing point of water and salinity, see Core Practical 1.1.

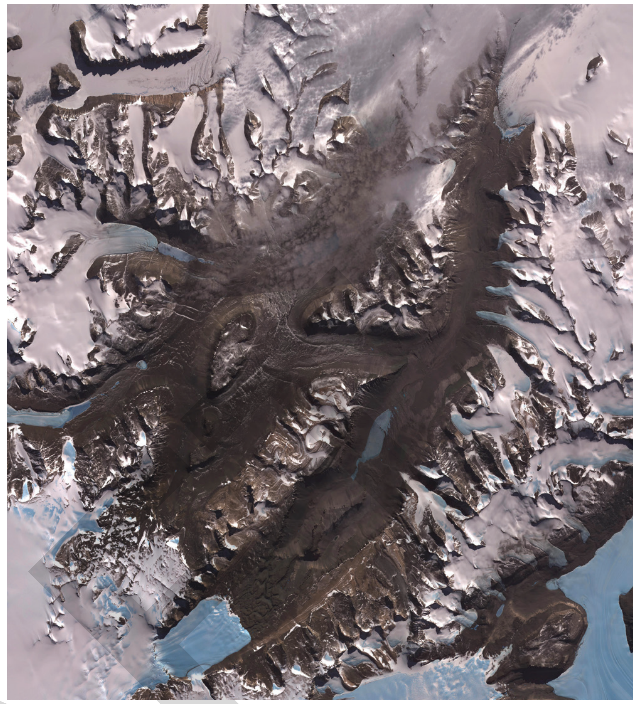


Figure 1.10: An aerial view Don Juan Pond located in the McMurdo Dry Valleys of Antarctica.

KEY WORDS

salinity: a measure of the quantity of dissolved solids in ocean water, represented by parts per thousand (ppt) or ‰

precipitation: water that falls from the atmosphere to the Earth's surface as rain, sleet, snow or hail

run-off: the flow of water from land caused by precipitation

evaporation: a change in state from liquid to gas below the boiling point of a substance

hypersaline: when a body of water has a salinity level greater than 40‰

CORE PRACTICAL ACTIVITY 1.1: INVESTIGATING THE EFFECT OF SALINITY ON THE FREEZING POINT OF WATER

Introduction

As the molecules of water are cooled, their movement slows and they form a lattice pattern that creates the solid ice. The temperature at which liquid water turns to solid ice is called the freezing point. This property of water has major implications for marine organisms. Organisms cannot swim through ice; however, much of our Arctic and Southern Oceans have thriving ecosystems despite the large volume of water that freezes each year. This is at least partially due to the presence of salts in seawater. Throughout this investigation, you will study how increased salinity impacts the point at which water freezes.

Equipment

You will need:

- temperature probe *or* digital thermometers
- 4 × medium test tubes marked 0.5 mol dm^{-3}, 1.0 mol dm^{-3}, 1.5 mol dm^{-3} and 2 mol dm^{-3}
- 4 × 100 ml beakers marked 0.5 mol dm^{-3}, 1.0 mol dm^{-3}, 1.5 mol dm^{-3} and 2 mol dm^{-3}
- 1 litre beaker *or* flask *or* graduated cylinder
- 400 cm^3 beaker
- freezer
- ice cube trays
- plastic bag
- rubber hammer
- digital balance
- black marker
- 230 g sodium chloride
- access to tap water (to create ice)
- 500 cm^3 of distilled water (to create solutions)

Safety considerations

- Follow all usual laboratory safety rules.
- Wear safety goggles, aprons and gloves while in the laboratory.
- Handle glassware carefully.

Before you start

1. Why are you using distilled water to create the solutions instead of tap water?
2. In this investigation, the independent variable is the amount of sodium chloride added to the water, and the dependent variable is the freezing point of the solution. What are *two* other variables that will need to be controlled in order to receive accurate results?
3. What do you predict will happen to the freezing point of water as sodium chloride is added to it?

Method

1. Create a results table in your notebook similar to Table 1.1.
2. Create your ice.
   - a Using the beaker or graduated cylinder, mix 200 g of Sodium chloride into 1 dm^3 of tap water.
   - b Pour the solution into ice trays.
   - c Place the trays in the freezer and leave them overnight.
3. The next day, label the four beakers and test tubes as Sodium chloride 0.5 mol dm^{-3}, Sodium chloride 1.0 mol dm^{-3}, Sodium chloride 1.5 mol dm^{-3}, Sodium chloride 2.0 mol dm^{-3}.
4. Prepare each of the solutions below in the appropriately labelled beaker:
   - a Sodium chloride 0.5 mol dm^{-3} – mix 100 cm^3 of distilled water with 2.9 g of sodium chloride
   - b Sodium chloride 1.0 mol dm^{-3} – mix 100 cm^3 of distilled water with 5.8 g of sodium chloride
   - c Sodium chloride 1.5 mol dm^{-3} – mix 100 cm^3 of distilled water with 8.7 g of sodium chloride
   - d Sodium chloride 2.0 mol dm^{-3} – mix 100 cm^3 of distilled water with 11.6 g of sodium chloride
5. Using the ice cubes prepared the previous day, create an ice bath.
   - a Place the prepared ice cubes in a large plastic bag.
   - b Using the rubber hammer (or appropriate substitute) carefully crush the ice.
   - c Fill the 400 cm^3 beaker with the crushed ice.
6. Pour the solution in each beaker into its marked test tube to the halfway mark.
7. Put a digital thermometer into each tube.
8. Add the test tubes to the ice bath.

CONTINUED

Results

1 Observe the test tubes and record the temperature when the first ice crystals begin to form along the surface into a copy of Table 1.1.

Concentration of sodium chloride in solution / mol dm^{-3}	Freezing point of solution / °C
0.5	
1.0	
1.5	
2.0	

Table 1.1: Data table.

2 Create a line graph of *Freezing point of solution* (*y*-axis) against *Concentration of sodium chloride in solution* (*x*-axis).

   a Create a scale for each axis based on your data. Your scale should be large enough that your data takes up more than half of the available space both vertically and horizontally.

   b As your temperatures will be below 0 °C, your *x*-axis should be at the top rather than along the bottom, so the *y*-axis can better represent the negative numbers.

   c Remember to use a ruler to create straight lines that will connect your carefully plotted data points.

Evaluation and conclusions

1 Identify the solvent and the solute in our solutions.

2 Compare the solubility of the sodium chloride when you are adding 2.9 g to the solubility of the sodium chloride when you are adding 11.6 g.

3 Describe the change in temperature as the concentration of sodium chloride increased.

4 Predict the freezing point of a solution with 40 g cm^{-3}.

5 How could you extend this experiment to test for other factors which may impact freezing point?

REFLECTION

After completing Core Practical Activity 1.1, think about these questions:

1 How could you improve your results for this practical?

2 Do you think this practical helped your understanding of this concept? Why or why not?

Mixing of the layers

The surface layer of the ocean, from zero to around 200 m deep, is the best-mixed area of the ocean. As the wind blows across the surface of the ocean, currents and turbulence are created. This water movement mixes the upper 200 m or so of the ocean, making it fairly uniform in both temperature and salinity.

Mixing of the layers within the ocean is typically density driven. For example, if the surface of the ocean cools, the density of the water will increase due to the temperature change. As the density increases, the water sinks, carrying with it all the nutrients and dissolved gases that it contained at the surface, mixing with the higher density water that is rising. This can happen in cold ocean as well when the density changes due to changes in salinity levels. Both the **halocline** and **thermocline** are considered areas of mixing where significant changes in the abiotic factors of the ocean happen.

KEY WORDS

halocline: a layer of water below the mixed surface layer where a rapid change in salinity can be measured as depth increases

thermocline: a layer between two layers of water with different temperatures

The deep ocean, or bottom layer of the ocean, is uniform, like the surface. The deep ocean tends to be very cold, salty and dense. There is oxygen and other gases present in this layer, but they are limited.

The pH scale

Potential of hydrogen, more commonly referred to as **pH**, is an important abiotic factor for the survival of aquatic organisms in a marine environment. This is used to measure the concentration of hydrogen ions in water. Hydrogen ions are spontaneously created in pure water when the water molecules will split into hydrogen ions (H^+) and hydroxide ions (OH^-). Solutions with high concentrations of hydrogen ions compared to pure water are **acidic** (called acids), while solutions with low concentrations of hydrogen ions are called **alkaline** (you may have also seen this referred to as 'basic'). Because pure water is the point of comparison, it is considered **neutral**. For scientists to easily determine the pH of a solution, they created the logarithmic **pH scale** (Figure 1.11). Using this scale, solutions with a pH:

- below 7.0 are acidic
- at 7.0 are neutral
- above 7.0 are alkaline.

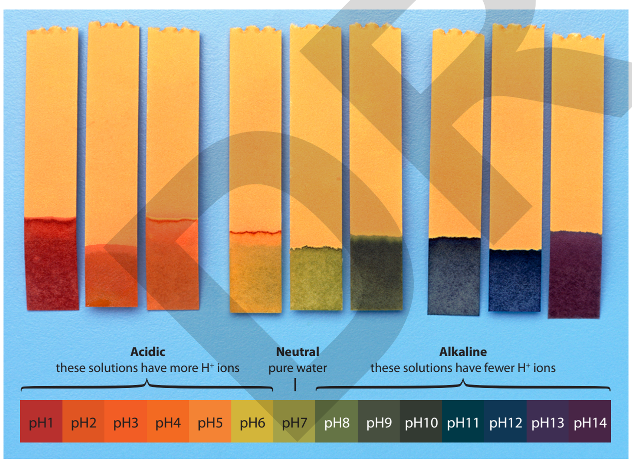


Figure 1.11: The colour pH scale used with universal indicator paper to determine hydrogen ion concentrations within a solution.

The pH of the world's oceans has been slightly alkaline since before we ever began collecting data. Historically, the pH of the open ocean has been an average of 8.2; however, there has been a recent drop in the worldwide average to an 8.1 pH due to increasing levels of carbon dioxide (CO_2) in our atmosphere. This seems like a small drop; but, it is easy to misjudge the readings on the pH scale because it is not linear. In a linear scale, a 0.1 decrease in pH would indicate a 1% increase in acidity. Instead, because this scale is logarithmic, a 0.1 decrease in pH is actually a 25% rise in acidity. Small changes in pH, therefore, can bring drastic issues to the environment.

Scientists typically use one of three methods to measure the pH of water samples: litmus indicator, universal indicator, and pH probes. Litmus indicator and universal indicator are both solutions but they are also commonly used as papers where an absorbent paper has been soaked in the solution and allowed to dry, providing a simple and easier method to test with these indicators that can be dipped into a solution. Once in contact with the solution being tested, the indicator begins to change colour. Litmus indicator only determines if a substance in an acid or an alkali, it cannot show how strong an acid or alkali is. Universal indicator shows a range of strengths for acids and alkalis: scientists then compare the colour of the paper to the colour pH scale provided to give a whole number pH. These methods are quick, but also subjective leading the scientist to try to determine the pH as closely as possible. Electronic pH probes can also be used to determine pH. These probes measure the hydrogen-ion concentration within a solution to provide a numerical read-out that is more precise and less subjective than the other methods.

KEY WORDS

pH: a numeric value expressing the acidity or alkalinity of a solution on a logarithmic scale

acidic: having a pH below 7

alkaline: having a pH above 7

neutral: having a pH that equals 7

pH scale: a logarithmic scale that measures the ratio of hydrogen ions to hydroxide ions

CORE PRACTICAL ACTIVITY 1.2: DETERMINING THE PH OF WATER

Introduction

When studying aquatic environments, like the ocean, it is important to understand how changes in pH can alter the ability of some organisms to survive or reproduce within an environment. Therefore, when checking water quality, scientists often test the pH of the water using one of three methods: universal indicator, litmus indicator, or pH probes. Each method measures the concentration of hydrogen ions, H^+, within the solution being studied. After testing, each method provides a number value between 0 and 14 along the pH scale. Those numbers between 0 and 6.9 are considered acidic, a 7.0 is considered neutral, and 7.1 to 14.0 are considered alkaline. As the pH scale is logarithmic, a decrease of 1 indicates that 10 times more hydrogen ions are present within the solution. This change can greatly alter the environment for organisms sensitive to pH.

Equipment

You will need:

- Distilled water (up to 60 cm^3 per group plus extra for rinsing test tubes and pH probe)
- White vinegar (10 cm^3 per group)
- Seawater or a solution of 35 g NaCl per litre of tap water (20 cm^3 per group)
- Pond water (20 cm^3 per group)
- Universal Indicator solution or paper with corresponding colour chart
- Litmus indicator solution (or red and blue litmus papers)
- Baking soda (0.5 mg per group)
- pH probe
- 5× test tubes (wide enough to fit the pH probe)
- Test tube rack
- 2× small beakers
- Dropping pipettes

Safety considerations

- Wear safety goggles, aprons, and gloves while in the laboratory.
- Handle glassware carefully.
- Check the Material Safety Data Sheets (MSDS) for the universal indicator solution used, and follow necessary safety precautions.

Before you start

1. Which properties of distilled water make it appropriate to use for cleaning and calibrating equipment?
2. What purpose might the vinegar and baking soda serve in a pH experiment?
3. Ocean acidification is a major concern for scientists due to potential impacts on marine organisms. What organisms do you think are at the greatest risk and why?

Method

1. For each solution listed in the results table, predict whether it will be acidic, neutral, or alkaline, and record your prediction in the results table.
2. Create a solution of vinegar and distilled water in one of the small beakers by combining 10 cm^3 acetic acid with 10 cm^3 distilled water. Set aside.
3. Create a solution of baking soda and distilled water in the second small beaker by combining 5 mg of baking soda and 20 cm^3 distilled water. Set aside.
4. Pour approximately 1 cm depth of distilled water into a test tube.
5. Using universal indicator to measure pH:
   a. With solution:
      i. Add a few drops of universal indicator to each solution.
      ii. Wait for colour change.
      iii. Compare colour to associated pH colour chart and note results in table.
   b. With universal indicator paper:
      i. Dip the indicator paper into the solution for about 1 second.
      ii. Allow the paper to dry completely.
      iii. Compare colour to associated pH colour chart and note results in table.

CONTINUED

6 For each of the remaining test tubes, pour approximately 1 cm depth of the remaining solutions (vinegar solution, baking soda solution, seawater, and pond water) so that each test tube only contains one solution.
7 Repeat step 5 for each test tube.
8 Rinse all test tubes with distilled water.
9 Create new samples of each solution as before.
10 Use litmus indicator solution or papers to see if each solution is acidic, alkaline, or neutral.
11 Record the results of the litmus indicator in the table (acidic, alkaline, or neutral).
12 Rinse all test tubes with distilled water.
13 Create new samples of each solution as before.
14 Using pH probe, determine the pH of each solution.
15 Note all pH readings in the results table.

Results

	Prediction: Acidic, Neutral, Alkaline	Colour and pH of Universal Indicator	Results of Litmus Indicator	pH Probe Reading
distilled water	neutral	yellow - 6	solution: red, acidic red paper: stays red blue paper: turns red	6.20
vinegar solution	acidic	orange - 5	solution: red, acidic red paper: stays red blue paper: turns red	4.78
baking soda solution	alkaline	dark green - 9	solution: blue, alkaline red paper: turns blue blue paper: stays blue	8.52
seawater	alkaline	mid-green - 8	solution: blue, alkaline red paper: turns blue blue paper: stays blue	7.65
pond water	neutral	light green - 7	solution: red, acidic red paper: stays red blue paper: turns red	6.30

Table 1.2: Data table for measuring pH

Evaluation and conclusions

1 Did each method provide uniform results for each solution? Why do you think different methods may have produced slightly different results?
2 Pond water may be slightly acidic to slightly alkaline. Where did your solution fall on the pH scale? Suggest a reason for that reading.
3 Predict what the pH would be if the vinegar solution were added to the baking soda solution. Suggest an explanation for your prediction.

REFLECTION

After completing Practical Activity 1.2, think about these questions:

1 Your results may be different from those of other groups. Why might that be?
2 What problems did you encounter when working through this practical? How do you think they could have impacted your results?

The solubility of gases in seawater

Gases in the atmosphere (nitrogen, carbon dioxide and oxygen) are in a state of equilibrium with the gases dissolved in ocean water. As the concentration of a particular gas in the atmosphere increases (carbon dioxide, for instance), the concentration of that gas in seawater also rises. Mixing, as a result of **turbulence** and wave action, works to maintain this equilibrium. The more turbulence there is, the easier it is for gases in the atmosphere to dissolve into the ocean. This can lead to higher concentrations of carbon dioxide and oxygen within the upper 200 m depth of the ocean than are found in the water below this. Factors contributing to the concentration of gases in seawater include the following.

KEY WORD

turbulence: irregular changes in the speed and direction of fluid movement

Gas solubility

Carbon dioxide is very soluble in seawater because of its ability to form carbonic acid, a weak acid, when introduced to water. Oxygen, however, has a low solubility because it does not chemically combine with the water molecules. This means that the level of carbon dioxide held by seawater is higher than that of oxygen.

Water temperature

Cold water can dissolve more gas than water at warmer temperatures. When water increases in temperature its molecules move faster. This results in dissolved gas molecules evaporating from the surface of water more quickly. All gases are less soluble in warmer water for the same reason. This means that water found near the poles will dissolve more oxygen than water found in the tropics (Table 1.3). The concentration of dissolved oxygen is particularly important to aquatic organisms, so increases in temperature can have a significant impact on the range of organisms that the water can sustain.

Temperature of water / °C	Concentration of dissolved oxygen / mg dm^{-3}
0	14.6
5	12.8
10	11.3
15	10.2
20	9.2
25	8.4

Table 1.3: Relationship between temperature and the maximum concentration of dissolved oxygen in fresh water.

Atmospheric pressure

The solubility of gases increases with increasing pressure. Atmospheric pressure plays a role in how soluble gases are at the ocean's surface. When atmospheric pressure increases, the equilibrium of gases in the atmosphere and those dissolved in the ocean changes – there is a greater concentration of the gas in the atmosphere, this pushes more of those gas molecules to dissolve in the seawater and increase the concentration of dissolved gases in the surface waters of the ocean. When atmospheric pressure decreases, during a tropical cyclone for instance, this equilibrium shifts the other way and more of the dissolved gas molecules escape from the surface and enter the atmosphere.

Water pressure due to depth

As you travel deeper into the ocean, the pressure of the water above you continues to increase due to the sheer mass of the water. With that increasing pressure, gases are better able to dissolve into the water and stay dissolved in the water. Note that, when describing depth of water be very careful with your wording – try to use words such as 'deeper' or 'shallower' instead of 'higher' or 'lower'. A statement such as 'higher depths' is ambiguous because a high value is deeper, but a low value could mean something is higher up in the ocean.

The salinity of the seawater

Gases are better able to dissolve in water with lower levels of salinity because there are less solutes taking up space between the water molecules and so more water molecules are able to interact with gas molecules and dissolve them. This can be seen very clearly if you add a teaspoon of salt to a carbonated drink such as sparkling water or cola – when the salt is added the gas molecules are released very quickly as the liquid fizzes up. Gases, like oxygen and carbon dioxide, are most soluble in fresh water entering the ocean from rivers, such as in estuaries; as the fresh water mixes with salt water in the sea, the solubility of these gases decreases. Therefore, you would expect to find higher levels of oxygen in an estuary than in the open ocean.

Impact of solubility on marine life

Organisms and dissolved gases are intricately linked. Carbon dioxide and oxygen are both necessary for the survival of marine organisms. At the surface, producers take in dissolved carbon dioxide for use in photosynthesis and then release oxygen as a result. All living organisms use dissolved oxygen for respiration. Nitrogen gas is transformed into ammonia by nitrogen-fixing bacteria making the nitrogen easier for other organisms to use for protein creation.

As a key requirement for respiration, the concentration of **dissolved oxygen (DO)** is incredibly important in the marine environment. In general, oxygen has a low solubility in water, and this characteristic is impacted further by temperature, salinity and pressure causing the concentration of DO to vary greatly throughout the ocean. As temperature and salinity increase, the concentration of DO decreases. The solubility of oxygen generally increases with depth due to both the decrease in temperature and the increasing pressure of the water above.

The area of the ocean with the greatest concentration of dissolved oxygen is the top 100 m of the ocean, known as the surface layer. Within this layer, the dissolved oxygen concentration can reach ‘supersaturation’. This means there is more oxygen dissolved in the seawater than it would normally be able to carry. Two major factors work together to increase the amount of dissolved oxygen to supersaturation level: the motion of the water and photosynthesis by producers. The more turbulent the water, the more oxygen is mixed into it by the movement of the waves. Meanwhile, producers, like **phytoplankton** and algae, carry out photosynthesis using light from the Sun to create glucose (for the producer) and generate oxygen as a by-product that is released into the ocean’s waters. Photosynthesis can only take place in the upper layer of the ocean, called the photic zone, where light is able to penetrate and be used by producers. This release of oxygen increases the concentration of dissolved oxygen in the surface layer. Dissolved oxygen is removed from the surface layer by the respiration by all organisms. The concentration of DO can also vary tremendously with latitude, as tropical waters have much higher temperatures reducing the concentration of DO that the water can dissolve. Polar waters are much colder and therefore able to dissolve a much higher concentration of DO.

Below the surface layer of the ocean, the concentration of dissolved oxygen changes dramatically. As the depth of the ocean increases, the level of dissolved oxygen decreases until it reaches the **oxygen minimum layer**. The oxygen minimum layer typically occurs at a depth of around 500 m but has been found anywhere between 100 m and 1000 m deep depending on location. At this point, the level of DO can sometimes nearly reach zero due to a lack of oxygen being introduced into the water and consumers still performing respiration to survive.

Some organisms, such as the vampire squid, are capable of living within the oxygen minimum zone, despite the lack of dissolved oxygen, but they do need special adaptations for survival. Most of the organisms found here are fairly inactive, which reduces their need for oxygen. The gills of the fish in this area are incredibly efficient at extracting oxygen from water, even at the low levels present in this layer. Additionally, many of the organisms here have a specially adapted form of haemoglobin, a blood protein responsible for carrying oxygen throughout the body.

KEY WORDS

dissolved oxygen (DO): concentration of oxygen dissolved in a solution

phytoplankton: microscopic photosynthetic organisms that live in the upper, sunlit layers of water

oxygen minimum layer: the layer within the ocean where the concentration of dissolved oxygen is at its lowest, typically found below the photic zone between 100 m and 1000 m deep

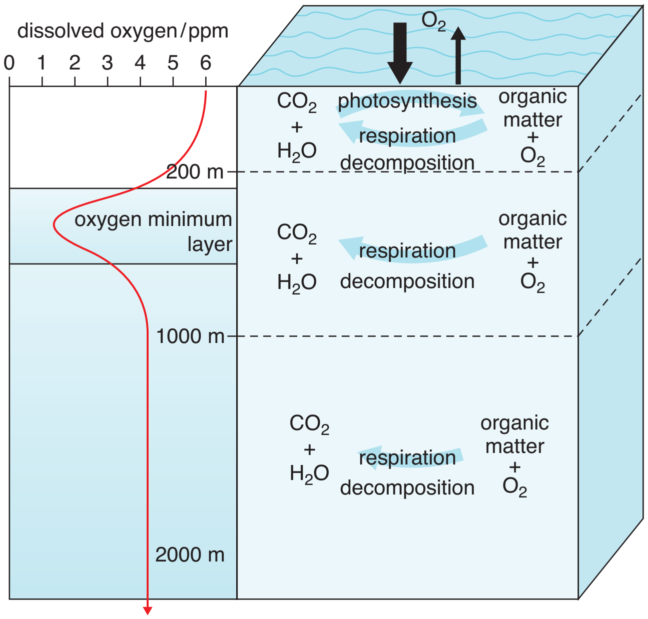


Figure 1.12: Oxygen minimum layer in the eastern tropical Pacific Ocean and the biological processes responsible.

After passing through the oxygen minimum layer, the DO concentration begins to increase with depth as expected. Several reasons exist for this increase in oxygen as you move deeper (Figure 1.12).

- Falling detritus is colonised by bacteria that decompose the organic matter carrying out aerobic respiration which uses up oxygen, as this detritus falls below the photic zone the oxygen cannot be replaced by photosynthesis.
- Below the oxygen minimum layer this decomposition has been completed and there is less respiration carried out by these bacteria. The organisms found below the oxygen minimum layer are in an area with very few food resources. This lack of food reduces the need for the organisms to respire, so they survive with less oxygen.
- The solubility of oxygen increases as the temperature decreases. As you go deeper into the ocean, the temperature decreases to near-freezing. The lower temperature means more oxygen can stay dissolved in the water.
- As pressure increases, the solubility of oxygen increases. For every 10 m you sink into the ocean, the pressure increases by one atmosphere.

Test yourself

5 What makes seawater a solution? How could you test this to verify your answer?

6 How does the salinity of seawater differ in areas where precipitation is greater than evaporation, compared to areas where evaporation is greater than precipitation?

7 How does the solubility of a gas impact its availability to marine life?

1.3 Density and pressure

Density is the mass of a defined volume of water divided by its volume. The formula for density is:

$$\text{density (kg m}^{-3}) = \frac{\text{mass (kg)}}{\text{volume (m}^3)}$$

When discussing density in seawater, the denser the water is, the lower it will sit in the **water column**. The least dense water will rise to the surface of the water column and the densest water will sink to the bottom. Temperature, salinity and water pressure all play a role in determining the density of seawater.

Temperature

Temperature is the factor most responsible for changes in density. As the temperature of seawater increases, density decreases. Warmer water tends to float near the surface of a body of water, and this is exposed to heating by the Sun, causing this layer to get even warmer and less dense. This warm layer is often fairly shallow and sits on top of colder, denser water. Between the two layers is an area where the temperature abruptly changes, known as the thermocline (Figure 1.13). Water at the surface may reach 25 °C or higher in tropical seas but is more likely to be 1 °C at depths of 2000 m or more. In polar seas, the temperature **gradient** in a

KEY WORDS

water column: a vertical section of water from the surface to the bottom; useful concept when discussing changes in the abiotic factors within the body of water

gradient: the rate of change in the *y*-axis value as the *x*-axis value increases thermocline is less drastic. In these areas, the surface water is likely to be close to freezing and remain at a fairly constant temperature with increasing depth.

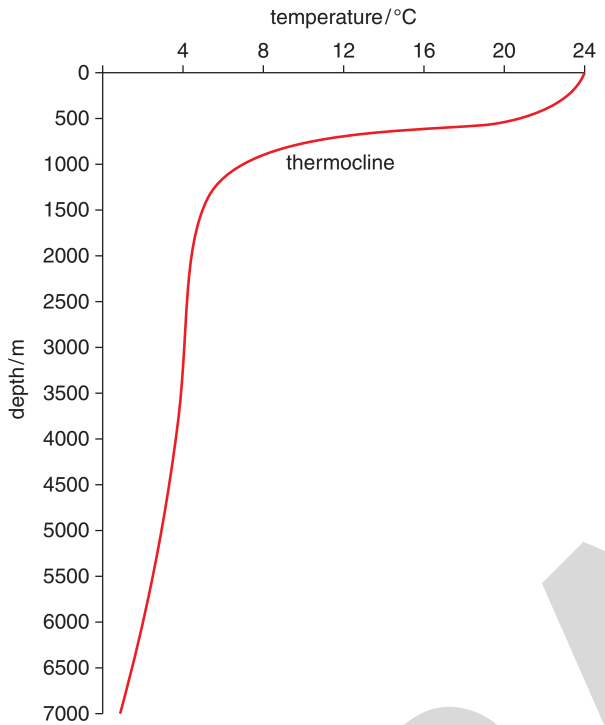


Figure 1.13: Thermocline in a typical tropical sea.

Why is it that the water at the bottom of the ocean doesn't freeze? The answer has two parts: salinity and density. As salinity increases, the freezing point of water decreases making it more difficult to create ice. For more information, see Core Practical 1.1. When water begins to freeze, the individual water molecules begin to arrange into a lattice pattern (as you saw in Section 1.1) due to the hydrogen bonds holding them together. These bonds hold the water molecules at a slightly greater distance from one another, which is different from the arrangement in liquid water where the molecules of water are constantly making and breaking hydrogen bonds with each other as they move past each other. This reduces the density of ice compared to liquid water, which causes ice to float at the surface of liquid water. Therefore, even if the water freezes on the bottom of the ocean, an unlikelihood due to the salinity, it would float to the surface rather than remain at the bottom of the ocean.

The property of water that allows ice to float is of vital importance for marine organisms. If ice stayed at the bottom of the ocean, the ocean would freeze entirely from the bottom to the surface, which would leave marine organisms nowhere to go in the dead of winter. When ice forms on a body of water it begins to act as a **thermal insulator**, reducing the rate of further heat loss from the water beneath it. This means the water under the ice is warmer than the water exposed to the freezing air above the ice allowing marine organisms to stay at a temperature that is better suited for their adaptations. The floating ice sheets provide a habitat for animals such as penguins or polar bears to hunt from. Additionally, the underside of icebergs and ice sheets functions as a habitat for species of phytoplankton and algae that can grow there. The growth of these producers helps support the arctic and Antarctic ecosystems throughout the winter months when the food supply should be too low to maintain the food web.

Pressure

As pressure increases with increasing depth, so too does the density of seawater. There is approximately a 2% change in is density due to the pressure differences between the abyssal floor and the surface. This is due to the water pressure due to increasing depth acting on the individual molecules in the seawater. With increased pressure, the molecules are pushed closer together, forcing more molecules into smaller volumes. Therefore, there is more mass contained within the same volume of water. An area of water where the density changes quickly with depth is referred to as a **pycnocline**.

Salinity

As the salinity of water increases, the density increases, therefore fresher, lower density water floats on saltier, denser water. This is why in an estuary fresh water sits above the saltwater. Between the less saline, and therefore less dense, surface waters and the more saline, denser, bottom waters, there is an area where salinity changes significantly with depth. This area is called the halocline.

KEY WORDS

thermal insulator: a substance which reduces the rate of transfer of thermal energy

pycnocline: a layer of water between two layers of water with different densities

This would indicate that the saltiest water in the ocean is at the seabed. For the most part this is true, but there is one exception: tropical seas. In tropical seas between 30° N and 30° S, the surface temperatures create high evaporation rates at the surface. This results in a very warm, but also very salty, layer across the surface of the ocean. This layer floats on the surface, in spite of its increased salinity, because the temperature is so high. Just below that layer, the salinity profile shows a steep decrease in salinity, the halocline, until 750 m, followed by a slow increase, as expected (Figure 1.14).

In non-tropical oceans the halocline can be in the reverse direction, since a greater rate of precipitation than evaporation can result in lower salinities at the surface, as we find in estuaries, and the salinity therefore increases with as you move deeper.

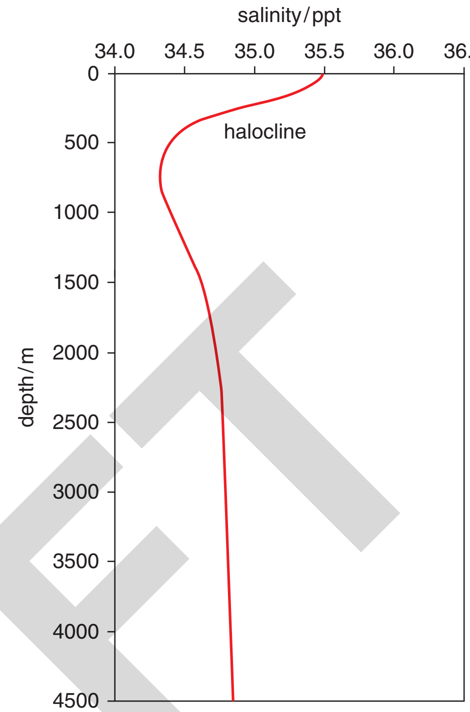


Figure 1.14: Typical halocline in a tropical sea.

Mixing of layers in the ocean

Calm, still waters in the ocean lead to the formation of distinct layers due to temperature and salinity differences as you move deeper. These layers can be mixed by several factors including strong winds and wave action (especially in stormy weather), and by currents and upwellings pushing water of different densities together. This mixing can cause thermoclines and haloclines to weaken or break down completely. For example, temperature waters generally only experience a thermocline in the summer months when the surface waters are heated by more intense sunlight and the weather is generally calmer. As the weather becomes stormier in the autumn the thermocline weakens and eventually disappears completely until late in the following spring. This mixing is due to great forces from strong winds or currents churning the water to considerable depths; the passing of ships or large animals such as whales has virtually no impact on mixing these layers of water.

CASE STUDY 1.1: DISCOVERING THE COMPOSITION OF SEAWATER

The Challenger expedition was the first true scientific study of the open ocean. Led by Charles Wyville Thomson, the expedition took place between December 1872 and May 1876 aboard a modified British warship named the *HMS Challenger*. After petitioning for years, the Royal Society of London, of which Thomson was a member, was able to purchase an outdated warship from the Royal Navy. To prepare for the journey, 15 of the *HMS Challenger's* 17 cannons were removed and the space created by their removal was fitted with scientific laboratories (Figure 1.15). When the *HMS Challenger* set sail, among the nearly 250-person crew were seven scientists and an official expedition artist to document the scientists' findings.

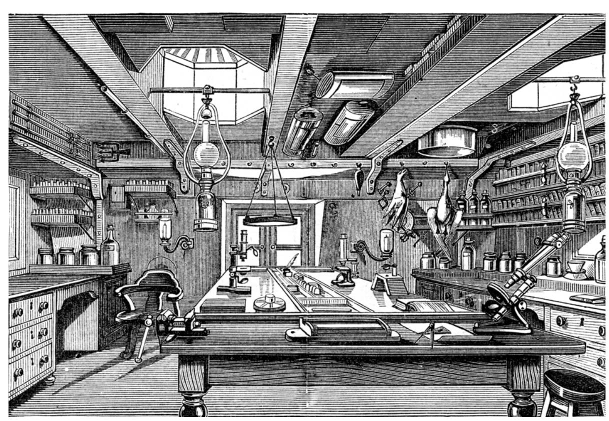


Figure 1.15: An illustration of the natural history workroom aboard the *HMS Challenger*.

CONTINUED

The laboratories on board enabled the scientists to collect an incredible amount of data in the fields of natural history and chemistry over the course of the 68 890 nautical-mile scientific voyage. In fact, they collected so much data that once they returned to land it took nearly 20 years for all of their findings to be analysed and published in a 50-volume report containing nearly 30 000 pages. Within those findings, more than 4000 new species of marine life were discovered as well as some necessary pieces of chemical oceanography.

When the *Challenger* returned to England in 1876, the water samples taken during the voyage were sent to a well-known chemist, William Dittmar. After years of analysing the samples, Dittmar discovered a multitude of evidence that the same six ions made up the majority of the solutes in seawater: chloride, sodium, sulfate, magnesium, calcium, and potassium. Additionally, he found that, regardless of the concentration of salts in the water, the ions were always present in the same percentages within the seawater. This phenomenon, first proposed by Johan Georg in 1865, is now called the **principle of constant proportions**. Even with the modern technology of today, scientists continue to revisit this research and come to the same conclusions. Dittmar's theory of constant proportions holds true for the open ocean and, generally, for coastal regions.

Thanks to William Dittmar and his evidence solidifying the theory of constant proportions, we now know chloride (Cl^-) ions in the open ocean account for 55% of the ions present and sodium ions (Na^+) follow at 30%. It really should be no surprise, then that seawater tastes like table salt – the common name for the compound sodium chloride (NaCl). Four other ions can also be found in regular proportions within our oceans: sulfate (SO_4^{2-}), magnesium (Mg^{2+}), calcium (Ca^{2+}), and potassium (K^+). Their proportions can be seen in Table 1.4.

In 2018, scientists met from all over the globe to share new data on ocean salinity investigations at the Ocean Salinity Conference in Paris, France. These scientists worked to share new data gathered from modern technology such as satellite observations and computer models. While the theory of constant proportions has not changed, scientists are able to monitor changing salinity to look at variations in the way currents flow and the impacts of these changes on our freshwater cycle.

ion	mean concentration in seawater / parts per thousand	Ratio of ion : total salts / percentage (%)
chloride (Cl^-)	19.35	55.04
sodium (Na^+)	10.75	30.61
sulfate (SO_4^{2-})	2.70	7.68
magnesium (Mg^{2+})	1.30	3.69
calcium (Ca^{2+})	0.42	1.16
potassium (K^+)	0.38	1.10
minor ions	0.10	0.72

Table 1.4: Concentrations of the six most common ions in seawater.

Questions

1 Charles Wyville and the Royal Society of London spent years trying to convince the British government to send a scientific ship to learn about the world's oceans. The British government did not see the potential benefits of such an endeavour. Suggest how the benefits justified the cost of the expedition.

2 Scientists still struggle to receive funding even though less is known about the contents of our oceans than the surface of Mars. Why do you think scientific exploration of our oceans is still in the position of having to justify support?

3 Using the data presented in Table 1.4, create a pie chart to represent the percentages of ions in ocean water.

4 According to studies conducted by Dittmar and many chemists since, chloride ions make up 55% of the ions present in seawater. Besides sodium chloride, what ionic compounds could be formed with chloride from the ions listed?

KEY WORD

principle of constant proportions: the ratio of any two major ions dissolved in seawater is constant

MATHS SKILLS

1.1 GRAPHING DENSITY AND TEMPERATURE

Density is a major component of survival for marine organisms. The formula for density is:

$$\text{density (kg m}^{-3}\text{)} = \frac{\text{mass (kg)}}{\text{volume (m}^3\text{)}}$$

You need to remember this formula so you can calculate density if you are given the mass and volume of an object or body of water. Conversely, you should be able to use this formula to determine either mass or volume, as well. A good starting point is to know that the density of freshwater at sea level is 1000 kg m^{-3}; however, the density of seawater, with a salinity of 35 ppt, is slightly higher due to the mass of the ions dissolved within the solution. This density will vary with depth and temperature.

Worked example

In Table 1.5, data has been collected for you about the density of seawater at different temperatures. This data assumes pressure remains the same at 101 kPa, which is the average atmospheric pressure at the sea surface.

Temperature of seawater / °C	Density of seawater / kg m^{-3}
30	1021.76
25	1023.37
20	1024.79
15	1026.00
10	1026.98
5	1027.70
0	1028.13
−5	1028.22
−10	1027.90

Table 1.5: The density of seawater at various temperatures.

You will need to be able to graph data sets for different experiments throughout this course. Make sure to plan your graph appropriately. When plotting data, it is important to begin by identifying which variable belongs on the *x*-axis and which belongs on the *y*-axis. The simplest way to do this is to determine which variable is the independent variable or the variable that is being controlled by the scientist. Usually, the independent variable is the variable with a regular, easily predicted pattern; in this case, the temperature of the seawater was controlled by the researcher, and is normally the first column of data in a results table. Generally, your independent variable will lie on the *x*-axis. (This may not always be the case, but it is the normal rule – a notable exception is graphs plotted against depth; the depth is usually the independent variable but we plot depth on the *y*-axis to match the actual changes in depth in the ocean. This has an impact on how the gradient is measured.)

Next, you will need to figure out the scale of your axes. Your scale should represent the data so it is easy to see trends. To do this, you must find the range of your data. In this case our range is 1028.22 – 1021.76 = 6.46. Many people would start numbering their *y*-axis from zero out of habit, but that will not showcase the data and the changes that need to be analysed. It is important to note that axes do not need to start at zero, in fact the most important consideration is the spread of your data – the points (when plotted) must occupy over half the scale on each axis. They must also have consistent intervals between numbers of the axis. In Figure 1.16, a graph has been started for you with appropriate intervals and scale on the *y*-axis.

Questions

1. Using the rest of the data, complete the graph.
2. Using the data presented in your graph, describe the shape of your graph.
3. At 1.9 °C the density of seawater is 1028.21 kg m^{-3}. If you were to add that data point to your graph, would the pattern change? Why or why not?
4. What do you predict would happen to the density of the seawater if the pressure was increased from 101 kPa to 101 000 kPa? Justify your response.
5. What would happen to the line on your graph if the *y*-axis had started at zero instead of 1020?

CONTINUED

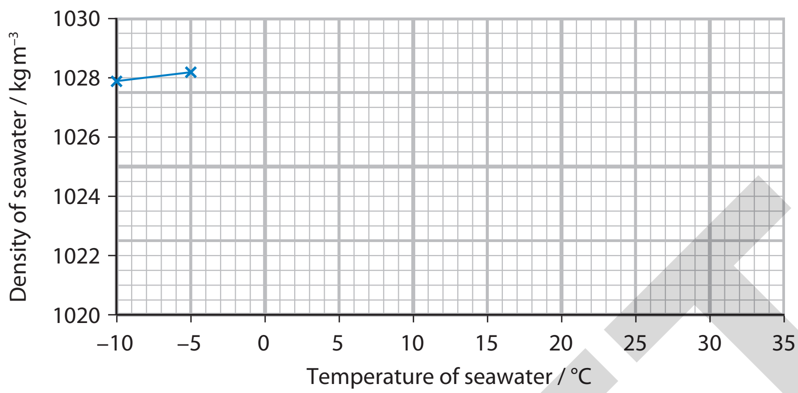


Figure 1.16: Line graph comparing the density of seawater and temperature at sea level.

PROJECT: ATOMIC BONDING PLAY

Work with fellow students to create a play showing how different types of bonds form between atoms in the ocean. These plays can be serious or silly as long as they detail the processes the atoms go through (e.g. the sharing or exchange of electrons). Your performance should be no longer than three minutes and focus on one type of bond with examples that are commonly found in marine ecosystems. The use of props is encouraged; for example, a beach ball could represent an electron.

Thinking about your project

- Now that you have performed your play and watched others, do you feel more comfortable with the bonding processes in atoms?
- How would you rate your group's performance in comparison to the other groups?
- What changes would you make to your play if you could do it over again?

Test yourself

8 What impact do temperature and salinity have on density?

9 Sketch what you would expect the temperature profile with depth to look like in an Arctic environment. What clues did you use to create your profile?

EXAM-STYLE QUESTIONS

1 a Through the use of an annotated diagram, **describe** covalent bonding in a water molecule. [3]

b **Explain** how water changes state from a liquid to a gas with reference to hydrogen bonds. [3]

c When creating the solid form of water, ice, individual water molecules link together through the attractive forces of hydrogen bonds forming a lattice structure. **State** how this change in structure affects the density of ice compared to liquid water. [1]

d Explain how the change you identified in **1c** impacts the organisms in arctic ecosystems. [3]

e Using knowledge gained in your practical, **predict** the temperature of the water below the ice in the arctic ecosystems mentioned in **1d** and **suggest** a reason why. [2]

[Total: 12]

2 a **Define** the term *salinity*. [1]

b **Outline** the effect evaporation and freezing have on salinity. [2]

c Explain why the salinity of water in the open ocean tends to be higher than that near the coastlines. [2]

d Explain how salinity and temperature affect the density of seawater creating layers within the ocean, and how mixing of these layers occurs. [6]

[Total: 11]

3 Scientists studying dissolved oxygen rates in aquatic ecosystems collected data from the surface of a river, the open ocean, and a tropical lagoon. The data is shown in table 1.6.

	Dissolved oxygen (DO) / mg L^{-1}			Mean DO concentration / mg L^{-1}
	Collection 1	Collection 2	Collection 3	
River mouth	10.0	11.1	10.3	
Open ocean	7.5	5.2	8.1	
Tropical lagoon	3.2	3.7	2.9	

Table 1.6: Data collected regarding dissolved oxygen concentrations.

a Complete a copy of Table 1.6 by **calculating** the mean dissolved oxygen concentration for each environment. [3]

b Describe how means were calculated for each environment. [2]

c **Compare** the data for the three environments. [2]

d Suggest explanations for the differences in DO concentration in these habitats. [8]

[Total: 15]

COMMAND WORDS

describe: state the points of a topic / give characteristics and main features

explain: set out purposes or reasons / make the relationships between things evident / provide why and/or how and support with relevant evidence

state: express in clear terms

predict: suggest what may happen based on available information

suggest: apply knowledge and understanding to situations where there are a range of valid responses in order to make proposals

define: give precise meaning

outline: set out main points

calculate: work out from given facts, figures or information

compare: identify / comment on similarities and/or differences

CONTINUED

4 Scientists are attempting to find a correlation between sea surface temperatures and ocean acidity to indicate that global warming is impacting ocean acidification. These scientists have already collected temperature data for ten sites along the Great Barrier Reef (Figure 1.17).

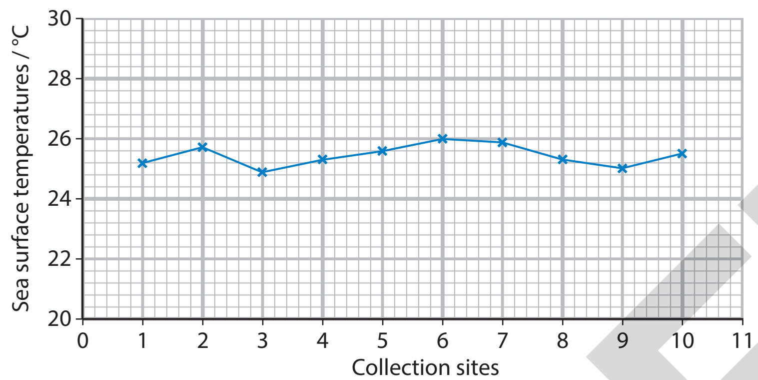


Figure 1.17: A graph of the seas surface temperatures at ten collection sites on the Great Barrier Reef, Australia.

a **Identify** the 'best' technique for the scientists to collect pH data from the same ten sites where temperature data was collected, and how they would ensure the results are reliable. **[2]**

b Suggest reasons why the technique you chose in part (a) would be the best choice in this instance. **[3]**

c In a healthy ocean, state the pH levels you would expect to find. **[1]**

d Using the data in Table 1.7, plot a graph of the pH values on a copy of Figure 1.17. **[4]**

Collection site	pH
1	8.15
2	8.21
3	8.34
4	8.20
5	8.22
6	8.24
7	8.20
8	8.19
9	8.24
10	8.30

Table 1.7: pH values collected at ten collections sites on the Great Barrier Reef, Australia.

COMMAND WORD

identify: name / select / recognise

CONTINUED

e To what extent does the graph support a correlation between sea surface temperatures and ocean pH? [2]

[Total: 12]

5 a **Sketch** an annotated diagram depicting the creation of an ionic bond formed from a sodium atom and a chloride atom. [4]

b Complete a copy of Table 1.8 with each compounds bond type, chemical formula and chemical name. [6]

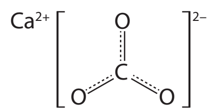
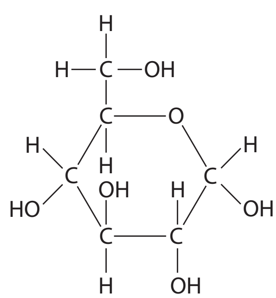
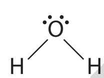
Diagram	Bond types	Chemical name	Chemical formula
			
			
			

Table 1.8: The bond types of common compounds found in seawater.

[Total: 10]

6 Seawater is a solution made of many solutes including ions and covalent molecules.

a Define the following terms:

i *solute* [1]

ii *solvent* [1]

b Suggest a reason why scientists think a warming ocean may have a higher salinity. [2]

c State the most abundant ionic compound found in seawater. [1]

[Total: 5]

COMMAND WORD

sketch: make a simple freehand drawing showing the key features, taking care over proportions

CONTINUED

7 Scientists were conducting research in the waters off the Southern California coastline. They took measurements of temperature and dissolved oxygen concentration from the sea surface to approximately 300 m down. See the results in Figure 1.18.

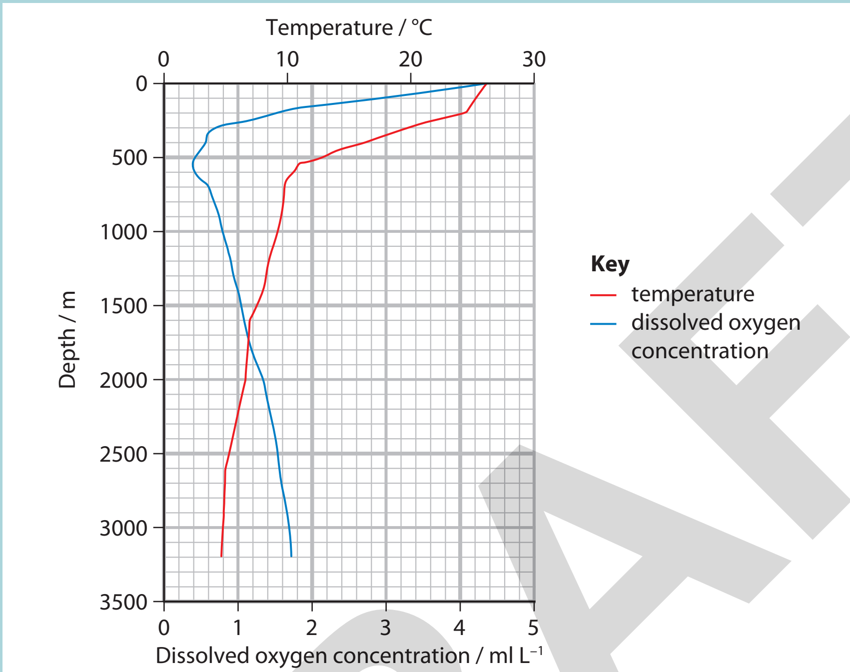


Figure 1.18: A comparison of DO levels and temperature off the coast of Southern California.

a State the term used to describe the region of a water column where there is a drastic change in water temperature. **[1]**

b State the approximate range of depths during which this drastic temperature change occurs. **[1]**

c Use Figure 1.17 to find the following information:

   i The depth at which the dissolved oxygen concentration is 0.4 ml L^{-1}. **[1]**

   ii The temperature at 1000 m. **[1]**

d Figure 1.17 shows an area of extremely low oxygen concentration at 500 m deep.

   i State the name for that region of the ocean. **[1]**

   ii Explain why the oxygen at this level is so low. **[4]**

e Oxygen concentrations begin to rise after 500 m deep. Explain how that is possible. **[3]**

[Total: 12]

SELF-EVALUATION CHECKLIST

I can:	See topic...	Needs more work	Almost there	Ready to move on
use the kinetic particle theory to explain the changes of state in water, between solid, liquid and gas				
describe how the structure of atoms leads to the formation of different bonds such as covalent, ionic and hydrogen bonds				
explain how hydrogen bonding provides special properties to water				
explain and compare the terms solute, solvent, solution and solubility in order to apply these terms to the dissolution of salt in the ocean				
explain the impacts of temperature and salinity on the solubility of salts and gases in seawater.				
explain how run off, precipitation and evaporation impact the salinity of seawater				
describe the pH scale and know three techniques used to measure pH in water				
explain the effects on the density of seawater caused by water temperature, pressure and salinity.				
state that the reason ice can float is because the density of ice is lower than seawater and discuss the importance of that to marine organisms.				
describe how temperature and salinity gradients form in water columns to produce ocean layers and how subsequent mixing of these layers may occur				

EXTENDED CASE STUDY: THE DEAD SEA

The Dead Sea is a hypersaline lake located in the Middle East in the Jordan Rift Valley. At 377 m deep, the Dead Sea is considered to be the deepest hypersaline lake in the world. This depth also helps make the Dead Sea the lowest elevation on land, at 423 m below sea-level.

The waters of the Dead Sea are replenished by the Jordan River which flows into the northern end of the lake. This 50 km long and 15 km wide body of water is considered to be one of the saltiest places on Earth.

The salinity of the water in the Dead Sea ranges from 280 ppt to 350 ppt. As typical ocean water contains salinity levels of only 35 ppt, the waters of the Dead Sea are, on average, 8.5 times as salty. However, the salinity levels vary depending on the time of year and where in the water column the measurement was taken. Salinity typically decreases in the winter and spring as there is more inflow from the Jordan River during these times, although that water has been dwindling for years as neighbouring countries divert more and more of the river for their country's needs. Measurements taken nearest the immediate surface tend to be higher than the waters directly below because of the high evaporation rates in the desert-like conditions of the Jordan Rift Valley. Evaporation rates are so high that salt crystals actually from along the surface and shore of the water (Figure 1.19). As you dive deeper into the water column you see a general trend of increasing salinity as you reach the bottom.

Figure 1.19: Salt crystals on the surface of the Dead Sea.

Due to the high salinity levels in the bottom water, the lake has historically had two different water masses existing simultaneously within its confines. The last time this happened lasted for nearly three hundred years and ended in the late 1970s. In this case, the first 40 metres of the Dead Sea maintained an average salinity that was just under 300 ppt. The most common salts found in this layer were bicarbonates and sulfates – very different from the open ocean where these salts occur at much lower percentages. Below the surface layer was a transition zone where the water's temperature decreased while the salinity gradually increased creating both a thermocline and halocline. Below this transition zone, at approximately 100 metres, the water became more uniform with a constant temperature and salinity. The salts present in the water saw a drastic shift to hydrogen sulfide, magnesium, potassium, chlorine, and bromine. The high concentrations of salt made this water incredibly dense preventing it from ever rising to the surface and, in essence, creating a permanent bottom layer with distinctly different characteristics from the surface layer.

Cultural history

For thousands of years, the Dead Sea has been a vacation destination. The salty waters are rumoured to have healing powers because of its mineral content. It is believed that soaking in these ion-laden waters can help reduce skin disorders, such as psoriasis and acne, and alleviate joint pain from arthritis. Many tourists will cover their bodies in the mineral-enriched muds hoping for health benefits. Science has yet to conclusively say any of these rumours are true and yet they have persisted throughout history. According to historical legend, the first health spa was located at the Dead Sea for Herod I (37–34 BCE).

However, if you are trying to get a work-out in these waters, you might want to visit somewhere else. Swimming here is really just floating as bathers are buoyant on the incredibly dense waters (Figure 1.20). Tourists have been seen reading the newspaper while floating on their backs with no problem.

CONTINUED

Figure 1.20: A woman floats on her back in the Dead Sea.

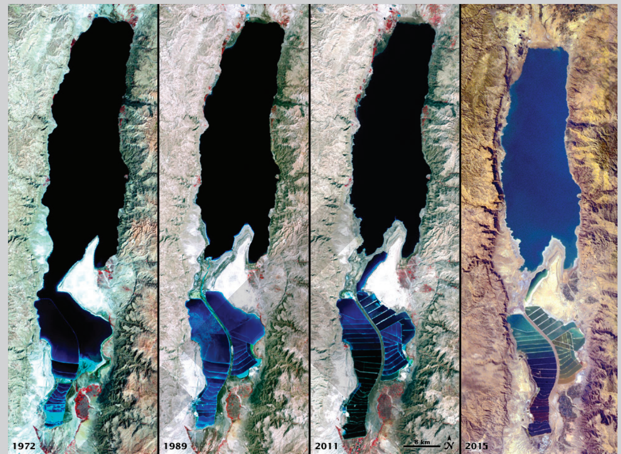


Figure 1.21: Aerial views of the Dead Sea taken in 1972, 1989, 2011 and 2015.

It is ironic that the Dead Sea has always been considered a place of health and healing considering salinity levels make it impossible for most organisms to live there. Humans have even been killed by accidentally swallowing the water. The salt content is so high that even a mouthful of water can shut down your kidneys and damage your heart, which is why lifeguards are always on duty on a beach where no one drowns. Only a few species of archaea, bacteria and fungi are capable of making their homes in the Dead Sea on a continuous basis. In recent history, there has only been one occasion where new life has made its way into the sea. A particularly rainy winter in 1980 reduced the salinity so much that a new type of algae became established and turned the waters red, an unusual occurrence.

Profiting from salinity

People have always taken salt in small amounts from the Dead Sea. After all, it washes up on the shores. That changed when the Dead Sea Works was established to produce a major component of fertilisers: potash. Potash is the common name for potassium chloride and it has been mined from the Dead Sea in great quantities since 1929. Potash is such an important and expensive part of fertilisers that it is often referred to as 'white gold'. In order to remove potash from the waters of the Dead Sea, shallow evaporation pools have been created in the southernmost portion of the lake (Figure 1.21). This allows sunlight to evaporate water from the brine and leave the salts behind. However, in order to make these pools successful, the southern end of the Dead Sea has had several barricades, or dykes, built to prevent water from the Jordan River from flowing in naturally. This allows the corporations mining the potash, such as Dead Sea Works, to control rainwater flow.

Unfortunately, this evaporation process, which has been happening for nearly 100 years, has caused a severe drop in water levels. Between 1970 and 2018, the water levels in the Dead Sea dropped an average 1 m year^{-1}. This reduction in surface water has allowed groundwater to move below the surface dissolving subterranean caverns in the salt layer below the lake leading to sinkholes when the underground salt structures collapse. Several hundred sinkholes have formed around the Dead Sea, many in areas that are popular with tourists. It will not surprise you that resorts in this area are now turning even the sinkholes into tourist attractions. Concerned over this water loss the governments of countries neighbouring the Dead Sea have been in talks about how to restore water levels and conserve the water of the Jordan River.

CONTINUED

Questions

1 Unlike the Dead Sea, in the open ocean potassium is a minor component in seawater. When seawater is evaporated, which minerals would you expect to find the most of?

2 Based on your knowledge of run-off, why do you think the levels of potassium are so high in the Dead Sea?

3 Evaporation is a major factor in the salinity of the Dead Sea. What role does it play in the ocean?

4 How does the increased salinity of the Dead Sea due to the fertiliser industry impact upon the microscopic organisms that live there?

5 Do you believe the history and culture of the Dead Sea should play a role in trying to save it? How?

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Marine Science for Cambridge International AS & A Level

Digital Teacher's Resource

Contents

1 Water

Syllabus overview

- This section of the syllabus gives students an introduction to particle theory and the ways in which particles can be bonded together. This is then used to explain some of the properties of water and why this is important for marine life. Temperature, salinity and pressure of the water are all covered.
- The study of water is fundamental to marine science and links to many other topics. This includes photosynthesis in Chapter 3 and 7, abiotic factors affecting populations in Chapter 4, marine ecosystems in Chapter 5, osmoregulation in Chapter 6, and ocean acidification in Chapter 9.
- The two core practical activities in this chapter are investigations into the effect of salinity on the freezing point of water solubility of gases in water. They will give students the opportunity to make predictions, present their data in the form of a graph, make criticisms of the experimental procedure and identify anomalous values.
- Maths skills covered include calculation of density and plotting accurate line graphs.
- There are many opportunities to cover AO1 (knowledge and understanding) and AO2 (handling and applying information. Guidance to the types of questions which can be used is found at the beginning of each section. During the core practical activity there will be an opportunity to cover AO3 (experimental skills and investigations), particularly presentation of data and evaluation.

Topic teaching plan

Topic	Suggested time (hours)	Outline of lessons	Coursebook	Workbook
1.1	5	Structure of an atom; covalent, ionic and hydrogen bonding, the properties of water and seawater	Section 1.1	
1.2	4–5	Solubility in water; the effect of temperature, pressure and salinity on solubility; pH; Core practicals 1.1 and 1.2 should take place here	Section 1.2	
1.3	3–4	Calculation of density; plotting graphs; the effect of temperature, pressure and salinity on density	Section 1.3	

Topic 1.1 Particle theory and bonding

Assessment ideas

These questions can be used to assess student understanding after you have given an explanation. This could be during the lesson or a starter for topics that follow on.

Knowledge and understanding (AO1)

- Sketch the particles in a generalised solid, liquid and gas. Alternatively, you could give students the diagrams and ask them which state of matter they represent.
- Describe what happens to the particles in a liquid as it freezes.
- Give students the keywords from the topic (e.g. bond, covalent, ionic, hydrogen, ion, polar, solvent, density). Ask them to write down the definitions.

Handling and applying information (AO2)

- Show a simple dissolving reaction (e.g. adding sugar to water) and ask students to explain why water is such a good solvent.
- Explain why ice is less dense than water. Alternatively, ask which is less dense and use it as a hinge point. If students are unable to identify that ice is less dense, then they need more explanation. [Note: a hinge point is a question which is designed to have a simple answer which will help you to decide whether to continue with the topic, recap or reteach something which has not been fully understood.]

Experimental skills and investigations (AO3)

- Give students data on the different percentages of each ion found in seawater and ask them to present it as a pie chart.
- Plan an experiment to find the specific heat capacity of water. They should think about safety and you could also ask them to prepare a risk assessment. This should include the hazard, the risk and the control measures. For example, a hazard is hot water, the risk is scalding, the control measures are keeping stools out of the way and not having the water near the edge of the bench.

Common misconceptions

Misconception	How to elicit	How to overcome
Students often confuse the idea that water is a compound formed of two types of atoms, with the idea that seawater is a mixture of different elements and compounds.	Name different elements, mixtures and compounds, or show pictures, for example water, air, oxygen, seawater, paint, nitrogen, carbon dioxide. Ask students to tell you which category each picture falls into.	Show a diagram of a water molecule and explain that the hydrogen and water atoms are bonded together, making it a compound. Then discuss with students the different things found in seawater, including water molecules, and explain that they are mixed together but not joined chemically.

Lesson starters

1 Before you start question (5 mins)

Learning aim: Students should be able to recall what they have been taught previously about the structure of atoms.

Resources: Coursebook Chapter 1: Before you start question 1.

Description: This question asks pairs of students to draw and label an atom. This is a useful introduction as it will enable you to assess the current knowledge of your class. If nobody can draw an accurate picture then use some of the support ideas in the differentiation section of this guide. If most students can already draw accurate diagrams then you will be able to start introducing them to the different types of bonding.

2 Solids, liquids and gases (15 mins)

Learning aim: Students should be able to describe the differences between solids, liquids and gases in terms of the particles they are made up of.

Resources: Examples of solids, liquids and gases. Ideally you will have some different containers they can be placed into, and perhaps syringes, so that students can attempt to compress each substance.

Description: Let the students examine your examples, pour them into different containers and try to compress each substance. Then ask them to explain what they have found in terms of the particles. You could ask why the liquid takes the shape of the container but the solid does not; or why some substances can be more easily compressed than others. Students at this point should start to think about the arrangement of the particles and whether they are able to move or not.

3 Bonding definitions (15 mins)

Learning aim: Students should be able to differentiate between covalent bonding, ionic bonding and hydrogen bonding.

Resources: For each type of bond you will need a piece of paper with the correct definition and two incorrect or partial definitions. For example for ionic bonding you could have:

1. atoms share electrons
2. a bond between a metal and a non-metal
3. a bond formed from the transfer of electrons between a metal and a non-metal, which leads to the formation of ions with opposite charges.

You could also project the definitions on to the whiteboard for students to look at.

Description: Ask students to work in groups to discuss the definitions you have given them. They should decide which one they think is the correct definition and why that is. You could extend the activity by giving them some nearly correct definitions. In this case, once they have decided on the best definition they must add to it.

Main activities

Below are several teaching activities which you can pick and choose from in order to tailor the lesson to your class's needs.

1 Particles in solids, liquids and gases (45 mins)

Learning objective: Explain the changes of state in water, between solid, liquid and gas, in terms of the kinetic particle theory.

Resources: Ice, beaker, Bunsen burner, Coursebook Chapter 1 Figure 1.1.

Description: Show the ice to the students and ask them to describe the arrangement of the particles. Then gently heat the ice in the beaker until it melts. Again ask the students to describe the particles. Finally heat it more intensely until steam starts to form. Once this is finished students should draw diagrams to show the arrangement of particles in the ice, the water and the steam. Underneath each of their diagrams they should write an explanation to show what the particles are doing.

Answers:
The particles in the ice (solid) are held in place and are not moving as much as they are in the water (liquid). In the liquid the particles can move freely but are attracted to each other, so they take the shape of their container. As they are given more energy (in the form of heat from the burner), the particles move further apart until they form a gas (water vapour).

Scaffolding and extension ideas: Support students by giving them the key words to use in their explanations, for example energy, movement, distance, particle. You could give students the particle drawings and ask them to work out which one is the solid, the liquid and the gas. Challenge students to explain why they think we have special words for solid water (ice) and gaseous water (steam) but not for other substances.

› **Reflection opportunities:** Ask students to compare their explanations in pairs. They can also compare their diagrams to Figure 1.1 from the Coursebook. Students should think about whether their diagram shows what is happening to the particles effectively and if not what they could change about it. If necessary you could ask them to make the changes but in a different colour so you can still assess their original work.

2 Structure of the atom (30 mins)

Learning objective: Describe the structure of an atom. This should include the nucleus, containing protons and neutrons, surrounded by electrons that are arranged in shells.

Resources: Coursebook Figure 1.2.

Description: Show the picture of a helium atom from the Coursebook and ask students to identify the main parts of the atom. They may need help to do this, in which case you can describe the nucleus as being formed from equal numbers of protons and neutrons, with an equal number of electrons orbiting the nucleus. Then ask students to draw and label an atom in their notes. Ask them what the charge is on the atom in their picture. Ask them to suggest where positive and negative ions might come from.

Answers:
The atom in their picture should be neutral if they have drawn equal numbers of protons and electrons. Positive and negative ions are formed when atoms lose or gain electrons.

Scaffolding and extension ideas: Support students by giving them an unlabelled diagram and simply asking them to add the labels. Challenge students by giving them different examples of atoms to draw, with more protons, neutrons and electrons.

3 Ionic and covalent bonding posters (60 – 90 mins)

Learning objectives: Describe, including through the use of diagrams, the covalent bonding in a water molecule, limited to the sharing of electron pairs between atoms; Describe, including through the use of diagrams, the ionic bonding in sodium chloride, limited to the loss and gain of electrons to form ions and the subsequent attraction between positive and negative ions.

Resources: TedEd atomic bonding video, Coursebook Chapter 1, poster paper and pens.

Description: Show students the video (3 mins), which introduces covalent and ionic bonding. Discuss with students what happens in each type of bonding and what they think the differences are. Divide students into groups and ask each group to make a poster summarising either ionic or covalent bonding. They can use the Coursebook for ideas to put on their posters. Posters should include both words and pictures. Afterwards each group should present their poster to a group who did the other type of bonding. Finally students should write a written summary of the ionic and covalent bonding based on the posters. You could also photocopy the posters and hand them out to students to use for revision.

Scaffolding and extension ideas: Give students a checklist of what you would like to see in each poster, for example, covalent must include sharing of electrons, both posters must include at least one diagram, ionic must refer to positive and negative charges and explain where they come from. You could challenge students by giving them examples of compounds found in seawater which they must include in their posters. This could include carbon dioxide and oxygen for the covalent group and magnesium sulfate and calcium carbonate for the ionic group.

› **Reflection opportunities:** This is a good place to try some peer assessment. Ask students to assess the posters, using the following criteria:

- Is the poster easy to understand?
- Is there a good mix of diagrams and text?
- Does it explain the type of bonding effectively?

Students should then write a comment which gives at least one thing they liked or found useful in the poster and one thing which could be even better.

4 The importance of water (60 mins)

Learning objective: Explain how hydrogen bonding in water affects the properties of water, limited to solvent action, density and specific heat capacity.

Resources: Crash Course science video.

Description: Show the video (12 mins). Explain the formation of hydrogen bonds in water or ask students to read that section in the Coursebook. Then ask students to work in pairs and to list the properties of water, which come from the hydrogen bonding (solvent action, density, specific heat capacity), in order of importance. They should give a reason for each of their choices. It does not matter what order they choose: it is the discussion and the justification of their choices which is important. Ask each pair to report back on the order they have chosen. The class must then come up with a class order, which may require a vote if there is disagreement. Once there is agreement on a class list, students should be able to write a summary of each of the three properties, including what causes them and why they are important.

Scaffolding and extension ideas: Some students may need to use the Coursebook for further support when considering the importance of the properties. Challenge students to research adhesion and cohesion and their importance to living things. These are properties of water that are not covered by this syllabus but are interesting to consider.

› **Reflection opportunities:** Ask students why they chose their most important feature and whether they changed their minds once the class discussion started. If they did change their mind, ask them what they had not considered in their initial ranking.

Plenary ideas

1 Test yourself questions (20 mins)

Resources: Coursebook Chapter 1: Test yourself questions 1–4.

Description: Ask students to work in pairs and to take it in turns to read out the questions to each other. The student who is listening should explain their answer orally. The pairs should then work together to produce an ideal written answer based on this initial discussion. They must do this without referring to their notes or the Coursebook.

› **Assessment ideas:** Group the pairs into fours and swap the ideal answers between the two pairs. Students should then read through the Coursebook to check the other pair's answers. Anything which was incorrect should be corrected.

› **Reflection ideas:** If students made mistakes ask them to think about why they think this happened. Were they rushed or distracted or did they not understand? Encourage them to seek further help if necessary and to make a note of any minor mistakes that could have been avoided for future reference.

2 Mini whiteboards (10 mins)

Resources: Mini whiteboards and pens. If these are not available they can be made by laminating a piece of white paper. Alternatively, students can be given large pieces of paper, which they can write their answers on.

Description: Test student understanding by asking them simple questions, which they can answer by drawing on a mini whiteboard.

› **Assessment ideas:** This enables you to assess the entire class as they must all hold up their answers at the same time. You could ask them to: draw an atom, show different compounds and ask them to identify the compound or the type of bonding, write the keyword to a definition you have given them, draw the particles in solids, liquids or gases. If you want to challenge students you can also give bonus points for the fastest answer to each question.

3 Traffic lighting of learning objectives (10 mins)

Resources: Three colours of card for each student (green, amber, red) or three coloured pens.

Description: Show the learning objectives for your lesson and ask students to traffic light their current understanding. They can either do this by drawing circles next to the relevant parts of their notes or they can hold up coloured card in class. Green means they are confident and could explain it to someone else. Amber means they are getting there but may need support. Red means they do not understand and will definitely need more help.

› **Assessment ideas:** Look at the colours chosen by the students. If they all rate something as green you know you can move on. If they are all red then go back over the work. If there is a mixture or some students are amber you can group them together, so that students who chose green can support those who chose amber or red.

Differentiation ideas

Stretch and challenge

- Ask students to research different types of ionic and covalent compounds and write an explanation of how the bonding in each compound affects its properties.
- Ask students to predict the problems which would be caused, if water was missing one of its important properties. For example, what would happen if ice stopped floating on water, if water stopped being such a good solvent, or if it did not have a high specific heat capacity? Depending on how long students have to answer this question you may get some detailed and interesting answers.

Support

- Use this GCSE bitesize revision website to help students with the concepts of bonding. It includes revision notes, a video and a test.
- Give students a list of the key vocabulary from this topic (you could use the glossary to help set this up) and ask them to draw a diagram to illustrate each word or phrase. They can then keep this with the rest of their notes and use it to help with their written work.

Homework ideas

- Students should read through Exam-style question 5 and use it as a guide to write a similar question worth the same number of marks. They must also provide the answers for their question, showing what they expect someone to write for each part of the question. Once you have assessed their questions and checked the answers, students can swap questions and answer them as a revision activity in a later lesson.
- Read Case study 1.1 on the composition of seawater and then research the new methods of investigation, which are mentioned (satellite observations and computer models). Students should then summarise one of these methods.
- Make a model to show the bonding in one of the important compounds found in seawater. You can extend this task by asking students to provide a poster which goes with the model that explains the key features.

Topic 1.2 Solubility in water

Assessment ideas

These questions can be used to assess student understanding after you have given an explanation. This could be during the lesson or a starter for topics that follow on.

Knowledge and understanding (AO1)

- Give the definitions of solute, solvent and solution.
- Draw a diagram to show what happens when NaCl dissolves in water.

Handling and applying information (AO2)

- Explain what happens to the mass of solute, which will dissolve in a given volume of solvent as the temperature increases.
- Explain why oxygen can be found even at depths of the ocean where no photosynthesis can take place. You can also ask this in a simpler form as a hinge question: Is there oxygen in the depths where no photosynthesis takes place? If students answer no then you will need to recap the effect of pressure on solubility of gases.
- Describe how and why changes in the solubility of oxygen will affect marine organisms.

Experimental skills and investigations (AO3)

- Design an investigation into the effect of temperature on the solubility of NaCl in water.
- During the core practical draw a clear results table and record data accurately.
- After the core practical students can present their data in the form of a graph.

Common misconceptions

Misconception	How to elicit	How to overcome
Once students have learned that increasing temperature increases the solubility of salts they can become confused when considering the solubility of oxygen and other gases.	Ask students whether there will be more oxygen in warm or cold water.	Explain that oxygen has a low solubility in water because it does not combine with the water molecules. You can show boiling water and ask students what they can see (bubbles). Ask what is in the bubbles (most will know that it is gas) and then ask what has happened to the amount of gases dissolved in the water as temperature has increased. Having seen this demonstration most students will be able to explain that there is less gas dissolved in the boiling water as it has been released in the bubbles. This can then be linked back to differing temperatures of water in the ocean.

Lesson starters

1 Ocean salinity demonstration (10 mins)

Learning aim: Students should be able to describe what happens when a salt is mixed with water and state the average salinity of seawater.

Resources: Salt (NaCl) and water, balance to find the mass of salt, a one litre container.

Description: First dissolve a small amount of salt in a small amount of water and ask students to describe what has happened to it and why they cannot see it any more. Then weigh out 35 g of salt and show this to the students. Dissolve it in one litre of water. Explain that this is the average salinity of the ocean and that it is measured in parts per thousand. Ask how many ml or cm^3 there are in one litre (1000), ask how much salt was added (35 g) and then ask students to write down the salinity in parts per thousand (how many grams of salt there are for every 1000 ml of water).

2 Measuring the pH (10 mins)

Learning aim: Students should be aware of the three main ways in which pH can be measured.

Resources: Fuse school video on measuring pH.

Description: Watch the video (3 mins) on measuring pH and then ask students to summarise each method and give an example of when each method might be used. Ask students which method they would choose and why, if they wanted to test water samples.

3 Keyword card sort (15 mins)

Learning aim: Students should be able to describe how salts dissolve in water and the effect of different factors on the solubility.

Resources: Use the card sort template (refer to contents page) to provide some of the key terms and definitions from this section of the Coursebook. Examples of the words you can use are solute, solvent, solution, solubility, dissolution, salinity, evaporation, precipitation and run-off.

Description: Ask students to see how many key terms and definitions they can match, using their current knowledge. Words they cannot match should be written down and returned to at the end of the lesson. This will also be a visual reminder to students of what they have learned during the lesson.

Main activities

Below are several teaching activities which you can pick and choose from in order to tailor the lesson to your class's needs.

1 Dissolving and salinity (60 mins)

Learning objective: Describe how soluble salts such as sodium chloride dissolve in water by the dissolution of ions.

Resources: Coursebook Topic 1.2.

Description: Refer back to the ocean salinity demonstration starter and ask students to explain what happened to the salt. You can also refer again to the Crash Course science video on water, if you used it in Topic 1.1. If necessary recap the meaning of the words solute, solution, solubility and solvent and ask students to use them in their explanation. Ask students how they could increase the amount of salt which dissolved in a given volume of water. Finally ask students to think of ways in which the salinity of sea water might change. Collect all the ideas from the class and discuss them. Explain any ideas, which have been missed out if necessary. Finally ask students to draw a simple diagram to show how salinity increases (evaporation) and decreases (precipitation and fresh water run-off). Students can read Topic 1.2 of the Coursebook to help them to draw the diagram.

Answers:
The salt dissolves because the ionic bonds between the sodium and chloride ions are disrupted by the water molecules. The positive part of the water molecule (the hydrogen) is attracted to the negative part of the sodium chloride (the chloride ion). More salt can be dissolved if the water is heated as the molecules will have more kinetic energy and will therefore move apart more quickly. The diagrams should show water either being added or taken away, which will affect the concentration of dissolved salts.

Scaffolding and extension ideas: Support students by giving them the beginning of each sentence they will need to describe dissolving. For example, you could give them 'When the salt was added to the water it …' and then 'This takes place because the bonds between the sodium and chloride ions …'. You could also demonstrate the effects of evaporation and by leaving salt water to evaporate and returning to it in a later lesson and then precipitation by adding freshwater to it and asking students to describe the changes in salinity. Figure 1.9 in the Coursebook shows the arrangement of atoms in solid sodium chloride and its dissolved form. Challenge students by asking them to find out which types of substances are soluble and insoluble in water and to explain why.

〉**Reflection opportunities:** Students should consider whether they found the diagram or the written description easier to understand. This will then be something to consider when revising as they should be choosing revision techniques, which use their strengths and preferred method of learning.

2 Solubility of gases in water (60 mins)

Learning objective: Describe the effect of water temperature, water pressure (depth), atmospheric pressure and salinity on the solubility of gases in water and the implications this has for marine organisms.

Resources: Coursebook Chapter 1 Topic 1.2 and solubility of gases video, or bottles of sparkling water a bucket of ice, a bucket of warm water and balloons.

Description: Either show the video (3 mins) or carry out the same demonstration in class. If you are carrying out the demonstration, you need a bottle of sparkling water at room temperature, in ice and in hot water. Open each bottle in turn. The room temperature bottle should hiss a little as gas escapes. The cold bottle will open without much happening. The warm water will probably spray out of the bottle quite quickly, so be prepared to get wet. You can also try attaching balloons to the necks of each bottle to collect the gas. The larger the balloon, the more gas has been collected. Ask students which bottle lost the most gas. Then ask them to explain what this means in terms of solubility. Ask students to suggest what else might affect the solubility of the gas and make a list of their ideas. Explain that the most important factors other than temperature are water pressure, atmospheric pressure and salinity. Divide the class into groups and let each group research the effect of one of these three factors. The groups should each give a 2 mins presentation to the class explaining what they have found out. Then each student should write a summary of the four factors affecting the solubility of gas in water. Finally ask students why this is important for marine organisms, which gases they think are the most important and what would happen if the solubility changed.

Answers:
The hot bottle lost the most gas, which means that the solubility of the gas was lower. The most important gases that dissolve in the water are nitrogen (so that it can be fixed into ammonia to produce proteins), oxygen (for respiration), and carbon dioxide (for photosynthesis). If the solubility of any of these changes it will have implications for the food chain and for survival of the organisms.

Scaffolding and extension ideas: Support students by providing groups with a checklist of what you would like them to include in their presentations. Students writing the summaries at the end can also use the Coursebook to help them. Challenge students to draw a diagram showing layers of water in the ocean, the changes in temperature, salinity and pressure in these layers and the effect on gas solubility in each layer.

Plenary ideas

1 Keyword glossary (15 mins)

Resources: Glossary template (see contents page for link).

Description: Use the glossary template to help students produce a glossary of the main words from this section. This could include solute, solvent, solution, solubility, dissolution, salinity, evaporation, precipitation and run-off. Students should also use each word in a sentence to show that they have understood the meaning.

〉**Assessment ideas:** Ask students to compare their glossary to the Coursebook and make any corrections they feel necessary.

〉**Reflection ideas:** If students have made corrections they should think about why they got the definition wrong and how they can remember the correct one for next time. If they did not make any mistakes they should think about how they can replicate that success with the keywords from the next topic.

2 Test yourself questions (20 mins)

Resources: Course book Chapter 1: Test yourself questions 5–7

Description: Ask students to answer the test yourself questions without referring back to their notes to see how much they have remembered.

Assessment ideas: Students should self-assess their work by reading through their notes and adding in any missing detail in another colour. The more they must add then the more they have forgotten. If they cannot answer the questions even with their notes or the Coursebook then they have not understood and will need to go back over the topic.

3 Incorrect test yourself questions (30 mins)

Resources: Coursebook Chapter 1: Test yourself questions 8 and 9, which you have written incorrect answers to.

Description: Provide students with incorrect answers to these test yourself questions and ask them to correct what you have written. This is a really good way to test their understanding, particularly if the mistakes you include in the answers are quite minor and difficult to find.

Reflection ideas: Go through the answers and ask students how many of the mistakes they found. Did they correct anything which was already right? If they found this a useful way to learn, then answering questions and swapping with a partner to correct would be a good revision strategy in the future.

Differentiation ideas

Stretch and challenge

- Ask students to research how to make simple indicators (e.g. from red cabbage). If there is time they can calibrate their indicators against Universal indicator or a pH probe and produce a colour scale.
- Ask students to find out more about the Don Juan pond in Antarctica and explain why it does not freeze even at temperatures of −50 °C.

Support

- Use this Khan Academy guide to pH to support students finding the ideas difficult.
- Let students use the BBC Bitesize revision website which explains solubility very clearly and then has a test for students to take.

Homework ideas

- After students have completed Core practical 1.1 they should be able to answer Exam-style question 1 which refers to their results. As the rest of the question covers Topic 1.1 it is a good revision exercise. Ask students to answer the question for homework, but without using their notes or the Coursebook to help them.
- Exam-style question 4 tests students on their ability to plan a valid investigation as well as to draw a graph. It would be worth going over your marking criteria for the graph, for example the axes are the right way around, labelled, have a linear scale. Then ask them to complete the question at home.
- Design an investigation into the effect of a named factor on the solubility of salt in water.

Topic 1.3 Density and pressure

Assessment ideas

These questions can be used to assess student understanding after you have given an explanation. This could be during the lesson or a starter for topics that follow on.

Knowledge and understanding (AO1)

- Give the equation to calculate density.
- State the factors which affect density.
- State which factor has the greatest effect on density.

Handling and applying information (AO2)

- Explain why a thermocline forms in the water.
- Describe the problems which marine organisms would face if ice was denser than water.

Experimental skills and investigations (AO3)

- Plot accurate graphs to show the changes in density at different pressures, salinities or temperatures.
- Calculate density showing the working and to the correct significant figures.

Common misconceptions

Misconception	How to elicit	How to overcome
Students can find the idea that ice is less dense than water difficult to understand. In their experience solids tend to be denser, despite the fact many will have seen ice floating in their drinks they have never thought about why that might be.	Show students a drink with ice cubes floating in it (or a photograph of the same thing). Ask them to explain why the ice is floating. If they have understood then they should be able to explain that the ice is less dense than the water.	Show a diagram of the water molecules in ice and explain that they are further apart as they are held at constant distances by the hydrogen bonds. This means there are fewer molecules in a set area, so it is less dense than liquid water.

Lesson starters

1 Answering student exam-style questions (15 mins)

Learning aim: Students should be able to recall information about solubility in water.

Resources: Exam-style questions written by students for homework in Topic 1.2.

Description: Pair students and ask them to swap the exam questions they wrote for homework. Students must answer the question and then pass them back to the original student for marking.

2 Introduction to density (20 mins)

Learning aim: Students should be able to explain what density means.

Resources: Two items, which have the same volume but have different densities (e.g. equally-sized pieces of wood and polystyrene). Then a range of items with different densities (e.g. chalk, stone, wood, sand, paper, oil, wax). A bucket or tank of water.

Description: Show students your two chosen items and ask them to compare the volume (they should be the same). Then pass them around and let students feel the difference. Ask why one feels heavier than the other and what this must mean in terms of the particles (if the volume is the same the particles must be closer together). Show the range of items and ask students to predict which ones will float and which ones will sink. Place each item into the water to test their predictions. Then introduce the idea of density being the amount of mass in a given volume and explain that the items which are less dense than the water float, and those which are denser than water sink.

Main activities

Below are several teaching activities which you can pick and choose from in order to tailor the lesson to your class's needs.

1 Demonstration showing the factors affecting density (40 mins)

Learning objective: Explain how water temperature, water pressure and salinity affect the density of seawater.

Resources: A glass container that contains tap water at room temperature, food colouring (three colours), cups containing saltwater, warm tap water and cold tap water (add a different food colouring to each type of water).

Description: Remind students that density is the mass of a defined volume of water. Show the tap water in the container and remind students that it is made from particles as discussed in Topic 1.1. Then show the three different cups of coloured water and explain what is in each one. Ask students to write down what they think has happened to the particles in each cup compared to the water in the container, and what they think will happen when each cup of water is added to the tank. Then slowly pour each cup into the tank one at a time (it does need to go in slowly to prevent too much mixing). Ask students to draw and label the layers in the tank at the end of the demonstration and to write an explanation of what has happened. Finally show Figure 1.13 (the thermocline in a tropical sea) and ask students to explain the diagram, using what they have learned in the demonstration.

Answers:
The salt water is denser than the tap water in the container and will sink to the bottom (there are more particles in the same volume). In the cold water the particles are closer together than in the room temperature water, so it will also sink but will be above the room temperature salt water. The hot water has fewer particles in the same volume and so will float above the freshwater. The final layers should be hot water at the top, then the room temperature tap water, then cold water, then salt water.

Scaffolding and extension ideas: Support students by giving them questions to answer instead of them simply writing an explanation. For example, you could ask what has happened to the particles in the salt water (there are more because of the salt), what does this do to the density (increases it), which layer does it form (the bottom layer). Challenge students by asking them to draw particle diagrams of each layer in the tank and to predict the effect of increasing the pressure.

› **Reflection opportunities:** Students should think about this model of water densities and what they like about it; how it could be improved and whether they think there are any problems with it (the most likely answer here is the addition of the food colouring). This could be avoided by also adding colouring to the room temperature tap water and making sure the same amount is added to each type of water.

2 Calculation of densities (60 mins)

Learning objective: Recall and apply the formula density = mass ÷ volume with units of $kg\,m^{-3}$, kg and m^3 respectively.

Resources: Coursebook Maths skills 1.1, graph paper, data on density of water at different pressures (for example from Encyclopaedia Britannica website).

Description: Give students the formula for calculating density and discuss the units. Provide some sample data for students to use to practise the calculation. As the density of seawater is normally between 1020 and 1030 $kg\,m^{-3}$ you can use any figures which will give this result (e.g. 2040 kg of water in 2 m^3). Then go through the Maths skills 1.1 in the Coursebook and allow students to attempt to plot the graph following the instructions. Afterwards give them the data on density at different pressures and ask them to use what they have learned to plot another graph. You may wish them to multiply the densities given by 1000 to convert them from $g\,cm^{-3}$ to $kg\,m^{-3}$. Students must describe the shape of their graph and then explain it, using what they have learned about density.

Answers:
The second graph should have pressure on the *x*-axis and density on the *y*-axis. The axes must be labelled, have units and use a linear scale, the scale for density will not start at zero. Each point must be plotted correctly and the points should be joined using a ruler and a sharp pencil line. The graph should show a linear relationship, with the density increasing as the pressure increases. This is because the particles are forced closer together as the pressure increases and so there is more mass per unit volume.

Scaffolding and extension ideas: Support students by drawing the graph from the maths skills as a class on the board. You could also provide students with axes for the second graph. Challenge students to explain the effect of the changes in density with pressure in the oceans.

› **Reflection opportunities:** Students should peer assess their graphs using the criteria in the answers section. Each student should then write down at least one improvement they could have made to their graph or to their explanation of the shape.

3 The importance of ice (60 mins)

Learning objectives: State that the density of ice is less than water, causing it to float; Explain the importance of ice floating, limited to its action as a thermal insulator and as a habitat for marine organisms.

Resources: Coursebook Topic 1.3, access to other books or the internet, TedEd video on why ice floats.

Description: Show the video (4 mins) to remind students of the properties of water that enable it to float when it is frozen. Using the video as a prompt, students should then choose a marine organism, which relies on ice either as an insulator or as a habitat. Each student should produce a fact file about their organism, including a picture, details of its habitat and food and why it relies on ice.

Answers:
This will depend on the organisms chosen by students. For example, many students will pick polar bears and explain that they need ice as a habitat and as a platform to hunt their prey. Many seals give birth and nurse their pups on the ice as well as sheltering from predators. Fish need ice at the top of ponds or lakes, so that the water below is insulated and does not freeze.

Scaffolding and extension ideas: Provide students with a list of suitable organisms to choose from and perhaps some weblinks to start their research. Challenge students to find out why ice is also a factor in global warming, which is mentioned in the TedEd video on why ice floats.

Plenary ideas

1 Plenary placemat (10 mins)

Resources: Plenary placemat template (see contents page for link).

Description: Ask students to fill in the plenary place mat to help them to think about what they have learned and what they would still like to find out about.

› **Reflection ideas:** If students have areas they would still like to find out about they should think about how they could do this and what would help them to learn it.

2 Self-evaluation (15 mins)

Resources: Self-evaluation from the Coursebook Chapter 1.

Description: Ask students to use the self-evaluation to work out how much they have learned during Topic 1. They should make a note of anything which they mark as needs more work or nearly there. They should then make a plan for how to find help with these areas. This could include asking for help, reading the relevant section in the Coursebook, working with another student or finding information online.

3 Quiz show hosts (20 mins)

Description: Ask students to imagine they are the host of a quiz show where there will be a round on density and pressure. They must design the questions for the show, remembering to start easy and then become gradually more difficult.

› **Assessment ideas:** Pair the students up and run the quizzes – each student must ask the questions they have written for the quiz show. With a small group you could do this as a class activity where students take it in turns to be the quiz show host and the rest of the class competes to answer the questions.

Reflection ideas: Students should think about what makes a good question and what was it that made some questions more difficult than others for them personally. The areas which they found more difficult are the areas they should focus their revision on.

Differentiation ideas

Stretch and challenge

- Explain to students that swimming competitions have very strict rules about the temperature of the pool for different types of competition (this website goes through the rules). Ask them to explain why this is important and what affect changing the water temperature could have on an athlete's performance.
- Ask students to write an essay describing and explaining what they think would happen if there was no thermocline in the ocean.

Support

- Use this revision website to help students to understand the concept of density.
- Use this website to help students to understand the thermocline and why it is important.

Homework ideas

- As this is the end of the topic, students should revise what they have learned (possibly for an end of topic test). Ask them to produce evidence of their active revision. This could be flashcards they have made, a mind-map, a revision poster or a signature from someone who has tested them. The key is that they must not just read their notes or copy them out.
- Provide students with an incorrect answer to Exam-style question 7 and ask them to work out where the mistakes are and to correct them. You can make this more interesting by setting one homework where students write an answer with a deliberate mistake and the following lesson have to find the mistakes in another students work. Bonus marks should be given for anyone who finds a non-deliberate mistake.
- Using the glossary template, students should make a glossary of all the important keywords from the topic and use each one in a sentence.

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Marine Science

for Cambridge International AS & A Level

WORKBOOK

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Cambridge Assessment
International Education
Endorsed for learner support

Contents

Chapter 1

Water

CHAPTER OUTLINE

The questions in this chapter cover the following topics:

- the composition of seawater
- ionic and covalent bonds
- the properties of water
- factors affecting the density of water
- haloclines and thermoclines.

Exercises

Exercise 1.1 Comparing the ionic composition of seawater by calculating percentages and drawing bar charts

This exercise will help you to compare the **solute** composition of seawater and represent this as a bar chart.

Seawater has many different solutes dissolved in it. The proportions and masses of each of these solutes can differ in different bodies of water. Table 1.1 shows the masses of solutes found in 1 dm^3 of seawater taken from three different bodies of water. Notice these two important features of the data:

- The different seawaters have different overall solute concentrations as the total amount of solute varies.
- The proportions of each individual solute are different.

Solute	Mass of solute dissolved in 1 dm^3 (mg)		
	Atlantic Ocean	Mediterranean Sea	Sea off coast of Kuwait
chloride	18 980	21 200	23 000
sodium	10 556	11 800	15 850
sulfate	2 649	2 950	3 200
magnesium	1 262	1 403	1 765
calcium	400	423	500
potassium	380	463	460
bicarbonate	140	143	142
others	98	229	92
Total	34 465	38 611	45 009

Table 1.1: The solute composition of different bodies of seawater

KEY WORD

solute: a solid that dissolves in a solvent

If you want to compare the proportions of the solutes of different samples of seawater, you could directly compare the masses of the solutes. This is valid if the overall volumes of the samples are the same, but not a fair comparison if they are different. The mass of chloride ions dissolved in one cubic decimetre of seawater will obviously be higher than in one cubic centimetre, simply because there is more seawater. Also, the overall concentrations (salinities) of the seawaters are different and we are trying to compare the proportion of total solutes that each individual solute takes up. A more valid way of comparing the proportions of the solutes would be to calculate the percentage of each solute compared to the total solutes.

To calculate a percentage, divide the number by the total and then multiply by one hundred.

For example, the total mass of solutes dissolved in Atlantic Ocean seawater in Table 1.1 is 34 465 mg.

To calculate the percentage of dissolved solute that consists of chloride ions, divide the mass of chloride by the total mass and then multiply by 100:

$$\text{percentage of chloride ions} = \frac{18\,980}{34\,465} \times 100\% = 55.1\%$$

1 a Calculate the percentages of all the solutes for the three different bodies of water shown in Table 1.1. Copy and complete Table 1.2.

b Compare and contrast the percentages of the solutes by identifying clear similarities and differences.

Solute	Percentage of each solute (%)		
	Atlantic Ocean	Mediterranean Sea	Sea off coast of Kuwait
chloride	55.1		
sodium			
sulfate			
magnesium			
calcium			
potassium			
bicarbonate			
others			

Table 1.2: Percentages of solutes in different bodies of seawater

Sometimes, it is useful to view data as a chart. Bar charts are used when one variable is categoric and the other variable is continuous. A **categoric variable** is something that has a particular category, or name; for example, the names of the solutes listed. A **continuous variable** is something that has numbers that can have any number of intermediate values, such as height, weight or percentage.

Follow the steps below to draw a bar chart for the data in Table 1.1. In this example, you will compare the masses of chloride, sodium, sulfate and magnesium in the different bodies of seawater.

KEY WORDS

categoric variable: a variable that is not continuous and has a value that is a name or label such as the colours red, blue and green

continuous variable: a variable that can take any value between its minimum value and its maximum value

Step 1: Decide which way round the axes will go. Although not essential, it is often good practice to place the **independent variable** on the horizontal (x) axis and the **dependent variable** on the vertical (y) axis. The data can be organised on the horizontal axis in different ways, depending on what you are comparing. For the data in Table 1.1, we want to compare the masses of each solute in the different bodies of seawater. We could group the data as similar solutes or as water bodies. In this example, you will group the data as solutes.

Step 2: Label the vertical axis 'mass of solute (mg/dm^3)' and the horizontal axis 'solute'. Decide on a suitable linear scale for your continuous variable. You should identify the maximum and minimum values and choose a scale that makes the best use of your graph paper, or grid. Ideally the graph should use at least half the grid. Scales should be always be linear, with even increments. For the data in Table 1.1, use increments of 5000 mg/dm^3, starting at 0 mg/dm^3 and ending at 25 000 mg/dm^3.

2 Draw the scale for the y-axis.

Step 3: Plot and draw the bars. Decide how many bars you need to fit onto your graph paper. There are 12 bars required for the data in Table 1.1 (three each for chloride, sodium, sulfate and magnesium.) Bars should be drawn with a sharp pencil and a ruler. They should not touch and should have equal gaps between them within the groups of data. In this example, you should group the bars for each body of seawater for each solute. Leave a slightly bigger gap between the three bars for each solute, as shown in Figure 1.1, which shows as example of a bar chart. The groups should be labelled with the correct solute underneath the horizontal axis.

c Draw your bars on your graph and add labels.

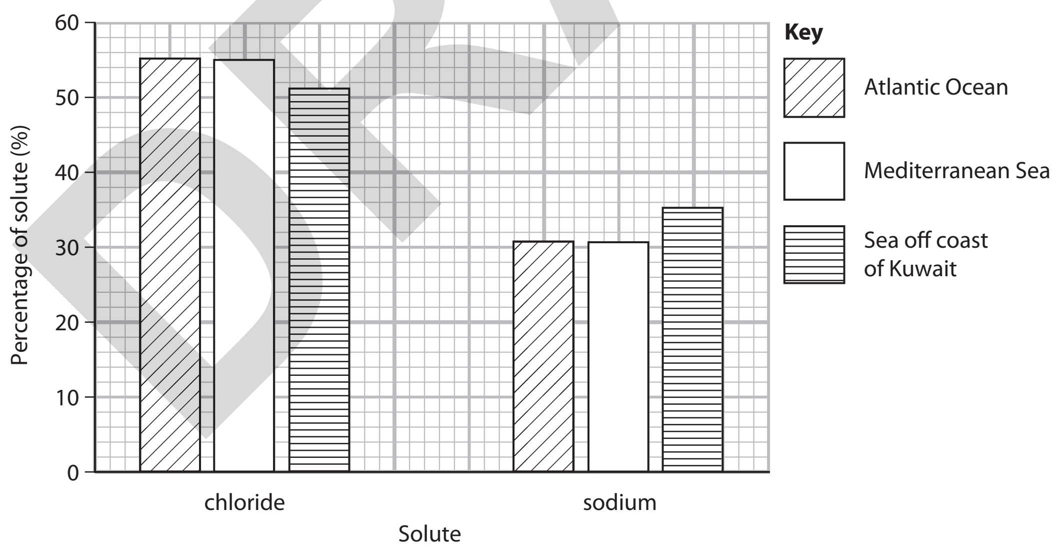

Figure 1.1: Grouping of bars for a bar chart

KEY WORDS

independent variable: the variable that is changed in an experiment to investigate its effect on the dependent variable

dependent variable: the variable that depends on another variable(s) and is measured in an experiment

TIP

When selecting scales, always use linear scales with even increments. Pick sensible increments that make it easy to plot points.

Step 4: Decide on a key for the different bars. For this example, choose a colour or pattern for each of the bodies of water, draw out a key on the chart and shade the bars appropriately. Figure 1.1 shows a bar chart of the percentages of sodium and chloride in the different areas. The bars are grouped as the solutes and a key to show each area of water is shown.

d Produce a key and shade or colour the bars.

e Produce a second bar chart. This time, group the bars as the different bodies or seawater so that the horizontal (x) axis is labelled 'body of seawater'.

f Look at your bar charts and the information in Table 1.1. Compare the masses of the solutes from the three bodies of seawater. Give similarities and differences.

3 Figure 1.2 shows the locations of the bodies of seawater. Use your knowledge of factors that affect solute concentrations to suggest reasons for the differences in composition of the water from the three bodies of seawater. Consider both the proportions and the overall concentrations of the seawaters.

Figure 1.2: Locations of the three bodies of seawater

Exercise 1.2 Understanding different variables and planning investigations

In this exercise, you will develop your understanding of the different types of variables that are considered when planning scientific investigations.

We consider three main types of variables when planning experimental investigations:

- Independent variable: This is the variable that the experimenter changes. Ideally, you should plan for at least five different values, with even increments between them. You also need a range of values that will produce a valid conclusion.
- Dependent variable: This is the variable that the experimenter measures after changing the independent variable. For reliable experiments, at least three replicates should be obtained.
- **Standardised variables:** These are other variables that could affect the results of the experiment. To generate valid data, these should be kept constant and you should also state how you will do this in your plan.

KEY WORD

standardised variable: a variable that is kept constant during an experiment

1 Read the following student practical.

An investigation into the effect of water temperature on the solubility of oxygen.

I will use a measuring cylinder to measure out 150 cm³ of 3% sodium chloride solution. I will place the solution into a 250 cm³ beaker. I will place the beaker into a thermostatically controlled waterbath and set the waterbath to 5 °C. I will then bubble oxygen into the water for five minutes (timed with a stopclock). After the five minutes, I will measure the concentration of oxygen in the water with an oxygen meter for 30 seconds. I will repeat this at temperatures of 10 °C, 15 °C, 20 °C, 25 °C, 30 °C and 35 °C. I will repeat the experiment three times to obtain mean values.

a Give the independent variable that the student changed. Describe how the independent variable was changed, and the number and range of different values used.

b Give the dependent variable. Describe how the student measured the dependent variable and how they ensured reliability.

c List the standardised variables. For each standardised variable, state how it was kept constant and why it was kept constant.

2 Plan an investigation into the effect of salinity on the solubility of oxygen.

Exercise 1.3 Atomic structure and chemical bonding

To understand the composition of seawater, you need to have a full understanding of atomic structure and the nature of **ionic bonds** and **covalent bonds**. This exercise will help you to understand atomic structure and how this affects the bonds formed between atoms.

You need to know the locations, charges and masses of the three main subatomic particles (protons, neutrons and electrons.)

1 a Copy out Table 1.3 and use your coursebook and your own knowledge to add the:

- relative masses (1 or 0)
- relative charges (+1, –1, 0)
- location of each particle within an atom (nucleus, orbital).

Subatomic particle	Relative mass	Charge	Location within atom
proton			
neutron			
electron			

Table 1.3: Properties of subatomic particles

The **atomic number** of an element is the number of protons that it has. It is also the number of electrons present, because in any atom, the number of protons is the same as the number of electrons.

The relative **atomic mass** of an element is the number of protons plus the number of neutrons.

KEY WORDS

ionic bond: chemical bond that involves the attraction between two oppositely charged ions

covalent bond: chemical bond that involves the sharing of electron pairs between atoms

atomic number: the number of protons contained in the nucleus of an atom

atomic mass: the mass of an atom that is approximately equal to the number of protons and the number of neutrons added together

For example, the element, sodium (Na) has an atomic number of 11 and a mass number of 23. This means that one atom has:

11 protons

11 electrons

12 neutrons (23 minus 11)

The PERIODIC TABLE OF THE ELEMENTS arranges all the elements in order of atomic number and gives the atomic number and relative atomic mass of each element. Figure 1.3 shows a Periodic Table.

1 H Hydrogen 1.008								atomic number Symbol Name atomic mass									2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminium 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.933	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.732	32 Ge Germanium 72.61	33 As Arsenic 74.922	34 Se Selenium 78.972	35 Br Bromine 79.904	36 Kr Krypton 84.80
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.29
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown

Figure 1.3: Periodic Table of the Elements

b Use Figure 1.3 to determine the numbers of protons, neutrons and electrons in each of the elements that are often found in compounds dissolved in seawater. Copy and complete Table 1.4.

Element	Atomic number	Relative atomic mass	Number of protons	Number of neutrons	Number of electrons
calcium (Ca)					
carbon (C)					
chlorine (Cl)					
hydrogen (H)					
magnesium (Mg)					
nitrogen (N)					
oxygen (O)					

Table 1.4: Properties of common elements present in compounds dissolved in seawater

TIP

Note that the relative atomic mass of chlorine is 35.5, because some chlorine atoms have a relative atomic mass of 35 and others 36.

Electrons form the chemical bonds between elements. Electrons are arranged in orbitals called shells and the number of electrons that fill up each shell depends on which shell it is. You will only consider the first three shells in this exercise. The innermost shell is full when it contains two electrons. The next two shells are both full when they contain eight electrons each.

We can illustrate the electron shells with Bohr diagrams. The element argon (Ar) has an atomic number of 18. This means that argon has 18 electrons arranged in the shells as 2, 8, 8 (this means there are two electrons in the first shell, eight in the second and eight in the third.) This arrangement of electrons is known as the electron configuration. Figure 1.4 shows a Bohr diagram for argon.

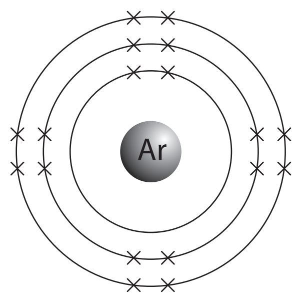

Figure 1.4: Bohr diagram showing 2, 8, 8 electron configuration of argon (Ar). The three electron shells and electrons are shown.

2 Draw Bohr diagrams to show the electron configurations of:

- **a** hydrogen atom (H)
- **b** sodium (Na)
- **c** chlorine (Cl)
- **d** magnesium (Mg)
- **e** oxygen (O).

Electron shells are stable when they are full. For the innermost electron shell, this is two electrons and for the next two electron shells, this is eight electrons. During chemical reactions, atoms lose or gain electrons so that the outermost shell is full. If an atom has only one or two electrons in its outermost shell, it will often lose them to become more stable. If an atom has six or seven electrons in its outermost shell, it will often gain electrons from another element. Losing or gaining electrons results in the production of a charged particle known as an ion.

For example, the element lithium (Li) has an atomic number of 3. This means that a lithium atom has three protons, each with a positive charge, and three electrons, each with a negative charge. The overall charge is zero because the three positives cancel out the three negatives. Lithium has a single electron in its outer shell, so to become more stable it can lose this electron. This means that it still has three positively charge protons but now has only two negatively charge electrons, for an overall charge of +1. This is a lithium ion, which we write as Li^+. What does lithium give this electron to? Atoms with six or seven electrons in their outer shell will accept electrons to fill up the

TIP

Electrons fill up from the innermost shell first. Use a compass to draw circles for each shell. Add electrons to the inner shell first.

shell. For example, fluorine has an electron configuration of 2, 7 and so can take an electron from a lithium atom to produce a fluoride ion (F^-) with an overall charge of –1. This chemical reaction produces an ionic compound called lithium fluoride, which is composed of Li^+ and F^- ions. Figure 1.5 shows the reaction between lithium and fluorine.

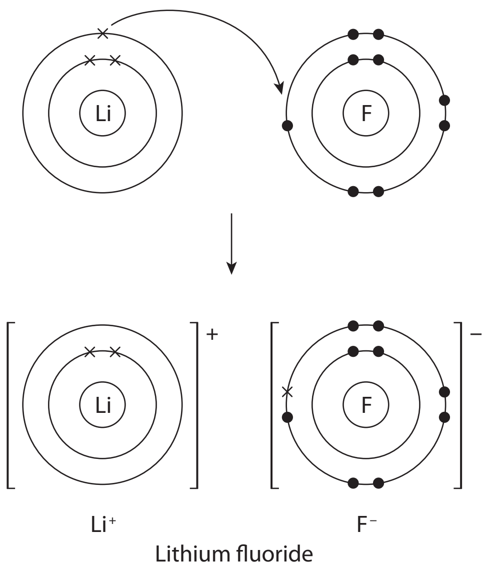

Figure 1.5: Reaction between lithium and fluorine

3 Draw diagrams similar to Figure 1.5 to show the reactions between:

a sodium and chlorine

b lithium and chlorine

c magnesium and chlorine (with two chlorine atoms and one magnesium atom).

In ionic compounds, one ion is negative and the other positive. The two ions attract each other and, when in a solid crystal, they arrange themselves so that positive and negative ions are touching. These are ionic bonds.

d Use your knowledge to draw out the crystal structure of sodium chloride.

Sometimes, instead of losing or gaining electrons, atoms can share electrons with other atoms. This sharing of electrons forms covalent bonds that join the atoms in a chemical compound.

Fluorine gas molecules exist as two fluorine atoms bonded together so that their outer shells share two electrons. This is shown in Figure 1.6. The electron shells of each atom overlap and so the two atoms are strongly bound together with a covalent bond. Both atoms have eight electrons in their outer shells as they each share one electron.

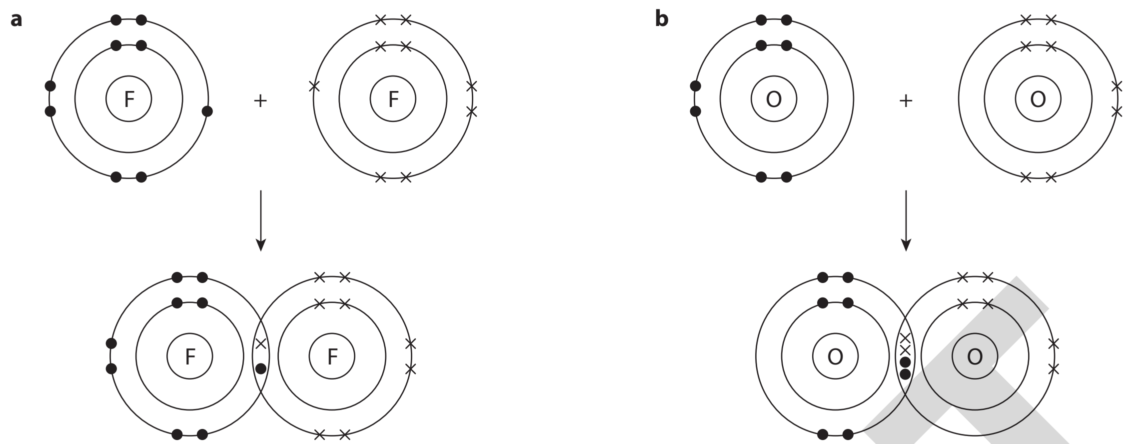

Figure 1.6: Covalent bonds in (a) fluorine molecules (b) oxygen molecules

Some substances, such as oxygen atoms, can form double bonds where two electrons from each atom are shared (shown in Figure 1.6).

4 Draw diagrams similar to Figure 1.6 to show the electron arrangements of:

- **a** chlorine (Cl_2)
- **b** carbon dioxide (CO_2)
- **c** water (H_2O)
- **d** sulfur dioxide (SO_2).

When bonds form between oxygen and hydrogen to make water, the oxygen and hydrogen do not share the electrons equally. The electrons are drawn closer to the oxygen atom, so that the oxygen atom develops a slight negative charge and the two hydrogen atoms develop a slight positive charge. This means that water molecules are dipolar molecules, which are molecules with both positive and negative charges. Because the charges on the water molecule are not whole positive and negative charges, but are small charges, we label them δ+ and δ−. This dipolar nature of water gives it unusual properties that make it important for life.

5 **a** Copy out Figure 1.7 and label the oxygen and hydrogen atoms, and the areas with charges of δ+ and δ-.

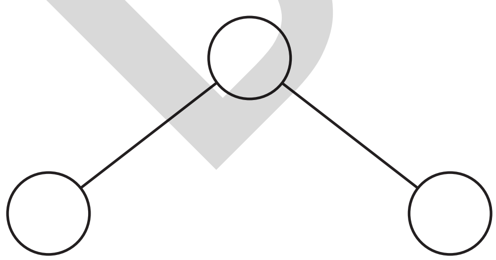

Figure 1.7: The structure of a water molecule

b Because water molecules have positively and negatively charged areas, water molecules attach to each other by forming **hydrogen bonds**. Draw a diagram with six molecules of water to show how hydrogen bonds form between water molecules.

c Draw a diagram to show how water molecules would associate around a sodium ion and a chloride ion. Label the charges on each ion or atom.

d Explain how the dipolar nature of water affects the specific heat capacity, **density** and solvent nature of water.

Exercise 1.4 Analysing data about water density, temperature and salinity

You need to be able to look at data patterns and give accurate descriptions and explanations of any patterns present. This exercise will help develop your data analysis skills.

Figure 1.8 shows the effect of temperature on the density of fresh water. If you are asked to describe the effect of one variable on another, follow these steps:

- Describe the general patterns giving clear indications of directions, for example, 'As *x* increases, *y* increases.' Use the labels on the axes to clarify your description.
- Look for positive and negative **correlations**. In a positive correlation, an increase in one variable is linked to an increase in another variable. In a negative correlation, an increase in one variable is linked to a decrease in another variable. A correlation means that there may be a link, but the link is not necessarily causal.
- Look for areas where there is a change in pattern (or turning points) such as an increase, decrease or levelling off.

1 Figure 1.8 shows the effect of temperature on the density of fresh water. Describe how temperature affects the density of water.

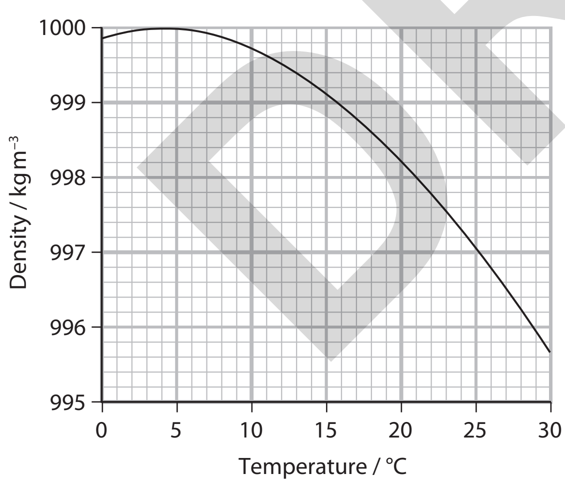

Figure 1.8: The effect of temperature on the density of fresh water

KEY WORDS

hydrogen bond: a weak bond between two molecules due to the electrostatic attraction between a hydrogen atom in one molecule and an atom of oxygen, nitrogen or fluorine in the other molecule

density: a measure of the mass of a defined volume of water

correlation: the tendency of two variables to change together in either the same or opposite directions

2 Look at the graphs in Figure 1.9. They are an unusual presentation because the *y*-axis seems to be upside down. The zero value is at the top because it illustrates the depth from the surface of the water. The graphs show how temperature, salinity and density change with depth of water. Answer the following questions in detail.

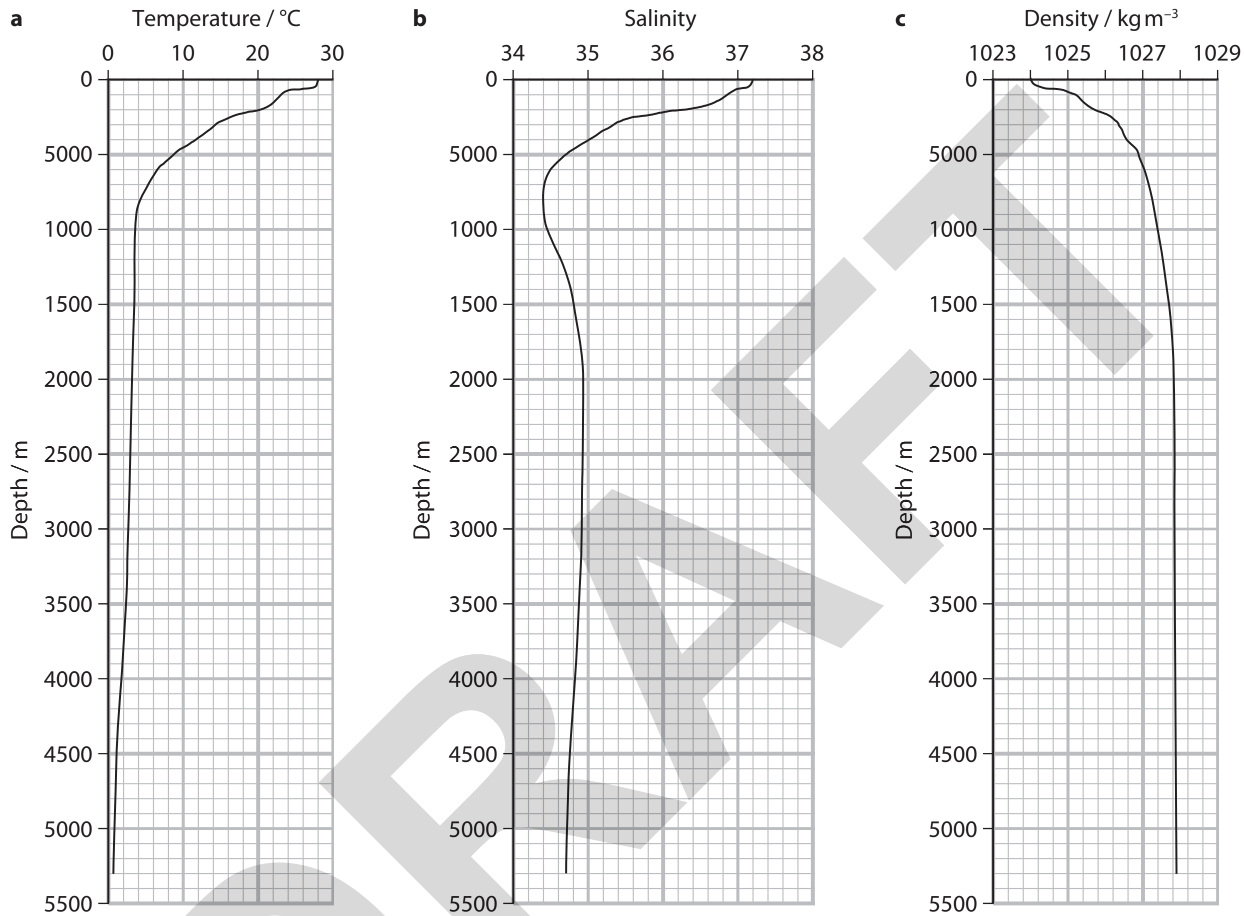

Figure 1.9: Graphs to show (a) temperature, (b) salinity and (c) density at different depths of water

- **a** Describe how temperature changes with depth.
- **b** Describe how salinity changes with depth.
- **c** Describe how density changes with depth.
- **d** Explain which variables show positive and negative correlations.
- **e** Explain which of the graphs shows a **halocline** and which shows a **thermocline**.

KEY WORDS

halocline: a layer of water below the mixed surface layer where a rapid change in salinity can be measured as depth increases

thermocline: a layer between two layers of water with different temperatures

You need to be able to extract data from graphs and charts that may be presented in varied styles. Figure 1.10 shows the effect of temperature and salinity on the density of water.

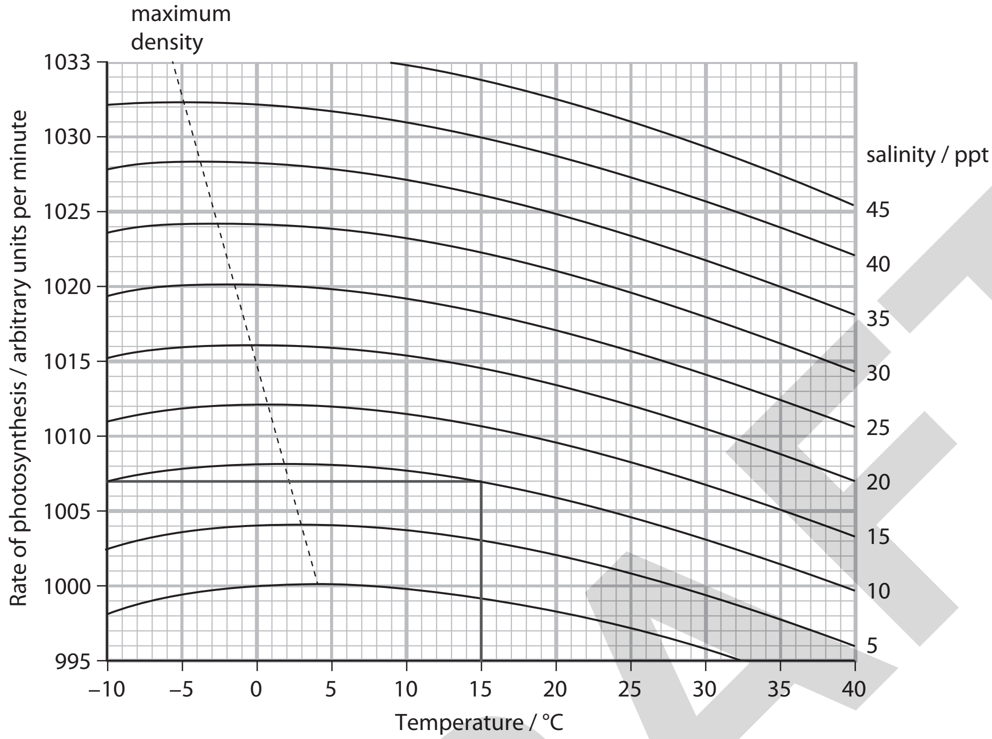

Figure 1.10: The effect of salinity and temperature on the density of water

You can use the graph to determine the density of water of different salinities at different temperatures. For example, to determine the density of water with a salinity of 5 ppt at 15 °C:

- Use a ruler to draw a line up to the 15 ppt curve from 15 °C.
- Draw a line from this point to the vertical axis.
- Read across to the vertical axis to see that the density would be 1007 kg/m^3.

3 **a** Determine the density of water of salinity, 25 ppt, at 20 °C.

b Determine the density of water of salinity, 35 ppt, at a temperature of 30 °C.

c Determine the temperature at which water of salinity 20 ppt has a density of 1015 kg/m^3.

4 Use the equation for density and Figure 1.10 to determine the mass of 0.5 dm^3 of water with salinity of 20 ppt at a temperature of 20 °C.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

5 Use Figure 1.10 to describe how the maximum density of water at different temperatures is affected by increasing salinity.

EXAM-STYLE QUESTIONS

1 Figure 1.11 shows the location of an ocean lagoon.

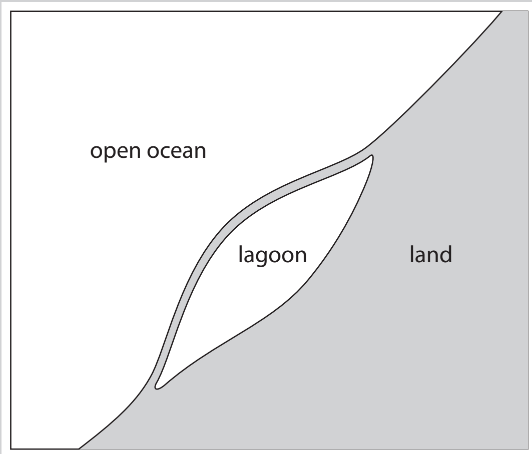

Figure 1.11

The solute concentrations of the lagoon and the open ocean were measured. The results are shown in Table 1.5.

Solute	Solute concentrations (g/dm^3)	
	Lagoon	Open ocean
sodium	17	12
chloride	25	19
sulfate	5	3

Table 1.5: Solute concentrations in lagoon and open ocean

a Use your knowledge of water and ionic compounds to **explain** how sodium chloride dissolves in water. **[4]**

b Draw a bar chart to **compare** the solute concentrations of the lagoon and open ocean. **[5]**

A scientist determined the mean temperature, mass of dissolved oxygen and wave speed of the lagoon and open ocean at 3.00 p.m. each day for one week. The results are shown in Table 1.6.

Area of water	Mean temperature at 3.00 p.m. (°C)	Mean concentration of oxygen (mg/dm^3)	Mean wave speed (m/s)
lagoon	25	6	
open ocean	18	10	24.3

Table 1.6: Mean temperature, oxygen concentration and wave speed of lagoon and open ocean

COMMAND WORDS

explain: set out purposes or reasons / make the relationships between things evident / provide why and/or how and support with relevant evidence

compare: identify / comment on similarities and/or differences

CONTINUED

The wave speed measurements for the lagoon were:

2.50 m/s, 2.70 m/s, 3.90 m/s, 1.10 m/s, 2.60 m/s, 3.80 m/s, 3.60 m/s

c **i** **Calculate** the mean wave speed for the lagoon. Give your answer to three significant figures and write it in Table 1.6. **[2]**

ii Use the information in Figure 1.11, Table 1.5 and Table 1.6 to **suggest** explanations for the different oxygen concentrations in the lagoon and open ocean. **[5]**

[Total: 16]

2 Figure 1.12 shows the effects of salinity and temperature on the freezing point and density of water.

The temperature at which liquid water has its maximum density is also shown. In areas above this line, the density of water decreases as temperature increases. In areas below this line, where water is a liquid, the density of liquid water decreases as temperature decreases.

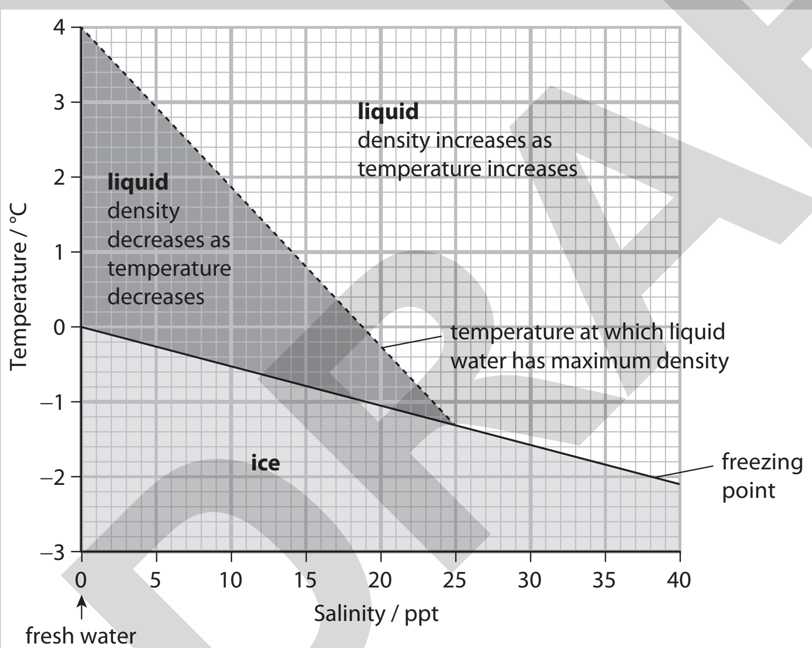

Figure 1.12

COMMAND WORDS

calculate: work out from given facts, figures or information

suggest: apply knowledge and understanding to situations where there are a range of valid responses in order to make proposals

CONTINUED

a **i** Use Figure 1.12 to **determine** the freezing point of water with a salinity of 35 ppt. **[1]**

ii **Describe** the effect of increasing salinity on the freezing point of water. **[1]**

iii **Give** the temperatures at which liquid freshwater (0 ppt salinity) and liquid seawater of 20 ppt salinity, have their maximum densities. **[2]**

iv Use Figure 1.12 to explain why seawater with a salinity of 35 ppt sinks as it cools but fresh water rises as it cools from 4 °C to freezing point. **[2]**

b Explain the importance of floating sea ice for marine organisms. **[3]**

c Describe an investigation into the effect of sodium chloride on the freezing point of water. Include a results table which you could use to record your data. **[6]**

[Total: 15]

3 Table 1.7 shows the concentrations of oxygen at different water depths in a region of the Pacific Ocean.

Depth (m)	Concentration of oxygen (mg/dm^3)
0	6.2
250	5.8
500	3.5
750	2.0
1000	1.1
1500	1.5
2000	1.7
3000	1.9
4000	2.0

Table 1.7: Change in oxygen concentration with increasing ocean depth

a **i** Describe the change in concentration of oxygen with increasing depth. **[3]**

ii Calculate the mean change in concentration of oxygen per metre between 0 metres and 1000 metres. **[2]**

iii Suggest reasons for the changes in oxygen concentration between 0 metres and 1000 metres. **[4]**

iv Suggest reasons for the changes in oxygen concentration between 1000 metres and 4000 metres. **[3]**

COMMAND WORDS

determine: To come

describe: state the points of a topic / give characteristics and main features

give: produce an answer from a given source or recall / memory

CONTINUED

b Describe how the effect of depth on the acidity of the water could be tested. **[2]**

[Total: 14]

4 a Magnesium ions (Mg^{2+}) are a solute of seawater.

The atomic number of magnesium is 12.

The relative atomic mass of magnesium is 24.

i **State** the number of protons, neutrons and electrons in a magnesium ion (Mg^{2+}). **[3]**

ii Copy and complete Table 1.8. Place a tick in the correct column of Table 1.8 to **identify** each of these substances found in seawater as a covalent molecule or an ionic substance. **[2]**

Substance	Covalent molecule	Ionic substance
calcium carbonate		
carbon dioxide		
magnesium sulfate		
oxygen		
sulfur dioxide		
water		

Table 1.8: Substances found in seawater

iii Explain how the structure of water enables it to form hydrogen bonds. **[3]**

iv Explain how the structure of water affects its ability to act as a solvent. **[3]**

COMMAND WORDS

state: express in clear terms

identify: name / select / recognise

CONTINUED

b Figure 1.13 shows the changes in temperature with depth of an area of temperate ocean and an area of tropical ocean in both winter and summer.

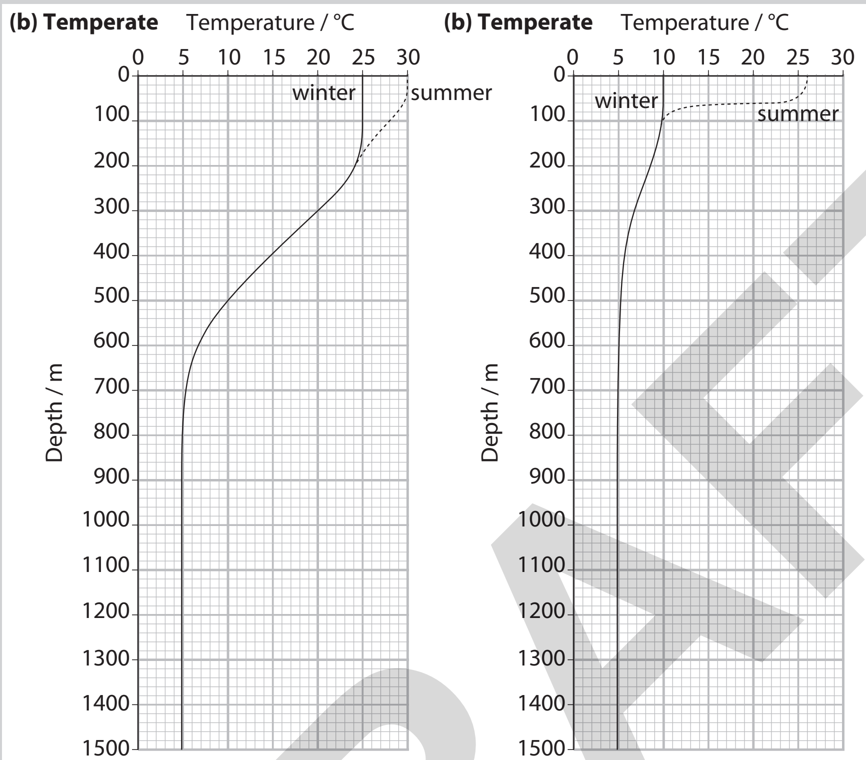

Figure 1.13

- **i** Estimate the depth limits of the thermocline in summer for the temperate ocean shown in Figure 1.13. **[1]**
- **ii** **Comment** on the water temperatures in summer and winter for the tropical and temperate oceans shown in Figure 1.13. **[4]**
- **iii** Explain how thermoclines are produced. **[3]**

[Total: 19]

COMMAND WORD

comment: give an informed opinion

Chapter 1

Water

CHAPTER OUTLINE

In this chapter you will complete investigations on:

- 1.1 properties of water
- 1.2 pH
- 1.3 salinity and temperature gradients.

Practical 1.1: Properties of water

Introduction

The interaction of water molecules with each other through hydrogen bonding affects the properties of water compared with non-hydrogen-bonded liquids, such as vegetable oil. This practical explores some of these properties and demonstrates how **hydrogen bonds** affect these properties of water. The varying ability of water to dissolve different types of substances has important consequences for the availability of nutrients and dissolved gases to organisms that live in marine environments.

KEY WORD

hydrogen bond: a weak bond between two molecules due to the electrostatic attraction between a hydrogen atom in one molecule and an atom of oxygen, nitrogen or fluorine in the other molecule

EQUIPMENT

You will need:

• vegetable oil (up to 20 cm^3 per group) • sodium chloride (up to 10 g per group) • glucose (up to 20 g per group) • 2 × 10 cm^3 measuring cylinders • 2 × dropping pipettes • 4 × test tubes • 1 × 50 cm^3 beaker • test tube rack • electronic balance • 2 × spatulas.

Safety considerations

Take care when using glassware that test tubes or other round glass items do not roll off the worktop or break. Report any breakages to your teacher.

BEFORE YOU START

a We can 'measure' substances in different ways. How can a liquid be measured?

b Liquids tend to 'stick' to the side of containers, resulting in a **meniscus** (Figure 1.1). How should you ensure that a volume of liquid is measured correctly?

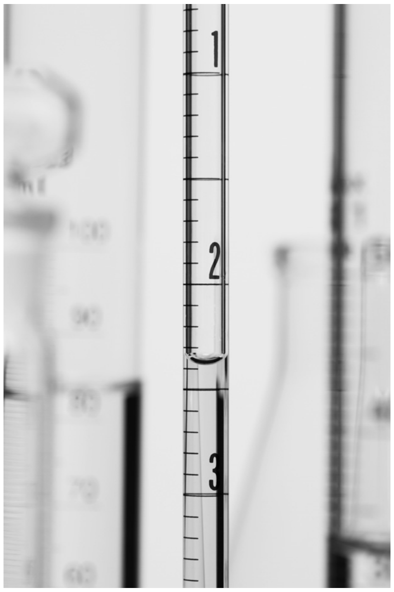

Figure 1.1: A meniscus at the top surface of water in a glass tube

c When using an electronic balance ensure that you use the 'zero' or 'tare' button. Why is this important?

KEY WORDS

meniscus: the upward or downward curve at the surface of a liquid where it meets a container

density: a measure of the mass of a defined volume

TIP

Record quantities to the maximum precision. If the volume is 4.0 cm^3, record to this precision. Remember that a result of 4 cm^3 could have been rounded from anything as low as 3.5 cm^3 to as high as 4.4 cm^3.

TIP

To calculate density, divide the mass of liquid used by the volume the liquid occupies.

Divide mass by 1000 to convert g to kg and divide volume by 1 000 000 to convert cm^3 to $metre^3$. The density in g/cm^3 can be multiplied by 1000 to convert this to $kg/metre^3$.

Part 1: Density

Method

1 Place a clean, dry 10 cm^3 measuring cylinder onto an electronic balance, zero (tare) the balance and add 5.0 g of water to the measuring cylinder, using a dropping pipette as you get close to 5.0 g. Copy Table 1.1 and use it to record the volume of water added.

2 Place another clean, dry 10 cm^3 measuring cylinder onto an electronic balance, zero (tare) the balance and add 5.0 g of vegetable oil to the measuring cylinder, using a dropping pipette as you get close to 5.0 g. Record the volume of vegetable oil added.

3 Calculate the **density** of each liquid in $grams/cm^3$.

4 Calculate the density of each liquid in $kg/metre^3$.

5 Pour both the vegetable oil and water into the beaker. Does the less dense liquid float or sink?

Results

	Water	Vegetable oil
volume of 5.0 g of liquid (cm^3)		
density (g/cm^3)		
density (kg/m^3)		

Table 1.1: Results for Density of liquids practical

Part 2: Solvent action

Method

1. Measure 10.0 cm^3 of water into each of two test tubes, labelled A and B.
2. Measure 10.0 cm^3 of vegetable oil into each of another two test tubes labelled C and D.
3. Weigh out and record (in a copy of Table 1.2) the exact mass of approximately 5 g of sodium chloride.
4. Add a small amount of the sodium chloride to test tube A, shake vigorously and check to see if all the solid has dissolved. If it has all dissolved, repeat adding small additional amounts of solid and shaking until no more will dissolve.
5. Record the mass of remaining sodium chloride and calculate the amount that has been dissolved.
6. Repeat steps 3–5 with:
   - 10 g of glucose in test tube B (water).
   - 5 g of sodium chloride in test tube C (vegetable oil).
   - 10 g of glucose in test tube D (vegetable oil).

Results

Test tube	Mass of solid at start (g)	Mass of solid remaining (g)	Mass of solid dissolved (g)
A			
B			
C			
D			

Table 1.2: Results for Solvent action practical

Evaluation and conclusions

d How does the density of water compare to the density of vegetable oil? How does this explain what happens when water and vegetable oil are mixed together?

e Is density the same for a certain substance at different temperatures? How could you investigate this?

f Salt is an ionic substance; glucose is covalent. Explain the solubility results in terms of the interactions between solvent molecules and solute particles.

g Outline an investigation to test this hypothesis: 'The solubility of a salt depends on the temperature of the water.'

h How does the ability of water in the oceans to absorb heat energy affect the rate at which global warming heats Earth's atmosphere?

Reflection

i How could the results for the solubility experiment be improved?

j Compare your results for both parts of the practical to the results of others in the class. How do your results compare? Suggest reasons for any differences among your results and how these could be minimised if you repeated the practical.

Practical 1.2: pH

Introduction

Whether a substance is neutral, acid or alkaline depends on the concentration of hydrogen ions, H^+. The more hydrogen ions there are in solution, the more acidic the solution is.

The **pH** scale is a logarithmic scale. This means that for each decrease in pH of 1 there are 10 times more hydrogen ions present. So, small changes in pH are due to large changes in the concentration of hydrogen ions present.

The pH of seawater is important because it affects the ability of organisms to carry out essential biochemical reactions. The aim of this practical is to show how small changes in pH represent a significant change in the concentration of hydrogen ions in water.

KEY WORD

pH: a figure expressing the acidity or alkalinity of a solution on a logarithmic scale

EQUIPMENT

You will need:

• 1.0 M hydrochloric acid (up to 30 cm^3 per group) • 1.0 M sodium hydroxide solution (up to 30 cm^3 per group) • universal indicator solution or paper with corresponding colour pH chart • litmus indicator solution (or red and blue litmus papers) • pH meter • 6 × test tubes or boiling tubes (need to be wide enough to allow the pH probe to be used) • test tube rack • distilled water (up to 20 cm^3 per group for testing, plus extra for rinsing boiling tubes and pH probe) • seawater (up to 20 cm^3 per group) • carbonated water (for example, bottled sparkling water) (up to 20 cm^3 per group) • dropping pipettes.

Safety considerations

1.0 M sodium hydroxide is corrosive and particularly dangerous to eyes. You must wear eye protection. Universal indicator solution – check risks of solution provided. Many are highly flammable and some are harmful.

BEFORE YOU START

a Why is it important for the pH probe to be calibrated before you record measurements?

b Universal indicator is a mixture of several different indicators. The combination of indicators varies between different manufacturers. Why is it important that you use the correct colour chart for the actual indicator you use?

c You will need to re-use your boiling tubes during this experiment. What steps will you take to ensure that all your results are accurate?

TIP

When recording colour changes, it is useful to hold the solution against a white background, such as a plain white sheet of paper or a white tile.

TIP

Record all numerical results to the same number of decimal places to show that you have recorded them as precisely as possible; for example, record pH 4.0 not pH 4.

Part 1: Different methods of measuring acidity and pH

Method

1 Pour approximately 1 cm depth of 1.0 M hydrochloric acid into a boiling tube.

2 Test the solution with a few drops of universal indicator solution or universal indicator paper. In a copy of Table 1.3, note the resulting colour of the indicator with the corresponding pH from the colour chart.

3 Repeat steps 1 and 2 with: 1.0 M sodium hydroxide solution, distilled water, seawater and carbonated water.

4 Repeat the tests on new samples of each solution using litmus indicator and then a pH probe. Record all your results in a copy of Table 1.3.

Results

	Colour and pH of universal indicator	Colour of litmus indicator	pH probe reading
1.0 M hydrochloric acid			
1.0 M sodium hydroxide			
distilled water			
seawater			
carbonated water			

Table 1.3: Results table for measuring acidity and pH

Part 2: Concentration of hydrogen ions and the pH scale

Method

1 Label six boiling tubes with numbers from 1 to 6.

2 Measure 10.0 cm^3 of 1.0 M hydrochloric acid and pour this into tube 1.

3 Remove exactly 1.0 cm^3 of the solution from tube 1 using a dropping pipette and add this into tube 2. Add 9.0 cm^3 distilled water and mix gently but thoroughly.

4 Remove exactly 1.0 cm^3 of the solution from tube 2 using a dropping pipette and add this into tube 3. Add 9.0 cm^3 distilled water and mix gently but thoroughly.

5 Repeat this diluting process until you have solutions in all six boiling tubes.

6 Test the pH of each solution with the pH probe and record your results in a copy of Table 1.4.

Results

Test tube	pH
1	
2	
3	
4	
5	
6	

Table 1.4: Results for diluting a sample of acid and measuring pH

Evaluation and conclusions

d What are the advantages and disadvantages of each method of measuring acidity?

e Why would the pH of the acid not increase above 7 with further dilution?

f What do you predict would happen to the pH of the carbonated water over time? Write a hypothesis that you could test. Outline an experiment you could carry out to test your hypothesis.

Reflection

g Compare your results with those from other groups. How similar are the results?

h How could the accuracy of the dilutions in part 2 be improved?

Practical 1.3: Salinity and temperature gradients

Introduction

You have learned how density is measured and how this varies for different substances. Density can also vary in the same substance depending on the temperature or amount of solutes dissolved in it. This is important in marine environments where the surface of oceans is heated by energy from the sun, and where rivers meet the sea bringing fresh water into the more saline seawater.

EQUIPMENT

You will need:

• salt water (40 g/dm^3) (approx. 40–50 cm^3 per group) • distilled water (up to 50 cm^3 per group) • 2 contrasting food colours • 2 × 100 cm^3 beakers • dropping pipette • hot water (students or the teacher could produce this).

Safety considerations

Take care using hot water because both steam and boiling water can cause burns. Beakers containing hot water will also quickly get very hot.

BEFORE YOU START

a Explain the meaning of the terms *thermocline* and *halocline*.

b How can you reduce the risk of handling hot water?

Part 1: Temperature gradients

Method

1. Add a small amount of food colouring to about 50 cm^3 of cold tap water in the first beaker to give a distinct colour and mix well.
2. In a second beaker add a small amount of a different food colouring to about 50 cm^3 of hot water from a kettle to give a distinct colour and mix well.
3. Make sure that the cold water has stopped swirling in the beaker.
4. Use a dropping pipette to carefully transfer about 1–2 cm^3 hot water. Insert the tip of the pipette into the middle of the cold water and gently release the hot water into the cold tap water. Observe what happens to the hot water.
5. Repeat this process until 15–20 cm^3 of hot water have been transferred.

Results

Sketch a diagram to show any layers that have formed. Label the layers clearly to identify which is hot water and which is cold water, and (if appropriate) where some mixing has taken.

Part 2: Salinity gradients

Method

1 Add food colouring to about 50 cm^3 of salt water in the first beaker to give a distinct colour and mix well.

2 In a second beaker add a different food colouring to about 50 cm^3 of distilled water to give a distinct colour and mix well.

3 Make sure that the salt water has stopped swirling in the beaker.

4 Use a dropping pipette to transfer about 1–2 cm^3 distilled water. Insert the tip of the pipette into the middle of the salt water and gently release the distilled water into the salt water. Observe what happens to the distilled water.

5 Repeat this process until 15–20 cm^3 of distilled water have been transferred.

Results

Sketch a diagram to show any layers that have formed. Label the layers clearly to identify which is salt water and which is fresh water, and (if appropriate) where some mixing has taken place.

Evaluation and conclusions

c How does **salinity** affect the density of water?

d How does temperature affect the density of water?

e What would happen if ice (frozen water) were added to cold water?

f Outline an investigation you could carry out to produce a line graph showing how temperature affects the density of water.

g What factors may cause different layers of water to mix?

h Suggest how changes in the density of water, such as changes caused by rapid cooling at the surface, would affect the movement of water in the ocean.

> **KEY WORD**
>
> **salinity:** a measure of the quantity of dissolved solids in ocean water, represented by parts per thousand, ppt or ‰

Reflection

i How has this practical helped you to understand the formation of thermoclines and haloclines?