PEARSON EDEXCEL INTERNATIONAL AS/A LEVEL

BIOLOGY

Student Book 1

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Text
Extract on page 22 from Luyckx J., Baudouin C. Trehalose: an intriguing disaccharide with potential for medical application in ophthalmology. Clinical ophthalmology (Auckland, NZ) 5 (2011): 577; Extract on page 70 from Mostafa Q Al-Shamiri. Heart failure in the Middle East. Current Cardiology Reviews 2013 May; 9(2):174–178https://www.ncbi.nlm.nih.gov/pmc/articles /PMC3682400/#R10; Extract on page 96 from Qingling Zhang, Zhiming Qiu, Kian Fan Chung, Shau-Ku Huang. Journal of Thoracic Disease. 2015 Jan; 7(1): 14–22https://www.ncbi.nlm.nih. gov/pmc/articles /PMC4311080/#r3; Extract on page 97 from Qingling Zhang, Zhiming Qiu, Kian Fan Chung, Shau-Ku Huang. Journal of Thoracic Disease. 2015 Jan; 7(1): 14–22https://www .ncbi.nlm.nih.gov/pmc/articles /PMC4311080/#r3; Extract on page 122 Based on a number of different websites promoting 'good health'; Extract on page 190 from In vitro fertilisation by Ann Fullick. 2nd ed. 2009. Heinemann series 'Science at the Edge'; Extract on page 218 from 'Me, myself, us. The human microbiome – looking at humans as ecosystems that contain many collaborating species could change the practice of medicine', The Economist, 18 August 2012; Extract on page 262 from Leonard, Jennifer A., Nadin Rohland, Scott Glaberman, Robert C. Fleischer, Adalgisa Caccone and Michael Hofreiter. 'A rapid loss of stripes: the evolutionary history of the extinct quagga.' Biology letters 1, no. 3 (2005): 291 –295; Extract on page 262 From Quagga rebreeding: a success story by Keri Harvey, Copyright 2014 by Farmer's Weekly Magazine. Used by permission of the Farmer's Weekly Magazine; Extract on page 294 from Alexander Nater, et al. Morphometric, behavioral, and genomic evidence for a new orangutan species. Current Biology November 2017.http://www.cell.com/ current-biology/fulltext/S0960-9822(17)31245-9.

TOPIC 1
MOLECULES, TRANSPORT AND HEALTH

TOPIC 2
MEMBRANES, PROTEINS, DNA AND GENE EXPRESSION

TOPIC 3
CELL STRUCTURE, REPRODUCTION AND DEVELOPMENT

TOPIC 4
PLANT STRUCTURE AND FUNCTION, BIODIVERSITY AND CONSERVATION

ABOUT THIS BOOK

This book is written for students following the Pearson Edexcel International Advanced Subsidiary (IAS) Biology specification. This book covers the full IAS course and the first year of the International A Level (IAL) course.

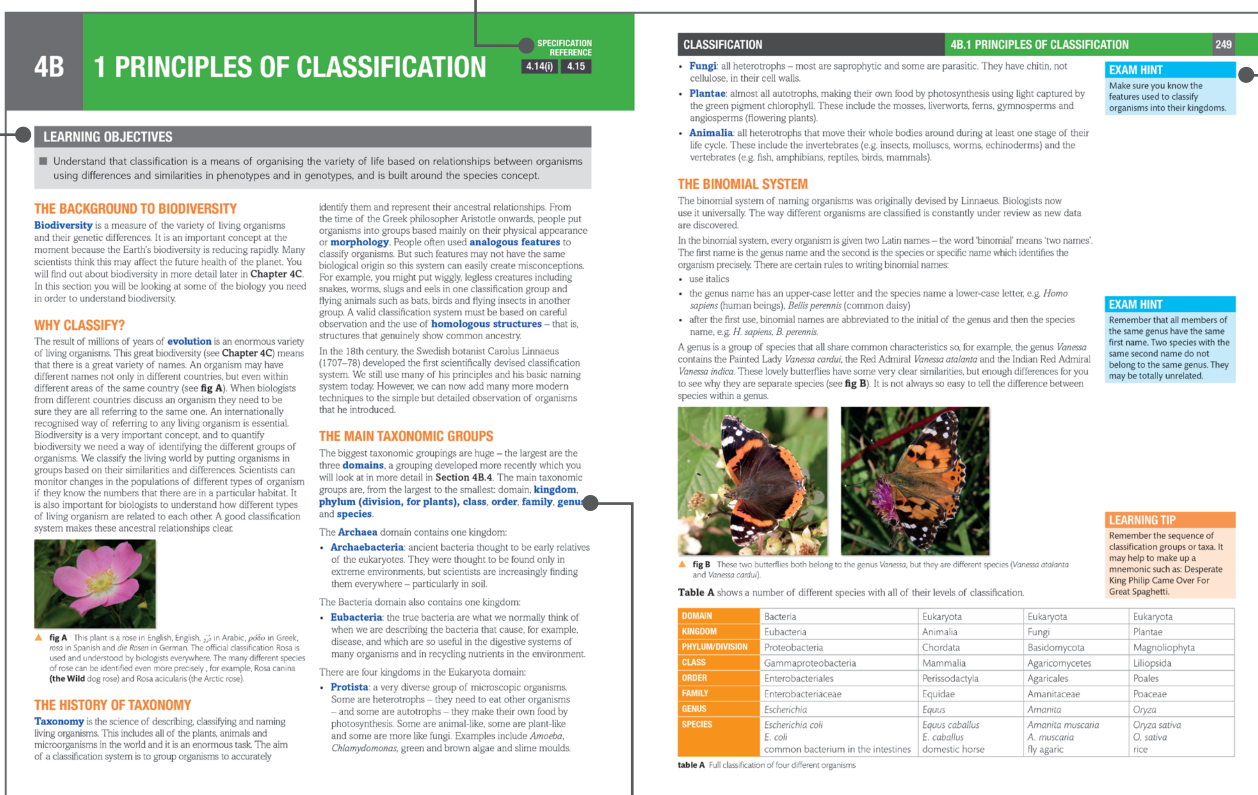
The book contains full coverage of IAS units (or exam papers) 1 and 2. Each unit in the specification has two topic areas. The topics in this book, and their contents, fully match the specification. You can refer to the Assessment Overview on page x for further information. Students can prepare for the written Practical Paper (unit 3) by using the IAL Biology Lab Book (see page viii of this book).

Each topic is divided into chapters and sections to break the content down into manageable chunks. Each section features a mix of learning and activities.

Learning objectives
Each chapter starts with a list of key assessment objectives.

Specification reference
The exact specification references covered in the section are provided.

Exam hints
Tips on how to answer exam-style questions and guidance for exam preparation. Orange **Learning Tips** help you focus your learning and avoid common errors.



4B 1 PRINCIPLES OF CLASSIFICATION

SPECIFICATION REFERENCE 4.14(i) 4.15

LEARNING OBJECTIVES

- Understand that classification is a means of organising the variety of life based on relationships between organisms using differences and similarities in phenotypes and in genotypes, and is built around the species concept.

THE BACKGROUND TO BIODIVERSITY

Biodiversity is a measure of the variety of living organisms and their genetic differences. It is an important concept at the moment because the Earth's biodiversity is reducing rapidly. Many scientists think this may affect the future health of the planet. You will find out about biodiversity in more detail later in **Chapter 4C**. In this section you will be looking at some of the biology you need in order to understand biodiversity.

WHY CLASSIFY?

The result of millions of years of **evolution** is an enormous variety of living organisms. This great biodiversity (see **Chapter 4C**) means that there is a great variety of names. An organism may have different names not only in different countries, but even within different areas of the same country (see **fig A**). When biologists from different countries discuss an organism they need to be sure they are all referring to the same one. An internationally recognised way of referring to any living organism is essential. Biodiversity is a very important concept, and to quantify biodiversity we need a way of identifying the different groups of organisms. We classify the living world by putting organisms in groups based on their similarities and differences. Scientists can monitor changes in the populations of different types of organism if they know the numbers that there are in a particular habitat. It is also important for biologists to understand how different types of living organism are related to each other. A good classification system makes these ancestral relationships clear.

fig A This plant is a rose in English, English, ورد in Arabic, *ρόδο* in Greek, *rosa* in Spanish and *die Rosen* in German. The official classification Rosa is used and understood by biologists everywhere. The many different species of rose can be identified even more precisely , for example, Rosa canina **(the Wild** dog rose) and Rosa acicularis (the Arctic rose).

THE HISTORY OF TAXONOMY

Taxonomy is the science of describing, classifying and naming living organisms. This includes all of the plants, animals and microorganisms in the world and it is an enormous task. The aim of a classification system is to group organisms to accurately identify them and represent their ancestral relationships. From the time of the Greek philosopher Aristotle onwards, people put organisms into groups based mainly on their physical appearance or **morphology**. People often used **analogous features** to classify organisms. But such features may not have the same biological origin so this system can easily create misconceptions. For example, you might put wiggly, legless creatures including snakes, worms, slugs and eels in one classification group and flying animals such as bats, birds and flying insects in another group. A valid classification system must be based on careful observation and the use of **homologous structures** – that is, structures that genuinely show common ancestry.

In the 18th century, the Swedish botanist Carolus Linnaeus (1707–78) developed the first scientifically devised classification system. We still use many of his principles and his basic naming system today. However, we can now add many more modern techniques to the simple but detailed observation of organisms that he introduced.

THE MAIN TAXONOMIC GROUPS

The biggest taxonomic groupings are huge – the largest are the three **domains**, a grouping developed more recently which you will look at in more detail in **Section 4B.4**. The main taxonomic groups are, from the largest to the smallest: domain, **kingdom**, **phylum (division, for plants), class**, **order**, **family**, **genus** and **species**.

The **Archaea** domain contains one kingdom:

- **Archaebacteria**: ancient bacteria thought to be early relatives of the eukaryotes. They were thought to be found only in extreme environments, but scientists are increasingly finding them everywhere – particularly in soil.

The Bacteria domain also contains one kingdom:

- **Eubacteria**: the true bacteria are what we normally think of when we are describing the bacteria that cause, for example, disease, and which are so useful in the digestive systems of many organisms and in recycling nutrients in the environment.

There are four kingdoms in the Eukaryota domain:

- **Protista**: a very diverse group of microscopic organisms. Some are heterotrophs – they need to eat other organisms – and some are autotrophs – they make their own food by photosynthesis. Some are animal-like, some are plant-like and some are more like fungi. Examples include *Amoeba*, *Chlamydomonas*, green and brown algae and slime moulds.

CLASSIFICATION 4B.1 PRINCIPLES OF CLASSIFICATION 249

- **Fungi**: all heterotrophs – most are saprophytic and some are parasitic. They have chitin, not cellulose, in their cell walls.
- **Plantae**: almost all autotrophs, making their own food by photosynthesis using light captured by the green pigment chlorophyll. These include the mosses, liverworts, ferns, gymnosperms and angiosperms (flowering plants).
- **Animalia**: all heterotrophs that move their whole bodies around during at least one stage of their life cycle. These include the invertebrates (e.g. insects, molluscs, worms, echinoderms) and the vertebrates (e.g. fish, amphibians, reptiles, birds, mammals).

EXAM HINT
Make sure you know the features used to classify organisms into their kingdoms.

THE BINOMIAL SYSTEM

The binomial system of naming organisms was originally devised by Linnaeus. Biologists now use it universally. The way different organisms are classified is constantly under review as new data are discovered.

In the binomial system, every organism is given two Latin names – the word 'binomial' means 'two names'. The first name is the genus name and the second is the species or specific name which identifies the organism precisely. There are certain rules to writing binomial names:

- use italics
- the genus name has an upper-case letter and the species name a lower-case letter, e.g. *Homo sapiens* (human beings), *Bellis perennis* (common daisy)
- after the first use, binomial names are abbreviated to the initial of the genus and then the species name, e.g. *H. sapiens, B. perennis.*

A genus is a group of species that all share common characteristics so, for example, the genus *Vanessa* contains the Painted Lady *Vanessa cardui*, the Red Admiral *Vanessa atalanta* and the Indian Red Admiral *Vanessa indica*. These lovely butterflies have some very clear similarities, but enough differences for you to see why they are separate species (see **fig B**). It is not always so easy to tell the difference between species within a genus.

EXAM HINT
Remember that all members of the same genus have the same first name. Two species with the same second name do not belong to the same genus. They may be totally unrelated.

fig B These two butterflies both belong to the genus *Vanessa*, but they are different species (*Vanessa atalanta* and *Vanessa cardui*).

LEARNING TIP
Remember the sequence of classification groups or taxa. It may help to make up a mnemonic such as: Desperate King Philip Came Over For Great Spaghetti.

Table A shows a number of different species with all of their levels of classification.

DOMAIN	Bacteria	Eukaryota	Eukaryota	Eukaryota
KINGDOM	Eubacteria	Animalia	Fungi	Plantae
PHYLUM/DIVISION	Proteobacteria	Chordata	Basidomycota	Magnoliophyta
CLASS	Gammaproteobacteria	Mammalia	Agaricomycetes	Liliopsida
ORDER	Enterobacteriales	Perissodactyla	Agaricales	Poales
FAMILY	Enterobacteriaceae	Equidae	Amanitaceae	Poaceae
GENUS	*Escherichia*	*Equus*	*Amanita*	*Oryza*
SPECIES	*Escherichia coli* *E. coli* common bacterium in the intestines	*Equus caballus* *E. caballus* domestic horse	*Amanita muscaria* *A. muscaria* fly agaric	*Oryza sativa* *O. sativa* rice

table A Full classification of four different organisms

Did you know?
Interesting facts help you remember the key concepts.

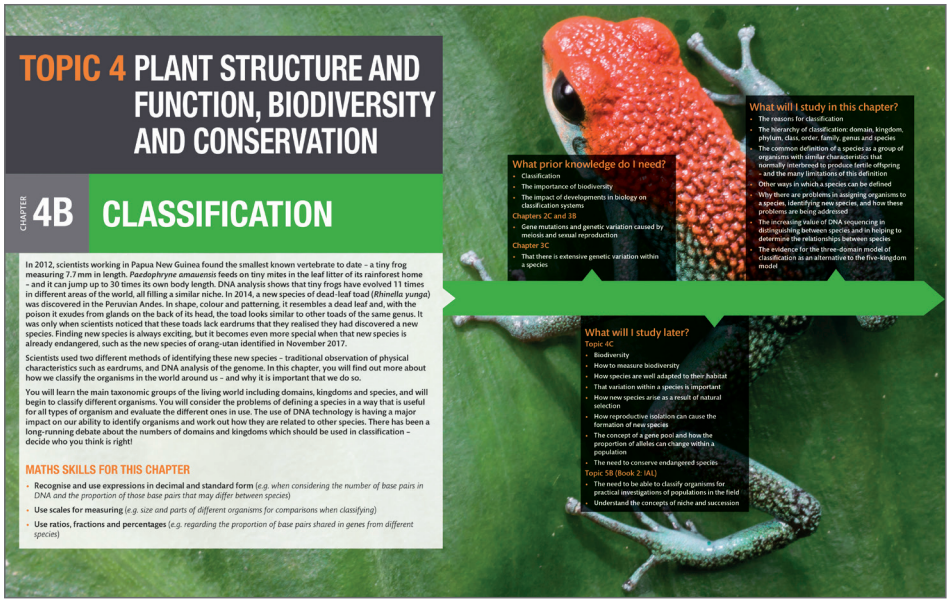
Worked examples show you how to work through questions, and set out calculations.

Subject vocabulary
Key terms are highlighted in blue in the text. Clear definitions are provided at the end of each section for easy reference, and are also collated in a **glossary** at the back of the book.

Checkpoint
Questions at the end of each section check understanding of the key learning points in each chapter.

Your learning, chapter by chapter, is always put in context.

- Links to other areas of Biology include previous knowledge that is built on in the topic, and future learning that you will cover later in your course.
- A checklist details maths knowledge required. If you need to practise these skills, you can use the **Maths Skills** reference at the back of the book as a starting point.



TOPIC 4 PLANT STRUCTURE AND FUNCTION, BIODIVERSITY AND CONSERVATION

CHAPTER 4B CLASSIFICATION

In 2012, scientists working in Papua New Guinea found the smallest known vertebrate to date – a tiny frog measuring 7.7 mm in length. *Paedophryne amauensis* feeds on tiny mites in the leaf litter of its rainforest home – and it can jump up to 30 times its own body length. DNA analysis shows that tiny frogs have evolved 11 times in different areas of the world, all filling a similar niche. In 2014, a new species of dead-leaf toad (*Rhinella yunga*) was discovered in the Peruvian Andes. In shape, colour and patterning, it resembles a dead leaf and, with the poison it exudes from glands on the back of its head, the toad looks similar to other toads of the same genus. It was only when scientists noticed that these toads lack eardrums that they realised they had discovered a new species. Finding new species is always exciting, but it becomes even more special when that new species is already endangered, such as the new species of orang-utan identified in November 2017.

Scientists used two different methods of identifying these new species – traditional observation of physical characteristics such as eardrums, and DNA analysis of the genome. In this chapter, you will find out more about how we classify the organisms in the world around us – and why it is important that we do so.

You will learn the main taxonomic groups of the living world including domains, kingdoms and species, and will begin to classify different organisms. You will consider the problems of defining a species in a way that is useful for all types of organism and evaluate the different ones in use. The use of DNA technology is having a major impact on our ability to identify organisms and work out how they are related to other species. There has been a long-running debate about the numbers of domains and kingdoms which should be used in classification – decide who you think is right!

MATHS SKILLS FOR THIS CHAPTER

- **Recognise and use expressions in decimal and standard form** (*e.g. when considering the number of base pairs in DNA and the proportion of those base pairs that may differ between species*)
- **Use scales for measuring** (*e.g. size and parts of different organisms for comparisons when classifying*)
- **Use ratios, fractions and percentages** (*e.g. regarding the proportion of base pairs shared in genes from different species*)

What prior knowledge do I need?

- Classification
- The importance of biodiversity
- The impact of developments in biology on classification systems

Chapters 2C and 3B

- Gene mutations and genetic variation caused by meiosis and sexual reproduction

Chapter 3C

- That there is extensive genetic variation within a species

What will I study in this chapter?

- The reasons for classification
- The hierarchy of classification: domain, kingdom, phylum, class, order, family, genus and species
- The common definition of a species as a group of organisms with similar characteristics that normally interbreed to produce fertile offspring – and the many limitations of this definition
- Other ways in which a species can be defined
- Why there are problems in assigning organisms to a species, identifying new species, and how these problems are being addressed
- The increasing value of DNA sequencing in distinguishing between species and in helping to determine the relationships between species
- The evidence for the three-domain model of classification as an alternative to the five-kingdom model

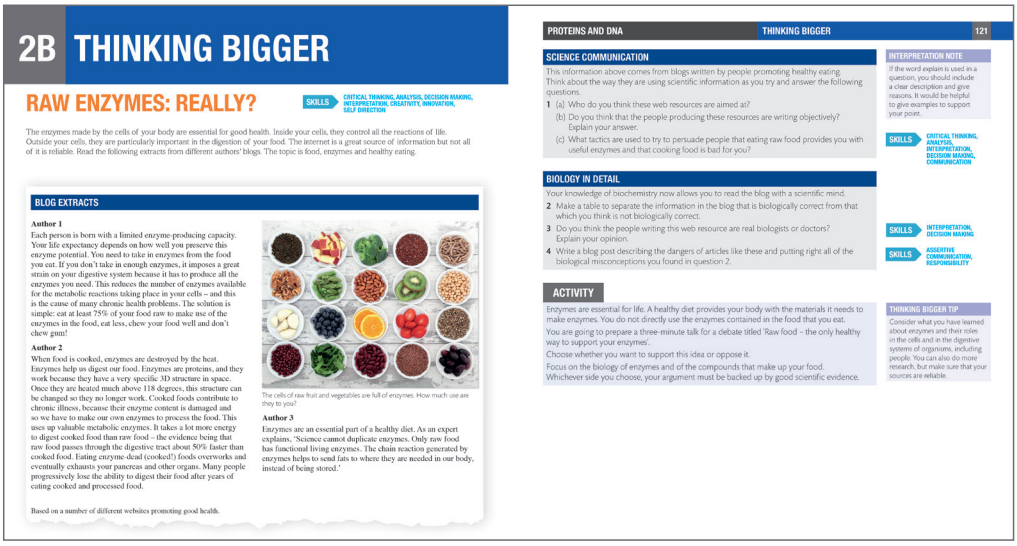
What will I study later?

Topic 4C

- Biodiversity
- How to measure biodiversity
- How species are well adapted to their habitat
- That variation within a species is important
- How new species arise as a result of natural selection
- How reproductive isolation can cause the formation of new species
- The concept of a gene pool and how the proportion of alleles can change within a population
- The need to conserve endangered species

Topic 5B (Book 2: IAL)

- The need to be able to classify organisms for practical investigations of populations in the field
- Understand the concepts of niche and succession



2B THINKING BIGGER

RAW ENZYMES: REALLY?

SKILLS CRITICAL THINKING, ANALYSIS, DECISION MAKING, INTERPRETATION, CREATIVITY, INNOVATION, SELF DIRECTION

The enzymes made by the cells of your body are essential for good health. Inside your cells, they control all the reactions of life. Outside your cells, they are particularly important in the digestion of your food. The internet is a great source of information but not all of it is reliable. Read the following extracts from different authors' blogs. The topic is food, enzymes and healthy eating.

BLOG EXTRACTS

Author 1

Each person is born with a limited enzyme-producing capacity. Your life expectancy depends on how well you preserve this enzyme potential. You need to take in enzymes from the food you eat. If you don't take in enough enzymes, it imposes a great strain on your digestive system because it has to produce all the enzymes you need. This reduces the number of enzymes available for the metabolic reactions taking place in your cells – and this is the cause of many chronic health problems. The solution is simple: eat at least 75% of your food raw to make use of the enzymes in the food, eat less, chew your food well and don't chew gum!

Author 2

When food is cooked, enzymes are destroyed by the heat. Enzymes help us digest our food. Enzymes are proteins, and they work because they have a very specific 3D structure in space. Once they are heated much above 118 degrees, this structure can be changed so they no longer work. Cooked foods contribute to chronic illness, because their enzyme content is damaged and so we have to make our own enzymes to process the food. This uses up valuable metabolic enzymes. It takes a lot more energy to digest cooked food than raw food – the evidence being that raw food passes through the digestive tract about 50% faster than cooked food. Eating enzyme-dead (cooked!) foods overworks and eventually exhausts your pancreas and other organs. Many people progressively lose the ability to digest their food after years of eating cooked and processed food.

Based on a number of different websites promoting good health.

The cells of raw fruit and vegetables are full of enzymes. How much use are they to you?

Author 3

Enzymes are an essential part of a healthy diet. As an expert explains, 'Science cannot duplicate enzymes. Only raw food has functional living enzymes. The chain reaction generated by enzymes helps to send fats to where they are needed in our body, instead of being stored.'

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SCIENCE COMMUNICATION

This information above comes from blogs written by people promoting healthy eating. Think about the way they are using scientific information as you try and answer the following questions.

1 (a) Who do you think these web resources are aimed at?
(b) Do you think that the people producing these resources are writing objectively? Explain your answer.
(c) What tactics are used to try to persuade people that eating raw food provides you with useful enzymes and that cooking food is bad for you?

INTERPRETATION NOTE

If the word explain is used in a question, you should include a clear description and give reasons. It would be helpful to give examples to support your point.

SKILLS CRITICAL THINKING, ANALYSIS, INTERPRETATION, DECISION MAKING, COMMUNICATION

BIOLOGY IN DETAIL

Your knowledge of biochemistry now allows you to read the blog with a scientific mind.

2 Make a table to separate the information in the blog that is biologically correct from that which you think is not biologically correct.
3 Do you think the people writing this web resource are real biologists or doctors? Explain your opinion.
4 Write a blog post describing the dangers of articles like these and putting right all of the biological misconceptions you found in question 2.

SKILLS INTERPRETATION, DECISION MAKING

SKILLS ASSERTIVE COMMUNICATION, RESPONSIBILITY

ACTIVITY

Enzymes are essential for life. A healthy diet provides your body with the materials it needs to make enzymes. You do not directly use the enzymes contained in the food that you eat.

You are going to prepare a three-minute talk for a debate titled 'Raw food – the only healthy way to support your enzymes'.

Choose whether you want to support this idea or oppose it.

Focus on the biology of enzymes and of the compounds that make up your food. Whichever side you choose, your argument must be backed up by good scientific evidence.

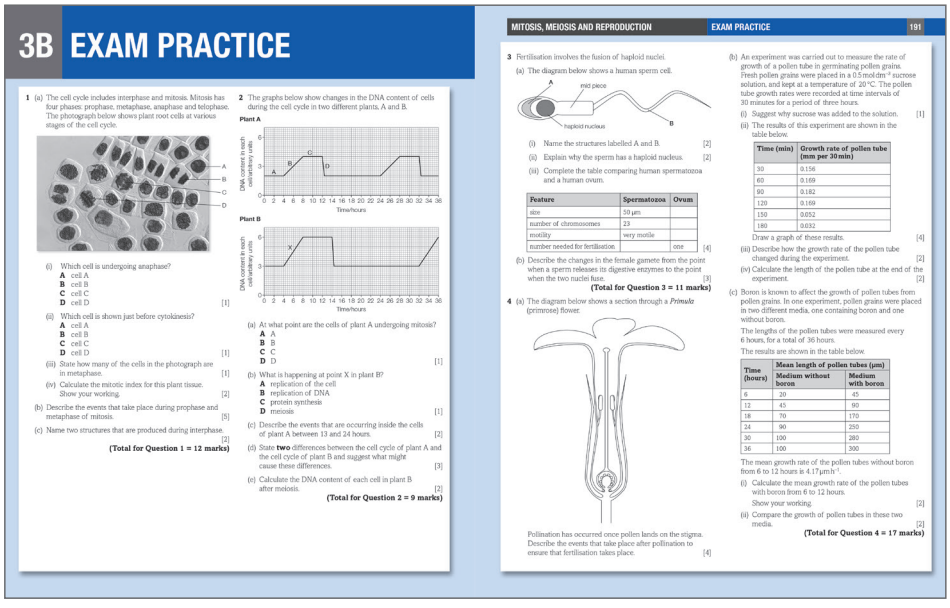
THINKING BIGGER TIP

Consider what you have learned about enzymes and their roles in the cells and in the digestive systems of organisms, including people. You can also do more research, but make sure that your sources are reliable.

Thinking Bigger
At the end of most chapters there is an opportunity to read and work with real-life research and writing about science. The activities help you to read real-life material that's relevant to your course, analyse how scientists write, think critically and consider how different aspects of your learning piece together.

Skills
These sections will help you develop transferable skills, which are highly valued in further study and the workplace.

Exam Practice
Exam-style questions at the end of each chapter are tailored to the Pearson Edexcel specification to allow for practice and development of exam-writing technique. They also allow for practice responding to the command words used in the exams (see the **command words glossary** at the back of this book).



3B EXAM PRACTICE

MITOSIS, MEIOSIS AND REPRODUCTION EXAM PRACTICE 191

1 (a) The cell cycle includes interphase and mitosis. Mitosis has four phases: prophase, metaphase, anaphase and telophase. The photograph below shows plant root cells at various stages of the cell cycle.

(i) Which cell is undergoing anaphase?
A cell A **B** cell B **C** cell C **D** cell D [1]

(ii) Which cell is shown just before cytokinesis?
A cell A **B** cell B **C** cell C **D** cell D [1]

(iii) State how many of the cells in the photograph are in metaphase. [1]

(iv) Calculate the mitotic index for this plant tissue. Show your working. [2]

(b) Describe the events that take place during prophase and metaphase of mitosis. [5]

(c) Name two structures that are produced during interphase. [2]

(Total for Question 1 = 12 marks)

2 The graphs below show changes in the DNA content of cells during the cell cycle in two different plants, A and B.

(a) At what point are the cells of plant A undergoing mitosis?
A A **B** B **C** C **D** D [1]

(b) What is happening at point X in plant B?
A replication of the cell **B** replication of DNA **C** protein synthesis **D** meiosis [1]

(c) Describe the events that are occurring inside the cells of plant A between 13 and 24 hours. [2]

(d) State **two** differences between the cell cycle of plant A and the cell cycle of plant B and suggest what might cause these differences. [3]

(e) Calculate the DNA content of each cell in plant B after meiosis. [2]

(Total for Question 2 = 9 marks)

3 Fertilisation involves the fusion of haploid nuclei.

(a) The diagram below shows a human sperm cell.

(i) Name the structures labelled A and B. [2]

(ii) Explain why the sperm has a haploid nucleus. [2]

(iii) Complete the table comparing human spermatozoa and a human ovum.

Feature	Spermatozoa	Ovum
size	50 µm	
number of chromosomes	23	
motility	very motile	
number needed for fertilisation		one

[4]

(b) Describe the changes in the female gamete from the point when a sperm releases its digestive enzymes to the point when the two nuclei fuse. [3]

(Total for Question 3 = 11 marks)

4 (a) The diagram below shows a section through a *Primula* (primrose) flower.

Pollination has occurred once pollen lands on the stigma. Describe the events that take place after pollination to ensure that fertilisation takes place. [4]

(b) An experiment was carried out to measure the rate of growth of a pollen tube in germinating pollen grains. Fresh pollen grains were placed in a 0.5 mol dm^{-3} sucrose solution, and kept at a temperature of 20 °C. The pollen tube growth rates were recorded at time intervals of 30 minutes for a period of three hours.

(i) Suggest why sucrose was added to the solution. [1]

(ii) The results of this experiment are shown in the table below.

Time (min)	Growth rate of pollen tube (mm per 30 min)
30	0.156
60	0.169
90	0.182
120	0.169
150	0.052
180	0.032

Draw a graph of these results. [4]

(iii) Describe how the growth rate of the pollen tube changed during the experiment. [2]

(iv) Calculate the length of the pollen tube at the end of the experiment. [2]

(c) Boron is known to affect the growth of pollen tubes from pollen grains. In one experiment, pollen grains were placed in two different media, one containing boron and one without boron.

The lengths of the pollen tubes were measured every 6 hours, for a total of 36 hours.

The results are shown in the table below.

Time (hours)	Mean length of pollen tubes (µm)	
	Medium without boron	Medium with boron
6	20	45
12	45	90
18	70	170
24	90	250
30	100	280
36	100	300

The mean growth rate of the pollen tubes without boron from 6 to 12 hours is 4.17 µm h^{-1}.

(i) Calculate the mean growth rate of the pollen tubes with boron from 6 to 12 hours. Show your working. [2]

(ii) Compare the growth of pollen tubes in these two media. [2]

(Total for Question 4 = 17 marks)

PRACTICAL SKILLS

Practical work is central to the study of biology. The Pearson Edexcel International Advanced Subsidiary (IAS) Biology specification includes nine Core Practicals that link theoretical knowledge and understanding to practical scenarios.

In order to develop practical skills, you should carry out a range of practical experiments related to the topics covered in your course. Further suggestions in addition to the Core Practicals are included below.

STUDENT BOOK TOPIC	IAS CORE PRACTICALS	
TOPIC 1 MOLECULES, TRANSPORT AND HEALTH	**CP1**	Use a semi-quantitative method with Benedict's reagent to estimate the concentrations of reducing sugars and with iodine solution to estimate the concentrations of starch, using colour standards.
	CP2	Investigate the vitamin C content of food and drink.
TOPIC 2 MEMBRANES, PROTEINS, DNA AND GENE EXPRESSION	**CP3**	Investigate membrane properties including the effect of alcohol and temperature on membrane permeability.
	CP4	Investigate the effect of temperature, pH, enzyme concentration and substrate concentration on the initial rate of enzyme-catalysed reactions.
TOPIC 3 CELL STRUCTURE, REPRODUCTION AND DEVELOPMENT	**CP5**	Use a light microscope to: (i) make observations and labelled drawings of suitable animal cells (ii) use a graticule with a microscope to make measurements and understand the concept of scale.
	CP6	Prepare and stain a root tip squash to observe the stages of mitosis.
TOPIC 4 PLANT STRUCTURE AND FUNCTION, BIODIVERSITY AND CONSERVATION	**CP7**	Use a light microscope to: (i) make observations, draw and label plan diagrams of transverse sections of roots, stems and leaves (ii) make observations, draw and label cells of plant tissues (iii) identify sclerenchyma fibres, phloem, sieve tubes and xylem vessels and their location.
	CP8	Determine the tensile strength of plant fibres.
	CP9	Investigate the antimicrobial properties of plants, including aseptic techniques for the safe handling of bacteria.

UNIT 1 (TOPICS 1 AND 2) MOLECULES, DIET, TRANSPORT AND HEALTH

Possible further practicals include:

- Investigate the structure of a mammalian heart by dissection.
- Investigate tissue water potentials using plant tissue and graded concentrations of a solute.
- Use a semi-quantitative method to estimate protein concentration using biuret reagent and colour standards.

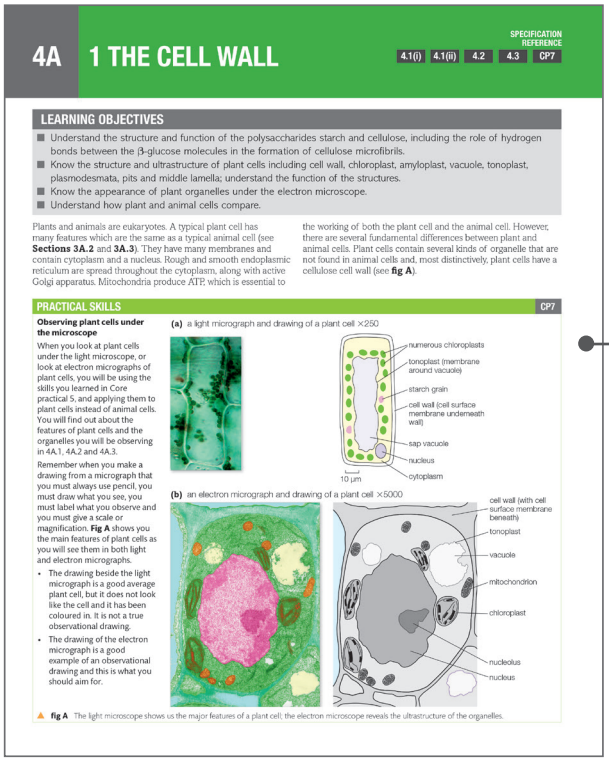
UNIT 2 (TOPICS 3 AND 4) CELLS, DEVELOPMENT, BIODIVERSITY AND CONSERVATION

Possible further practicals include:

- Investigate factors affecting the growth of pollen tubes.
- Investigate plant mineral deficiencies.

Your knowledge and understanding of practical skills and activities will be assessed in all examination papers for the IAS Level Biology qualification.

- Papers 1 and 2 will include questions based on practical activities, including novel scenarios.
- Paper 3 will test your ability to plan practical work, including risk management and selection of apparatus.



4A 1 THE CELL WALL

SPECIFICATION REFERENCE: 4.1(i) 4.1(ii) 4.2 4.3 CP7

LEARNING OBJECTIVES

- Understand the structure and function of the polysaccharides starch and cellulose, including the role of hydrogen bonds between the β-glucose molecules in the formation of cellulose microfibrils.
- Know the structure and ultrastructure of plant cells including cell wall, chloroplast, amyloplast, vacuole, tonoplast, plasmodesmata, pits and middle lamella; understand the function of the structures.
- Know the appearance of plant organelles under the electron microscope.
- Understand how plant and animal cells compare.

Plants and animals are eukaryotes. A typical plant cell has many features which are the same as a typical animal cell (see **Sections 3A.2** and **3A.3**). They have many membranes and contain cytoplasm and a nucleus. Rough and smooth endoplasmic reticulum are spread throughout the cytoplasm, along with active Golgi apparatus. Mitochondria produce ATP, which is essential to the working of both the plant cell and the animal cell. However, there are several fundamental differences between plant and animal cells. Plant cells contain several kinds of organelle that are not found in animal cells and, most distinctively, plant cells have a cellulose cell wall (see **fig A**).

PRACTICAL SKILLS CP7

Observing plant cells under the microscope

When you look at plant cells under the light microscope, or look at electron micrographs of plant cells, you will be using the skills you learned in Core practical 5, and applying them to plant cells instead of animal cells. You will find out about the features of plant cells and the organelles you will be observing in 4A.1, 4A.2 and 4A.3.

Remember when you make a drawing from a micrograph that you must always use pencil, you must draw what you see, you must label what you observe and you must **give a scale or magnification**. **Fig A** shows you the main features of plant cells as you will see them in both light and electron micrographs.

- The drawing beside the light micrograph is a good average plant cell, but it does not look like the cell and it has been coloured in. It is not a true observational drawing.
- The drawing of the electron micrograph is a good example of an observational drawing and this is what you should aim for.

(a) a light micrograph and drawing of a plant cell ×250

numerous chloroplasts
tonoplast (membrane around vacuole)
starch grain
cell wall (cell surface membrane underneath wall)
sap vacuole
nucleus
cytoplasm
10 μm

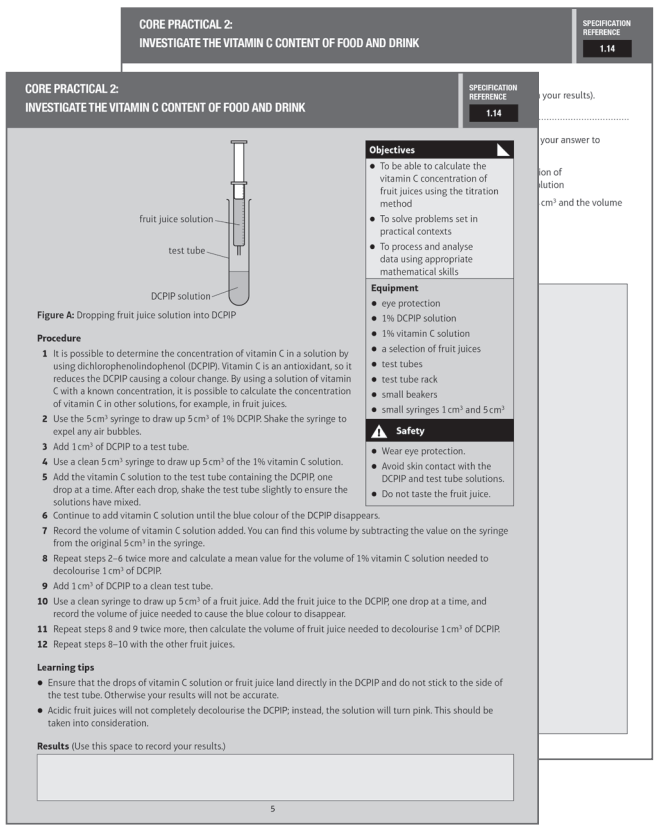
(b) an electron micrograph and drawing of a plant cell ×5000

cell wall (with cell surface membrane beneath)
tonoplast
vacuole
mitochondrion
chloroplast
nucleolus
nucleus

fig A The light microscope shows us the major features of a plant cell; the electron microscope reveals the ultrastructure of the organelles.

Practical Skills boxes explain techniques used in the Core Practicals, and also detail useful skills and knowledge gained in other related investigations.

This Student Book is accompanied by a **Lab Book**, which includes instructions and writing frames for the Core Practicals for students to record their results and reflect on their work. Practical skills practice questions and answers are also provided. The Lab Book records can be used as preparation and revision for the Practical Skills Paper.



CORE PRACTICAL 2:
INVESTIGATE THE VITAMIN C CONTENT OF FOOD AND DRINK

SPECIFICATION REFERENCE 1.14

fruit juice solution
test tube
DCPIP solution

Figure A: Dropping fruit juice solution into DCPIP

Objectives

- To be able to calculate the vitamin C concentration of fruit juices using the titration method
- To solve problems set in practical contexts
- To process and analyse data using appropriate mathematical skills

Equipment

- eye protection
- 1% DCPIP solution
- 1% vitamin C solution
- a selection of fruit juices
- test tubes
- test tube rack
- small beakers
- small syringes 1 cm³ and 5 cm³

Safety

- Wear eye protection.
- Avoid skin contact with the DCPIP and test tube solutions.
- Do not taste the fruit juice.

Procedure

1. It is possible to determine the concentration of vitamin C in a solution by using dichlorophenolindophenol (DCPIP). Vitamin C is an antioxidant, so it reduces the DCPIP causing a colour change. By using a solution of vitamin C with a known concentration, it is possible to calculate the concentration of vitamin C in other solutions, for example, in fruit juices.
2. Use the 5 cm³ syringe to draw up 5 cm³ of 1% DCPIP. Shake the syringe to expel any air bubbles.
3. Add 1 cm³ of DCPIP to a test tube.
4. Use a clean 5 cm³ syringe to draw up 5 cm³ of the 1% vitamin C solution.
5. Add the vitamin C solution to the test tube containing the DCPIP, one drop at a time. After each drop, shake the test tube slightly to ensure the solutions have mixed.
6. Continue to add vitamin C solution until the blue colour of the DCPIP disappears.
7. Record the volume of vitamin C solution added. You can find this volume by subtracting the value on the syringe from the original 5 cm³ in the syringe.
8. Repeat steps 2–6 twice more and calculate a mean value for the volume of 1% vitamin C solution needed to decolourise 1 cm³ of DCPIP.
9. Add 1 cm³ of DCPIP to a clean test tube.
10. Use a clean syringe to draw up 5 cm³ of a fruit juice. Add the fruit juice to the DCPIP, one drop at a time, and record the volume of juice needed to cause the blue colour to disappear.
11. Repeat steps 8 and 9 twice more, then calculate the volume of fruit juice needed to decolourise 1 cm³ of DCPIP.
12. Repeat steps 8–10 with the other fruit juices.

Learning tips

- Ensure that the drops of vitamin C solution or fruit juice land directly in the DCPIP and do not stick to the side of the test tube. Otherwise your results will not be accurate.
- Acidic fruit juices will not completely decolourise the DCPIP; instead, the solution will turn pink. This should be taken into consideration.

Results (Use this space to record your results.)

5

ASSESSMENT OVERVIEW

The following tables give an overview of the assessment for Pearson Edexcel International Advanced Subsidiary course in Biology. You should study this information closely to help ensure that you are fully prepared for this course and know exactly what to expect in each part of the examination. More information about this qualification, and about the question types in the different papers, can be found on page 302 of this book.

PAPER / UNIT 1	PERCENTAGE OF IAS	PERCENTAGE OF IAL	MARK	TIME	AVAILABILITY
MOLECULES, DIET, TRANSPORT AND HEALTH Written examination Paper code WBI11/01 Externally set and marked by Pearson Edexcel Single tier of entry	40%	20%	80	1 hour 30 minutes	January, June and October First assessment : January 2019
PAPER / UNIT 2	**PERCENTAGE OF IAS**	**PERCENTAGE OF IAL**	**MARK**	**TIME**	**AVAILABILITY**
CELLS, DEVELOPMENT, BIODIVERSITY AND CONSERVATION Written examination Paper code WBI12/01 Externally set and marked by Pearson Edexcel Single tier of entry	40%	20%	80	1 hour 30 minutes	January, June and October First assessment : June 2019
PAPER / UNIT 3	**PERCENTAGE OF IAS**	**PERCENTAGE OF IAL**	**MARK**	**TIME**	**AVAILABILITY**
PRACTICAL SKILLS IN BIOLOGY 1 Written examination Paper code WBI13/01 Externally set and marked by Pearson Edexcel Single tier of entry	20%	10%	50	1 hour 20 minutes	January, June and October First assessment : June 2019

ASSESSMENT OBJECTIVES AND WEIGHTINGS

ASSESSMENT OBJECTIVE	DESCRIPTION	% IN IAS	% IN IA2	% IN IAL
A01	Demonstrate knowledge and understanding of science	36–39	31–34	34–37
A02	(a) Application of knowledge and understanding of science in familiar and unfamiliar contexts.	34–36	33–36	33–36
	(b) Analysis and evaluation of scientific information to make judgments and reach conclusions.	9–11	14–16	11–14
A03	Experimental skills in science, including analysis and evaluation of data and methods	17–18	17–18	17–18

RELATIONSHIP OF ASSESSMENT OBJECTIVES TO UNITS

UNIT NUMBER	ASSESSMENT OBJECTIVE			
	A01	A02 (a)	A02 (b)	A03
UNIT 1	17–18	17–18	4.5–5.5	0
UNIT 2	17–18	17–18	4.5–5.5	0
UNIT 3	2–3	0	0	17–18
TOTAL FOR INTERNATIONAL ADVANCED SUBSIDIARY	**36–39**	**34–36**	**9–11**	**17–18**

TOPIC 1 MOLECULES, TRANSPORT AND HEALTH

CHAPTER 1A

CHEMISTRY FOR BIOLOGISTS

Water is essential to life. Everyone knows this. Yet the jerboa, a small rodent found throughout Asia and Northern Africa, may never drink water in its life. The jerboa (family Dipodidae) is found in both hot and cold deserts from the Sahara Desert to the Gobi Desert. It is extremely well adapted for dry desert environments and gets the water it needs from the food it eats. This includes plant leaves, roots and seeds, and in some cases insects. Jerboas also produce tiny amounts of very concentrated urine to get rid of their waste products, another adaptation for saving the water needed for life.

Biology is the study of living things. The basic unit of life is the cell, but underpinning all life is chemistry. The way atoms are bonded together affects the way chemicals work in the cells – and that affects everything, from the way plants make food by photosynthesis to the way your eyes respond to light.

In this chapter, you will be looking at some of the important ways in which atoms and molecules interact to make up the chemistry of life. You will be using these basic principles throughout your biology course because they are fundamental to the structures and functions of all the organisms you will study.

You will see how the chemistry of water enables life to survive and chemical reactions to continue. You will look at carbohydrates, from the simplest sugars to the most complex polysaccharides. These molecules have a wide variety of uses in organisms, from the fuel for cellular respiration to the main structural material in plants. As you discover how the molecules are joined together, you will recognise the relationships between the structure of the molecules and their functions in the body.

The same links between structure and function are clear when you look at the structure of lipid molecules. For example, lipids are used as energy stores in both animals and plants. Lipids are non-polar molecules but you will discover how they can become polar in combination with other inorganic groups such as phosphates. This polarity has great importance for the characteristics of the cell membrane.

At the end of this chapter, you will study the structure of proteins. They are long chains of amino acids that are held together by chemical bonds to make complex structures. The bonds include the covalent bonds, ionic bonds and hydrogen bonds.

MATHS SKILLS FOR THIS CHAPTER

- **Recognise and make appropriate use of units in calculations** (*e.g. millimetres*)
- **Use ratios, fractions and percentages** (*e.g. representing the relationships between atoms in an ion or molecule*)

What prior knowledge do I need?

- Life processes depend on molecules whose structure is related to their function
- All living things are made up of cells
- Many processes in living cells, including diffusion and osmosis, depend on water
- Reactions in cells take place in solution in water
- Complex carbohydrates are made up of sugars joined together
- Complex carbohydrates can be broken down to give simple sugars that can be used by cells
- Plants make carbohydrates in photosynthesis
- Lipids are made up of fatty acids and glycerol
- Lipids are molecules used to store energy in the bodies of animals and plants
- Proteins are long chains of amino acids
- Enzymes are made of proteins

What will I study in this chapter?

- How ionic and covalent bonding affect the nature of the compound formed
- The formation of anions and cations in ionic bonding
- The formation of dipoles in some covalent molecules leading to intra- and intermolecular bonds (e.g. hydrogen bonds)
- The chemistry of water and how this affects its properties
- The importance of water to living things
- The structure of different types of monosaccharide
- The formation of disaccharides by the joining of two monosaccharides in a condensation reaction
- The structure of complex polysaccharides and how their structure is related to their functions as storage molecules
- The structure of lipids including the formation of ester bonds
- The primary, secondary, tertiary and quaternary structure of proteins and how the structure is related to the function of the protein
- The structure of amino acids, peptides and polypeptides and how they relate to each other
- The formation of peptide bonds between amino acids

What will I study later?

Chapter 2A

- The importance of polarity in the structure and function of phospholipids
- How the structure of phospholipids determines many of the characteristics of the cell membrane
- How proteins act as carrier systems in cell membranes
- How water is taken into and moved around plants
- The movement of water into and out of cells, tissues and vessels in animals, plants and fungi

Chapter 2B

- The importance of hydrogen bonding in the tertiary and quaternary structure of proteins and in the structure and function of enzymes

Chapter 4A

- The structure of cellulose in plant cell walls

Chapter 5A (Book 2: IAL)

- The role of water in the reactions of photosynthesis

Chapter 7A (Book 2: IAL)

- The importance of carbohydrates in cellular respiration
- The role of water in the reactions of cellular respiration

Chapter 8B (Book 2: IAL)

- The importance of water in plant movements

LEARNING OBJECTIVES

- Understand the importance of water as a solvent in transport, including its dipole nature.

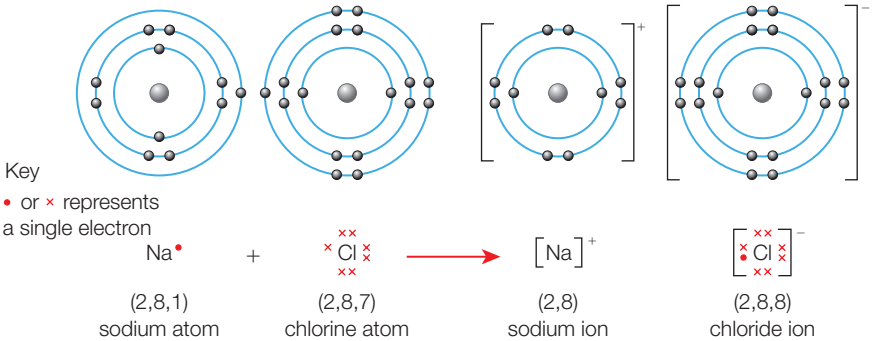
IONIC AND COVALENT BONDING

Biology is the study of living things – but living things consist of chemical substances. The dragonfly and the plant it is resting on in **fig A** are all made of chemicals. So is the cow in **fig C** – and it needs the chemical known as salt which it is licking to stay alive. If you understand some of the basic principles of chemistry, you will develop a much better understanding of biological systems. The chemical bonds within and between molecules affect the properties of the compounds they form. This affects their functions within the cell and the organism. For example, if you want to understand the chemistry of water, you need to understand chemical bonds and how dipoles are created within molecules.

▲ **fig A** All life depends on some very fundamental chemistry.

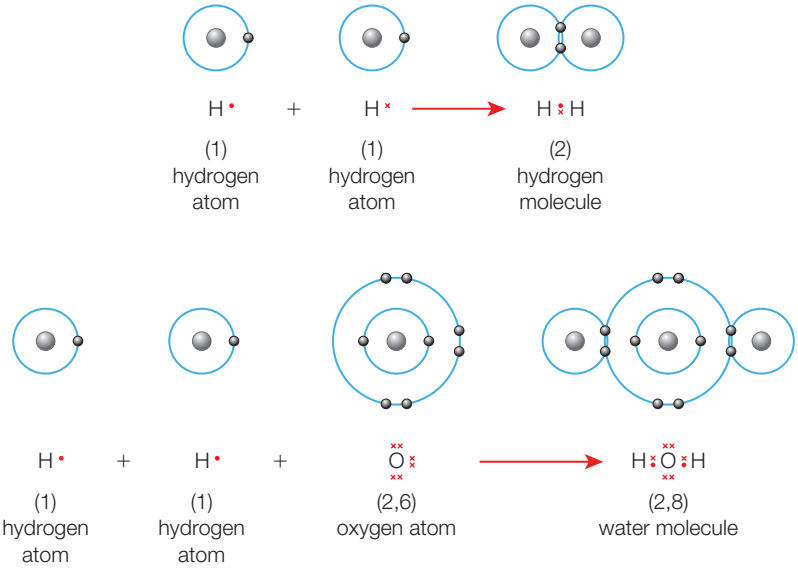
The basic unit of all elements is the atom. When the atoms of two or more different elements react, they form a compound. An atom is made up of a nucleus containing positive protons and neutral neutrons. The nucleus is surrounded by negative electrons. We can show this in a model as electrons orbiting around the nucleus in shells. When an atom has a full outer shell of electrons, it is stable and does not react. However, most atoms do not have a full outer shell of electrons. In chemical reactions, these electrons are involved in changes that give the atom a stable outer shell. There are two ways they can achieve this.

- **Ionic bonding:** the atoms involved in the reaction give or receive electrons. One atom, or part of the molecule, gains one or more electrons and becomes an **anion** (a negative ion). The other atom, or part of the molecule, loses one or more electrons and becomes a **cation** (a positive ion). Strong forces of attraction called **ionic bonds** hold the oppositely charged ions together (see **fig B**).



▲ **fig B** The formation of sodium chloride (salt), an inorganic substance that is very important in living organisms, is an example of ionic bonding.

- **Covalent bonding:** the atoms involved in the reaction share electrons (see **fig D**). **Covalent bonds** are very strong and the molecules formed are usually neutral. However, in some covalent compounds, the molecules are slightly polarised: this means that the electrons in the covalent bonds are not quite evenly shared. Consequently, the molecule has a part that is slightly negative and a part that is slightly positive. This separation of charge is called a **dipole**, and the tiny charges are represented as δ^+ and δ^- (see **fig F**). The molecule is described as a **polar molecule**. This polarity is particularly common if the bond involves one or more hydrogen atoms.



▲ **fig D** The formation of hydrogen molecules and water molecules are examples of covalent bonding.

▲ **fig C** Animals such as cows can use a mineral lick to get the salt they need to function.

THE IMPORTANCE OF INORGANIC IONS

When ionic substances dissolve in water, the ions separate in a process called **dissociation**. Cells are 60–70% water, so in living organisms most ionic substances exist as positive and negative ions. Many of these ions play specialised roles in individual cells and in the functioning of entire organisms. Here are some of the inorganic ions (and their roles) you will meet as you study biology.

IMPORTANT ANIONS

- Nitrate ions (NO_3^-) – these are needed in plants to make DNA and also amino acids and, therefore, proteins from the products of photosynthesis (see **Sections 1A.5**, **2B.3** and **Book 2 Chapter 5A**).
- Phosphate ions (PO_4^{3-}) – these are needed in all living organisms to make ATP and ADP as well as DNA and RNA (see **Section 2B.3** and **Book 2 Chapter 5A**).
- Chloride ions (Cl^-) – these are needed in nerve impulses, sweating and many secretory systems in animals (see **Book 2 Chapters 7C** and **8A)**.
- Hydrogencarbonate ions (HCO_3^-) – these are needed to buffer blood pH to prevent it becoming too acidic (see **Section 1B.2**).

IMPORTANT CATIONS

- Sodium ions (Na^+) – these are needed in nerve impulses, sweating and many secretory systems in animals (see **Book 2 Chapter 8A**).
- Calcium ions (Ca^{2+}) – these are needed for the formation of calcium pectate for the middle lamella between two cell walls in plants, and for bone formation and muscle contraction in animals (see **Section 4A.1** and **Book 2 Chapters 7B** and **7C**).
- Hydrogen ions (H^+) – these are needed in cellular respiration and photosynthesis, and in numerous pumps and systems as well as pH balance (see **Section 2A.4** and **Book 2 Chapters 5A** and **7A**).
- Magnesium ions (Mg^{2+}) – these are needed for production of chlorophyll in plants (see **Book 2 Chapter 5A**).

EXAM HINT

Make sure you understand and can explain the difference between ionic substances, charged particles and polar molecules.

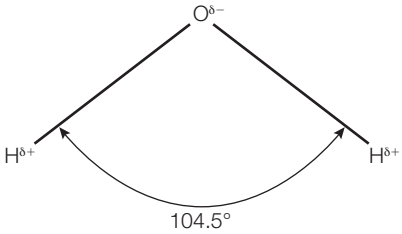
THE CHEMISTRY OF WATER

All reactions in living cells take place in water. Without water, substances could not move around the body. Water is one of the reactants in the process of photosynthesis, on which almost all life depends (see **fig E**). Understanding the properties of water will help you understand many key systems in living organisms.

Water is also a major habitat – it supports more life than any other part of the planet.

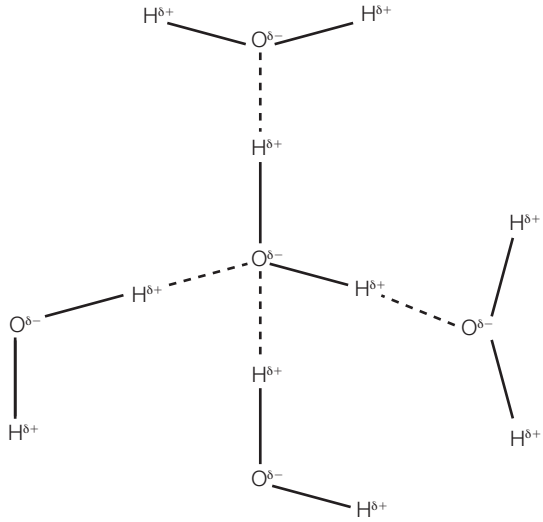
▲ **fig E** Water is vital for life on Earth in many different ways – in a desert, the smallest amount of water allows plants to grow.

The simple chemical formula of water is H_2O. This tells us that two atoms of hydrogen are joined to one atom of oxygen to make up each water molecule. However, because the electrons are held closer to the oxygen atom than to the hydrogen atoms, water is a polar molecule (see **fig F**).



▲ **fig F** A model of a water molecule showing dipoles.

One major effect of this polarity is that water molecules form **hydrogen bonds**. The slightly negative oxygen atom of one water molecule will attract the slightly positive hydrogen atoms of other water molecules in a weak electrostatic attraction called a hydrogen bond. Each individual hydrogen bond is weak but there are many of them so the molecules of water 'stick together' more than you might expect (see **fig G**). Water has relatively high melting and boiling points compared with other substances that have molecules of a similar size because it takes a lot of energy to break all the hydrogen bonds that hold the molecules together. Hydrogen bonds are important in protein structure (see **Sections 1A.5** and **2B.1**) and in the structure and functioning of DNA (see **Section 2B.3**).

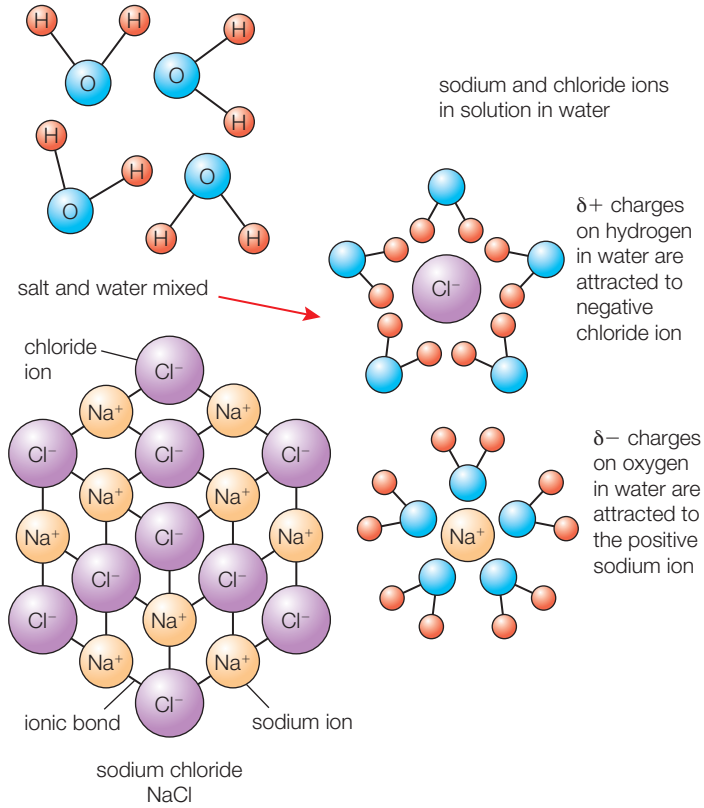


▲ **fig G** Hydrogen bonding in water molecules, based on attraction between positive and negative dipoles.

THE IMPORTANCE OF WATER

The properties of water make it very important in biological systems for many reasons.

- Water is a polar solvent. Because it is a polar molecule, many ionic substances like sodium chloride will dissolve in it (see **fig H**). Many covalently bonded substances are also polar and will dissolve in water, but often do not dissolve in other covalently bonded solvents such as ethanol. Water also carries other substances, such as starch. As a result, most of the chemical reactions within cells occur in water (in aqueous solution).



▲ **fig H** A model of sodium chloride dissolving in water as a result of the interactions between the charges on sodium and chloride ions and the dipoles of the water molecules.

- Water is an excellent transport medium because the dipole nature of water enables many different substances to dissolve in it (see **Sections 1B.2**, **4A.4** and **4A.5**).
- As water cools to 4 °C, it reaches its maximum density. As it cools further, the molecules become more widely spaced. As a result, ice is less dense than water and floats, forming an insulating layer and helping to prevent the water underneath it from freezing. It also melts quickly because, being at the top, it is exposed to the sun. It is very unusual for the solid form of a substance to be less dense than the liquid form. This unusual property enables organisms to live in water, even in countries where it gets cold enough to freeze in winter.
- Water is slow to absorb and release heat – it has a high specific heat capacity. The hydrogen bonds between the molecules need a lot of energy to separate them. This means the temperature of large bodies of water such as lakes and seas does not change much throughout the year. This makes them good habitats for living organisms.
- Water is a liquid – it cannot be compressed. This is an important factor in many hydraulic mechanisms in living organisms.
- Water molecules are cohesive – the forces between the molecules mean they stick together. This is very important for the movement of water from the roots to the leaves of plants (see **Sections 4A.3** and **4A.4**).
- Water molecules are adhesive – they are attracted to other different molecules. This is also important in plant transport systems and in surface tension.
- Water has a very high surface tension because the attraction between the water molecules, including hydrogen bonds, is greater than the attraction between the water molecules and the air. As a result, the water molecules hold together forming a thin 'skin' of surface tension. Surface tension is very important in plant transport systems, and also affects life at the surface of ponds, lakes and other water masses (see **fig 1**).

LEARNING TIP

Remember that *co* means two similar things together, as in cohabit, and *ad* means two different things together.

▲ **fig 1** Without surface tension, a raft spider like this could not move across the water and hunt.

EXAM HINT

All these properties are a result of dipoles and hydrogen bonding between water molecules. Make sure that you can explain the link between the property and the hydrogen bonding.

CHECKPOINT

SKILLS PROBLEM SOLVING

1. What is a dipole?
2. What are the differences between ionic substances and polar substances?
3. How are hydrogen bonds formed between water molecules and what effect do they have on the properties of water?
4. Discuss how the properties of water affect living organisms.

EXAM HINT

In exam questions, the command word *discuss* suggests that you may need to consider possible negative effects as well as the more obvious benefits to living organisms. You should identify the issue that is being assessed within the question. Explore all aspects of the issue. Investigate the issue by reasoning or argument.

SUBJECT VOCABULARY

anion a negative ion
cation a positive ion
ionic bonds bonds formed when atoms give or receive electrons; they result in charged particles called ions
covalent bonds bonds formed when atoms share electrons; covalent molecules may be polar if the electrons are not shared equally
dipole the separation of charge in a molecule when the electrons in covalent bonds are not evenly shared
polar molecule a molecule containing a dipole
dissociation splitting of a molecule into smaller molecules, atoms, or ions, especially by a reversible process
hydrogen bonds weak electrostatic intermolecular bonds formed between polar molecules containing at least one hydrogen atom

1A 2 CARBOHYDRATES 1: MONOSACCHARIDES AND DISACCHARIDES

SPECIFICATION REFERENCE: 1.2(i) 1.2(ii) 1.3 1.4 CP1

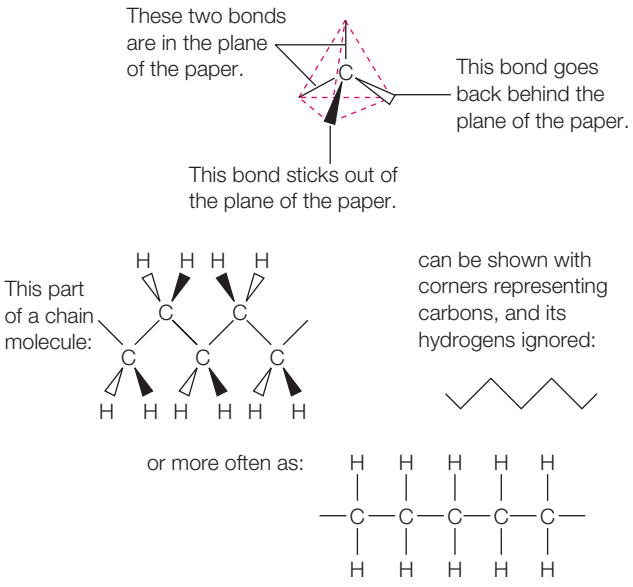
LEARNING OBJECTIVES

- Know the difference between monosaccharides and disaccharides.
- Know how to use Benedict's reagent.
- Know how monosaccharides (glucose, fructose and galactose) join to form disaccharides (maltose, sucrose and lactose) through condensation reactions forming glycosidic bonds, and how they can be split through hydrolysis reactions.

WHAT ARE ORGANIC COMPOUNDS?

Biological molecules are the key to the structure and function of living things. Biological molecules are often organic compounds. Organic compounds all contain carbon atoms. They also contain atoms of hydrogen, oxygen and, less frequently, nitrogen, sulfur and phosphorus. Most of the material in your body that is not water consists of these organic molecules. An understanding of why organic molecules are special will help you to understand the chemistry of biological molecules including carbohydrates, lipids and proteins.

Each carbon atom can make four bonds and so it can connect to four other atoms. Carbon atoms bond particularly strongly to other carbon atoms to make long chains. The four bonds of a carbon atom usually form a tetrahedral shape. This means carbon compounds can be rings, branched chains or any number of three-dimensional (3D) shapes (see **fig A**). In some carbon compounds small molecules (**monomers**) bond with many other similar units to make a very large molecule called a **polymer**. The ability of carbon to combine and make **macromolecules** (large molecules) is the basis of all biological molecules and provides the great variety and complexity found in living things.



▲ **fig A** The bonds in a carbon atom have a complicated 3D shape. This is difficult to represent, so in most molecular diagrams we use one of several different ways to draw them.

CARBOHYDRATES

Carbohydrates are important in cells as a usable energy source and important in human foods around the world (see **fig B**). They are also important for storing energy and they form an important part of the cell wall in plants, fungi and bacteria. Sugars and **starch** are the best known carbohydrates. **Sucrose** is the familiar white crystalline table sugar; **glucose** is used as a fuel by the cells of our bodies. Starch is in rice, flour and potatoes. But the group of substances called carbohydrates contains many more compounds, as you will discover.

▲ **fig B** Carbohydrates are important molecules in both plants and animals – and carbohydrate foods like this bread play a major role in the human diet.

The basic structure of all carbohydrates is the same. They consist of carbon, hydrogen and oxygen. There are three main groups of carbohydrates: **monosaccharides**, **disaccharides** and **polysaccharides**. Some have more complex molecules than others (see **Section 1A.3**).

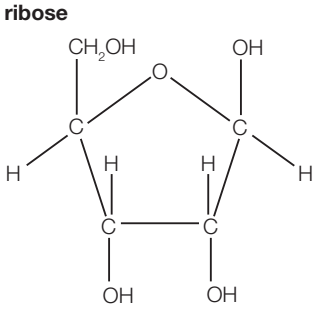
MONOSACCHARIDES: THE SIMPLE SUGARS

Monosaccharides are simple sugars in which there is one oxygen atom and two hydrogen atoms for each carbon atom in the molecule. A general formula for this can be written $(CH_2O)_n$. Here n can be any number, but it is usually low.

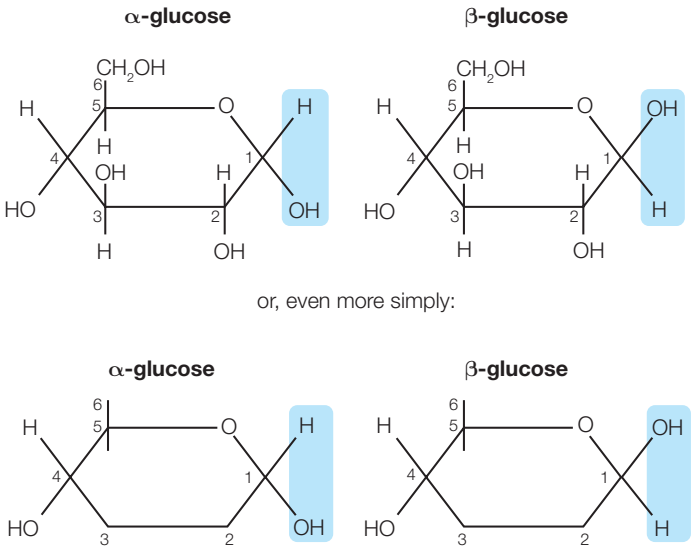
Triose sugars ($n = 3$) have three carbon atoms and the general formula $C_3H_6O_3$. They are important in mitochondria, where the respiration process breaks down glucose into triose sugars (see **Book 2 Chapter 7A**).

- **Pentose sugars** ($n = 5$) have five carbon atoms and the general formula $C_5H_{10}O_5$. **Ribose** and **deoxyribose** are important in the nucleic acids **deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA)**, which make up the genetic material (see **Section 2B.3**).
- **Hexose sugars** ($n = 6$) have six carbon atoms and the general formula $C_6H_{12}O_6$. They are the best known monosaccharides, often taste sweet and include glucose, galactose and fructose.

General formulae show you how many atoms there are in the molecule, and what type they are, but they do not tell you what the molecule looks like and why it behaves as it does. To show this, you can use displayed formulae. Although these do not show all the detailed shape in the carbon chain, they can give you a good idea of how the molecules are arranged in three dimensions. This can help to explain why biological systems behave as they do (see **figs C** and **D**).



▲ **fig C** Pentose sugars such as ribose have 5 carbon atoms.



In these diagrams, the positions of carbon atoms are represented by their numbers only.
Note carefully the different arrangement of atoms around the carbon 1 atom in α-glucose and β-glucose.

▲ **fig D** Hexose sugars have a ring structure. The arrangement of the atoms on the side chains can make a significant difference to the way in which the molecule can be used by the body. The carbon atoms are numbered in order to identify the different arrangements.

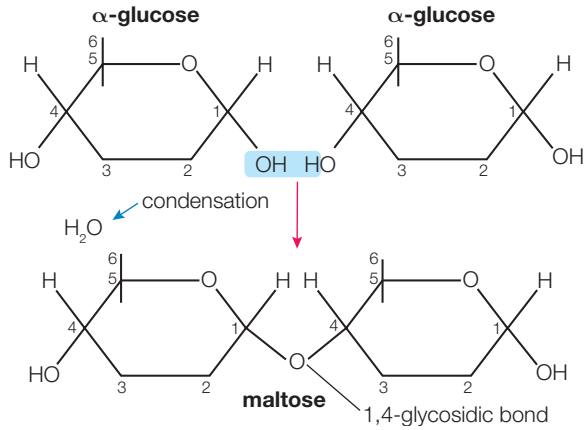
Glucose has two **isomers** (different forms): α-glucose and β-glucose. The two isomers have different arrangements of the atoms on the side chains of the molecule. The different isomers form different bonds between neighbouring glucose molecules, and this affects the polymers that are made. You will learn more about α- and β-glucose in **Section 4A.5**.

DID YOU KNOW?

Hydrogenating some sugars reduces the energy they provide. When glucose is hydrogenated, it forms sorbitol ($C_6H_{14}O_6$). Sorbitol tastes up to 60% sweeter than glucose but it provides less energy when it is used in the body (11 kJg^{-1} compared to 17 kJg^{-1}). The combination of the very sweet taste and the lower energy count makes it useful as a sweetener for people who want to lose weight. A small change in the chemical structure has a big effect on function.

DISACCHARIDES: THE DOUBLE SUGARS

Disaccharides consist of two monosaccharides joined together – for example sucrose (table sugar) is formed by a molecule of α-glucose joining with a molecule of fructose. Two monosaccharides join in a **condensation reaction** to form a disaccharide, and a molecule of water (H_2O) is released. The link between the two monosaccharides results in a covalent bond known as a **glycosidic bond** (see **fig E**). We use numbers to show which carbon atoms are involved in the bond. If carbon 1 on one monosaccharide joins to carbon 4 on another monosaccharide, we call it a 1,4-glycosidic bond. If the bond is between carbon 1 and carbon 6, it is a 1,6-glycosidic bond.



▲ **fig E** The formation of a glycosidic bond. The condensation reaction between two monosaccharides results in a disaccharide and a molecule of water.

When different monosaccharides join together, different disaccharides are made, and these have different properties. Many disaccharides taste sweet. **Table A** shows some of the more common ones.

DISACCHARIDE	SOURCE	MONOSACCHARIDE
sucrose	stored in plants such as sugar cane	glucose + fructose
lactose	milk sugar – this is the main carbohydrate found in milk	glucose + galactose
maltose	malt sugar – found in germinating seed such as barley	glucose + glucose

table A Three common disaccharides

EXAM HINT

A clearly labelled and annotated diagram will help your description of the formation of a glycosidic bond.

LEARNING TIP

All the common mono-saccharides and disaccharides are reducing sugars, except sucrose. When testing for the presence of a non-reducing sugar you must test for reducing sugar first to ensure there is no reaction with Benedict's reagent. Why?

SKILLS PROBLEM SOLVING

LEARNING TIP

Remember that '*iso*' means same, the same atoms.

PRACTICAL SKILLS CP1

Testing for sugars

Benedict's solution is a chemical reagent for testing **reducing sugars**. It is a bright blue solution that contains copper(II) ions. Some sugars react readily with this solution when heated gently and reduce the copper(II) ions to copper(I) ions; a precipitate is formed and a colour change from blue to orange occurs (see **fig F**). Sugars that react in this way are known as reducing sugars. All of the monosaccharides and some disaccharides (but not sucrose) are reducing sugars.

▲ **fig F** Benedict's test for reducing sugars

Some sugars do not react with Benedict's solution. They are known as **non-reducing sugars**. You can heat a non-reducing sugar such as sucrose with a few drops of hydrochloric acid, allow it to cool and then neutralise the solution with sodium hydrogen carbonate to hydrolyse the glycosidic bonds. This produces the monosaccharide units of the sugar, which will give a positive Benedict's test.

CHECKPOINT

1. What are carbohydrates?
2. Describe how a glycosidic bond is formed between two monosaccharides to form a disaccharide.

SUBJECT VOCABULARY

monomer a small molecule that is a single unit of a larger molecule called a polymer
polymer a long-chain molecule made up of many smaller, repeating monomer units joined together by chemical bonds
macromolecule a very large molecule often formed by polymerisation
starch a long-chain polymer formed of glucose monomers
sucrose a sweet-tasting disaccharide formed by the joining of glucose and fructose by a 1,4-glycosidic bond
glucose a hexose sugar
monosaccharide a single sugar monomer
disaccharide a sugar made up of two monosaccharide units joined by a glycosidic bond, formed in a condensation reaction
polysaccharide a polymer consisting of long chains of monosaccharide units joined by glycosidic bonds
triose sugar a sugar with three carbon atoms
pentose sugar a sugar with five carbon atoms
ribose a pentose sugar that is part of the structure of RNA
deoxyribose a pentose sugar that is part of the structure of DNA
deoxyribonucleic acid (DNA) a nucleic acid that is the genetic material in many organisms
ribonucleic acid (RNA) a nucleic acid which is the genetic material in some organisms and is involved in protein synthesis
hexose sugar sugar with six carbon atoms
isomers molecules that have the same chemical formula, but different molecular structures
condensation reaction a reaction in which a molecule of water is removed from the reacting molecules as a bond is formed between them
glycosidic bond a covalent bond formed between two monosaccharides in a condensation reaction, which can be broken down by a hydrolysis reaction to release the monosaccharide units
reducing sugars sugars that react with blue Benedict's solution and reduce the copper(II) ions to copper(I) ions giving an orangey-red precipitate
non-reducing sugars sugars that do not react with Benedict's solution

1A 3 CARBOHYDRATES 2: POLYSACCHARIDES

SPECIFICATION REFERENCE
1.2(i) 1.2(ii) 1.3 1.4 CP1

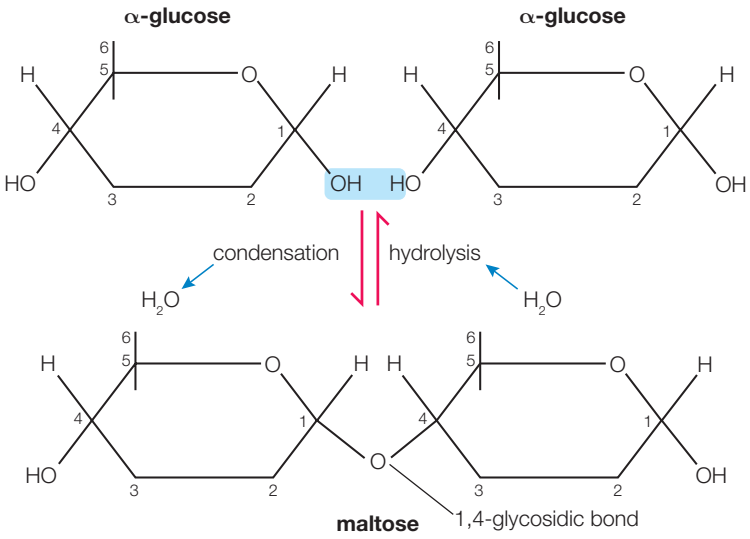
LEARNING OBJECTIVES

- Know the difference between monosaccharides, disaccharides and polysaccharides, including glycogen and starch.
- Explain how monosaccharides join to form polysaccharides through condensation reactions forming glycosidic bonds, and how these can be split through hydrolysis reactions.
- Relate the structures of monosaccharides, disaccharides and polysaccharides to their roles in providing and storing energy.

The most complex carbohydrates are the polysaccharides. They are made of many monosaccharide units joined by condensation reactions that create glycosidic bonds (see **Section 1A.2 fig E**). Polysaccharides do not have the sweet taste of many mono- and disaccharides, but these complex polymers include some very important biological molecules.

Molecules with between 3 and 10 sugar units are known as **oligosaccharides**, while molecules containing 11 or more monosaccharides are known as true polysaccharides. The glycosidic bonds in the polysaccharide can be broken to release monosaccharide units for cellular respiration.

The glycosidic bond between two glucose units is split by a process known as **hydrolysis** (see **fig A**). The hydrolysis reaction is the opposite of the condensation reaction that created the molecule, so water is added to the bond. Starch and glycogen are gradually broken down into shorter and shorter chains and eventually single sugars are left. Disaccharides break down to form two monosaccharides. Hydrolysis takes place during digestion in the gut, and also in the muscle and liver cells when the carbohydrate stores are broken down to release sugars for use in cellular respiration (see **Book 2 Chapter 7A**).



▲ **fig A** Glycosidic bonds are made by condensation reactions and broken down by hydrolysis.

LEARNING TIP

Glycosidic bonds are *formed* with the *removal* of a molecule of water in *condensation reactions.*

Glycosidic bonds are *broken* with the *addition* of a molecule of water in *hydrolysis reactions.*

CARBOHYDRATES AND ENERGY

MONOSACCHARIDES AND DISACCHARIDES

Every chemical reaction taking place in a cell needs energy. This energy is supplied by a substance called adenosine triphosphate, **ATP**. This ATP comes from the breakdown of the monosaccharide glucose, using oxygen, in the process of cellular respiration. You will learn much more about cellular respiration later in your course in **Book 2 Chapter 7A**.

The arrangement of atoms in a molecule of α-glucose means that it can be broken down completely in a series of reactions, if oxygen is available. The compounds that are produced, called the **end products**, are waste carbon dioxide and water, and lots of ATP. This supplies the energy needed for all the reactions in the cell.

EXAM HINT

Be careful not to say that this produces or creates energy for cell processes. Energy cannot be created – it is converted from one form to another. Here, chemical energy is transferred from the glucose molecule to the ATP molecules.

Any glucose in the food you eat can be absorbed and used directly in your cells. Other monosaccharides and disaccharides – for example, fructose, maltose and sucrose – are also easily absorbed in the body and rapidly converted to glucose. So foods containing monosaccharides and disaccharides are a good source of relatively instant energy (see **fig B**). However, these cannot be used to store energy because they are chemically active, and they are very soluble in water, so they affect the water balance of the cells. You will find out why that is so important in **Chapter 2A**.

fig B These medjool dates contain a lot of fructose. That is why they taste so sweet and give you instant energy.

POLYSACCHARIDES

The structure of polysaccharides makes them ideal as energy storage molecules within a cell.

- They can form very compact molecules, which take up little space.
- They are physically and chemically inactive, so they do not interfere with the other functions of the cell.
- They are not very soluble in water, so have almost no effect on water potential within a cell and cause no osmotic water movements.

STARCH

Starch is particularly important as an energy store in plants. The sugars produced by photosynthesis are rapidly converted into starch, which is insoluble and compact but can be broken down rapidly to release glucose when it is needed. Storage organs such as sweet potatoes (yams) are particularly rich in starch. You will find out a lot more about the importance of starch in plants in **Chapter 4A** of this book.

Starch consists of long chains of α-glucose. But if you look at it more closely you will see that it is a mixture of two compounds:

- **Amylose:** an unbranched polymer of between 200 and 5000 glucose units. As the chain lengthens the molecule spirals, which makes it more compact for storage.
- **Amylopectin:** a branched polymer of glucose units. The branching chains have many terminal glucose units that can be broken off rapidly when energy is needed.

Amylose and amylopectin are both long chains of α-glucose units – so why are the molecules so different? It all depends on the carbon atoms involved in the glycosidic bonds.

Amylose has only 1,4-glycosidic bonds, which is why the molecules are long unbranched chains.

In amylopectin, many of the glucose molecules are joined by 1,4-glycosidic bonds, but there are also a few 1,6-glycosidic bonds. This results in the branching chains that change the properties of the molecule.

EXAM HINT

Be sure you can relate the structure of the molecule to its function as a storage molecule.

Coiling makes it compact so it takes up less space and doesn't get in the way of organelles or substances moving around the cell.

Large molecules are insoluble so they do not interfere with the water potential of the cell.

PRACTICAL SKILLS CP1

Testing for starch

If you add a few drops of reddish-brown iodine solution to a sample containing starch (whether it is a solid sample or a sample in solution), the iodine solution will turn blue-black (see **fig C**).

fig C The iodine test for starch

Starch has a combination of straight-chain amylose and branched-chain amylopectin molecules (see **fig D**). This combination explains why carbohydrate foods like rice and pasta are so good for you when you are doing sport or hard physical work. The amylopectin releases glucose for cellular respiration rapidly when needed. Amylose releases glucose more slowly over time, keeping you going longer.

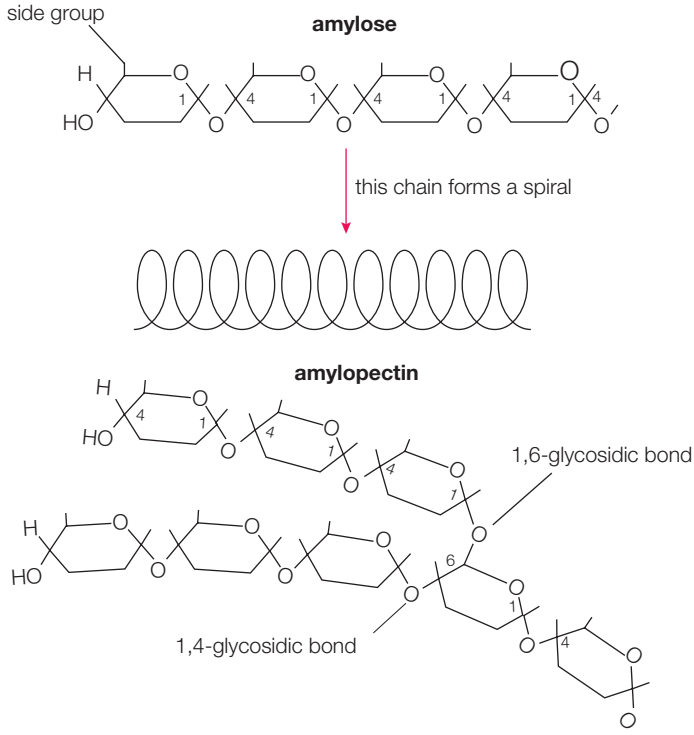
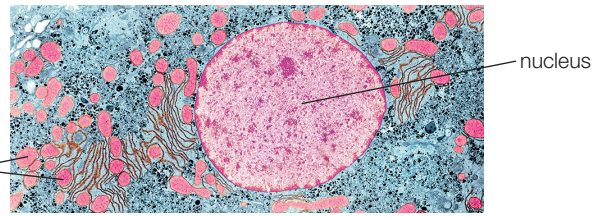


fig D Amylose and amylopectin – a small difference in the position of the glycosidic bonds in the molecule makes a big difference to the properties of the compounds.

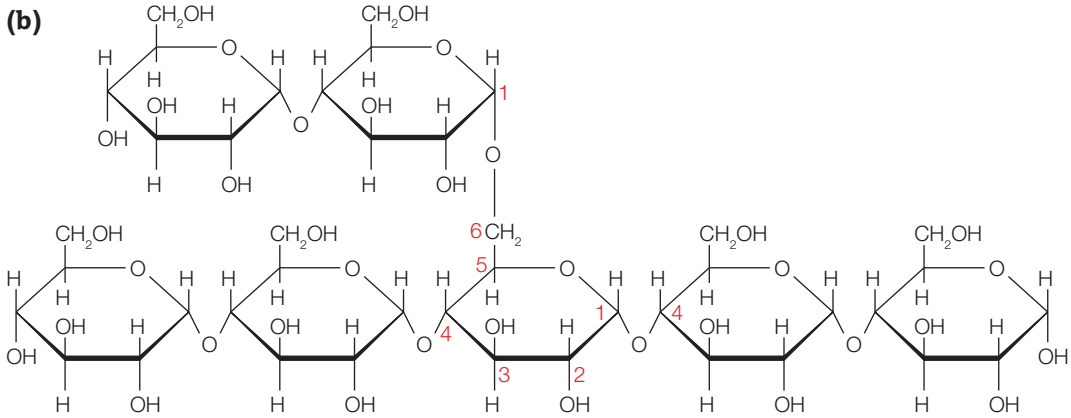
GLYCOGEN

Glycogen is sometimes referred to as 'animal starch' because it is the only carbohydrate energy store found in animals. It is also an important storage carbohydrate in fungi. Chemically, glycogen is very similar to the amylopectin molecules in starch, and it also has many α-glucose units. Like starch, it is very compact, but the glycogen molecule has more 1,6-glycosidic bonds than the starch molecule, giving it many side branches. This means that glycogen can be broken down very rapidly. This makes it an ideal source of glucose for animals which may require rapid release of energy at certain times of high activity levels (see **fig E**).

(a)

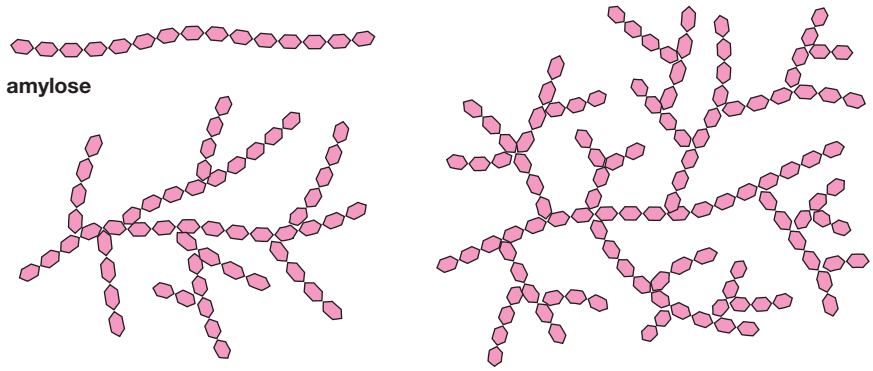


(b)



▲ **fig E** In **(a)** you can see liver cells full of small glycogen granules, stained pink in this micrograph. If your blood glucose levels are low, this glycogen store in your liver can be broken down to provide the glucose you need for cellular respiration. In **(b)** you can see the structure of glycogen with 1,4 and 1,6-glycosidic bonds.

The chemical structure of glycogen shown in **fig E (b)** looks very similar to that of amylopectin. However, when you look at bigger sections of the molecules in **fig F** you can see that glycogen has many more branches than amylopectin.



▲ **fig F** You can clearly see the many side branches which allow glycogen to be broken down so quickly when you compare amylose, amylopectin and glycogen.

CHECKPOINT

SKILLS CREATIVITY

1. Explain why sugars such as glucose and sucrose are useful for immediate energy, but are not suitable as long-term energy stores.
2. Explain how the structure of carbohydrates is related to their function as storage molecules providing the fuel for cellular respiration in animals and plants.

DID YOU KNOW?

When starch is cooked all the coiled molecules unwind and get tangled together. This is why flour can thicken a gravy or sauce, and why you can make glue from flour. It also explains why the molecules must be coiled. If they were not coiled, the cytoplasm would be a solid tangled mass of starch molecules.

EXAM HINT

Be clear about the differences between 1,4-glycosidic bonds and 1,6-glycosidic links. It is easy to get them wrong and lose marks as a result.

SUBJECT VOCABULARY

oligosaccharides molecules with between 3 and 10 monosaccharide units
hydrolysis a reaction in which bonds are broken by the addition of a molecule of water
ATP adenosine triphosphate, the molecule that acts as a universal energy supply molecule in all cells
end products the final products of a chemical reaction
amylose a complex carbohydrate containing only α-glucose monomers joined together by 1,4-glycosidic bonds so the molecules form long unbranched chains
amylopectin a complex carbohydrate made up of α-glucose monomers joined by 1,4-glycosidic bonds with some 1,6-glycosidic bonds so the molecules branch repeatedly
glycogen a complex carbohydrate with many α-glucose units joined by 1,4-glycosidic bonds with many 1,6-glycosidic bonds, giving it many side branches

1A 4 LIPIDS

SPECIFICATION REFERENCE
1.5(i) 1.5(ii)

LEARNING OBJECTIVES

- Know how a triglyceride is synthesised by the formation of ester bonds during condensation reactions between glycerol and three fatty acids.
- Describe the differences between unsaturated and saturated fatty acids.

▲ **fig A** Olive oil comes from pressed olives and is widely used for food and cooking around the world.

The **lipids** are another group of organic substances that play a vital role in organisms. They are an integral part of all cell membranes and are also used as an energy store. Lipids contain many carbon–hydrogen bonds and almost no oxygen. When lipids are oxidised in the respiration process, the bonds are broken and carbon dioxide and water are the final products. This reaction can be used to drive the production of much ATP (see **Sections 1A.3**, **2A.2** and **2A.4** and **Book 2 Chapter 5A**). Lipids, especially triglycerides, store about three times as much energy as the same mass of carbohydrates. Many plants and animals convert spare food into oils or fats as an energy store to use when needed. For example, the seeds of plants contain lipids to provide energy for the seedling when it starts to grow, which is why seeds are such an important food source for many animals.

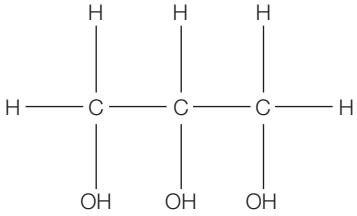
FATS AND OILS

Fats and oils are important groups of lipids. Chemically they are very similar, but fats such as butter are solids at room temperature whereas oils such as olive oil are liquids (see **fig A**). Fats come mainly from animal sources while oils are mainly from plant sources.

Like carbohydrates, the chemical elements that all lipid molecules contain are carbon, hydrogen and oxygen. However, lipids contain a much lower proportion of oxygen than carbohydrates. Fats and oils contain two types of organic chemical substance, **fatty acids** and **glycerol** (propane-1,2,3-triol). These are combined using **ester bonds**. Glycerol has the chemical formula $C_3H_8O_3$ (see **fig B**).

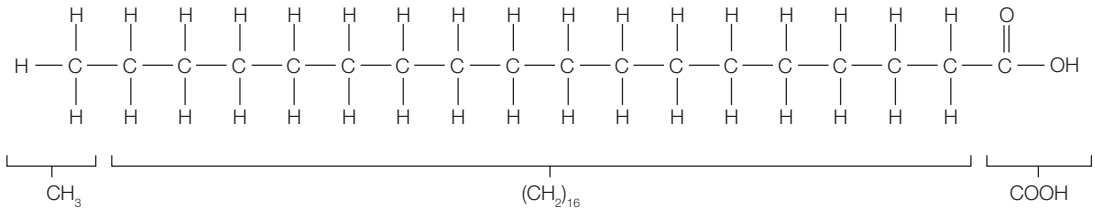
All fatty acids have a long hydrocarbon chain – a folded backbone of carbon atoms with hydrogen atoms attached, and a carboxyl group (–COOH) at one end. Living tissues contain more than 70 different types of fatty acid. Fatty acids vary in two ways:

- the length of the carbon chain can differ (but is often 15–17 carbon atoms long)
- the fatty acid may be a **saturated fatty acid** or an **unsaturated fatty acid**.

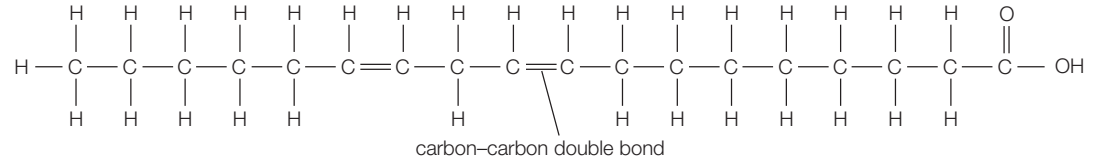


▲ **fig B** Displayed formula of glycerol (propane-1,2,3-triol)

In a saturated fatty acid, each carbon atom is joined to the one next to it by a single covalent bond. A common example is stearic acid (see **fig C**). In an unsaturated fatty acid, the carbon chains have one or more double covalent bonds between carbon atoms in them. A **monounsaturated fatty acid** has one carbon–carbon double bond and a **polyunsaturated fatty acid** has more than one carbon–carbon double bond (see **fig D**). Linoleic acid is an example of a polyunsaturated fatty acid. It is an essential fatty acid in our diet because we cannot make it from other substances.



▲ **fig C** Displayed formula of stearic acid, a saturated fatty acid found in both plant and animal fats

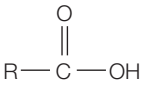


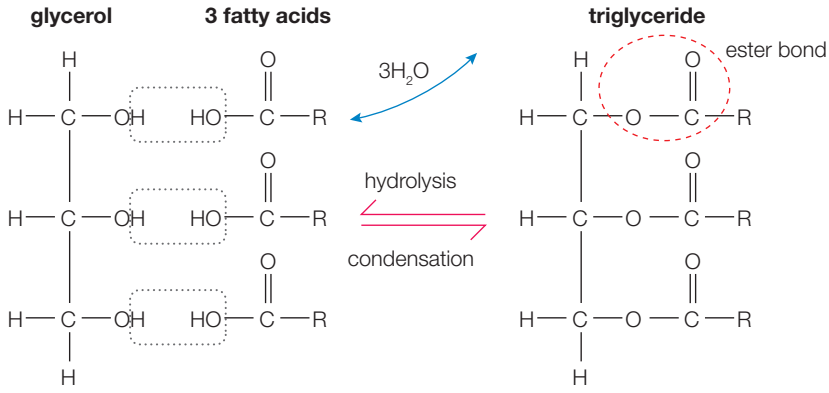
▲ **fig D** Displayed formula of linoleic acid, a polyunsaturated fatty acid

FORMING ESTER BONDS

A triglyceride is made when glycerol combines with three fatty acids. A bond is formed in a condensation reaction between the carboxyl group (–COOH) of a fatty acid and one of the hydroxyl groups (–OH) of the glycerol. A molecule of water is removed and the bond created is called an ester bond. This type of condensation reaction is called **esterification** (see **fig E**). The nature of the lipid formed depends on which fatty acids are joined together. For example, lipids containing saturated fatty acids are more likely to be solid at room temperature than those containing unsaturated fatty acids. Longer chain fatty acids are also more likely to produce solid fats.

For simplicity, fatty acids are represented by this general formula where 'R' represents the hydrocarbon chain. The fatty acids below are drawn in reversed form.





Note: there are only 6 atoms of oxygen in a triglyceride molecule.

▲ **fig E** The formation of ester bonds

EXAM HINT

When you discuss unsaturated fatty acids, make it clear that the double bonds are between carbon atoms. Refer to them as carbon–carbon double bonds, not just double bonds.

LEARNING TIP

Remember that animal fats are usually saturated fatty acids and are more likely to be solid at room temperature. This is why a spread made from plant oils is quite spreadable when you take it out of the fridge, but butter is not.

CHECKPOINT

1. Explain how triglycerides are formed.
2. Describe the main difference between a saturated and an unsaturated fatty acid, and the effect of this difference on the properties of the lipids formed from unsaturated fatty acids compared to lipids formed from saturated fatty acids.

SKILLS ADAPTIVE LEARNING

SUBJECT VOCABULARY

lipids a large family of organic molecules that are important in cell membranes and as an energy store in many organisms; they include triglycerides, phospholipids and steroids
fatty acids organic acids with a long hydrocarbon chain
glycerol propane-1,2,3-triol, an important component of triglycerides
ester bonds bonds formed in a condensation reaction between the carboxyl group (–COOH) of a fatty acid and one of the hydroxyl groups (–OH) of glycerol
saturated fatty acid a fatty acid in which each carbon atom is joined to the one next to it in the hydrocarbon chain by a single covalent bond
unsaturated fatty acid a fatty acid in which the carbon atoms in the hydrocarbon chain have one or more double covalent bonds in them
monounsaturated fatty acid a fatty acid with only one double covalent bond between carbon atoms in the hydrocarbon chain
polyunsaturated fatty acid a fatty acid with two or more double covalent bonds between carbon atoms in the hydrocarbon chain
esterification the process by which ester bonds are made

1A 5 PROTEINS

SPECIFICATION REFERENCE
2.6(i) 2.6(ii) 2.6(iii) 2.6(iv) CP2

LEARNING OBJECTIVES

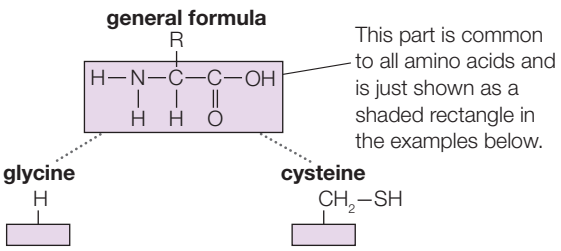
- Know the basic structure of an amino acid.
- Understand the formation of polypeptides and proteins, as amino acid monomers linked together by condensation reactions to form peptide bonds.
- Understand the significance of a protein's primary structure in determining its secondary structure, three-dimensional structure and properties, and the types of bond involved in its three-dimensional structure.
- Know the molecular structure of a globular protein and a fibrous protein and understand how their properties relate to their functions (including haemoglobin and collagen).

About 18% of your body is made up of protein. Proteins make hair, skin and nails, the enzymes needed for metabolism and digestion, and many of the hormones that control the different body systems. They enable muscle fibres to contract, make antibodies that protect you from disease, help clot your blood and transport oxygen in the form of **haemoglobin**. Understanding the structure of proteins helps you understand the detailed biology of cells and organisms. Like carbohydrates and lipids, proteins contain carbon, hydrogen and oxygen. In addition, they all contain nitrogen and many proteins also contain sulfur.

Proteins are a group of macromolecules made up of many small monomer units called **amino acids** joined together by condensation reactions. Amino acids combine in long chains to produce proteins. There are about 20 different naturally occurring amino acids that can combine in different ways to produce a wide range of different proteins.

AMINO ACIDS

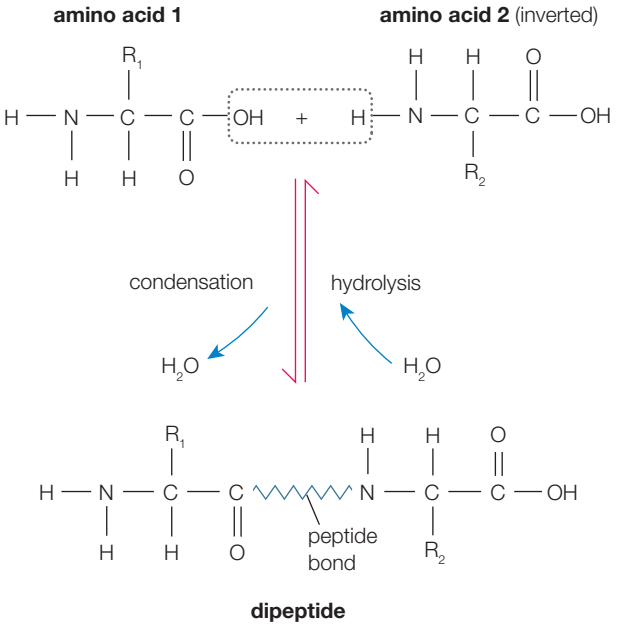
All amino acids have the same basic structure, which is represented as a general formula. There is always an amino group ($–NH_2$) and a carboxyl group (–COOH) attached to a carbon atom (see **fig A**). The group known as the R group varies between amino acids. Some amino acids contain sulfur and selenium in their R group. The R groups are not involved in the reactions which join the amino acids together, but the structure of the R group does affect the way the amino acid interacts with others within the protein molecule. This will mainly depend on whether the R group is polar or not, and these interactions affect the tertiary structure of the protein formed (see **page 18**).



▲ **fig A** Some different amino acids. In the simplest amino acid, glycine, R is a single hydrogen atom. In a larger amino acid such as cysteine, R is much more complex.

FORMING PROTEINS FROM AMINO ACIDS

Amino acids join by a reaction between the amino group of one amino acid, and the carboxyl group of another. They join in a condensation reaction and a molecule of water is released. A **peptide bond** is formed when two amino acids join, and a **dipeptide** is the result (see **fig B**). The R group is not involved in this reaction. More and more amino acids join to form **polypeptide** chains, which contain from about 100 to many thousands of amino acids. A polypeptide forms a protein when the structure of the chain changes by folding or coiling or associates with other polypeptide chains.



▲ **fig B** Amino acids are the building blocks of proteins, joined together by peptide bonds.

BONDS IN PROTEINS

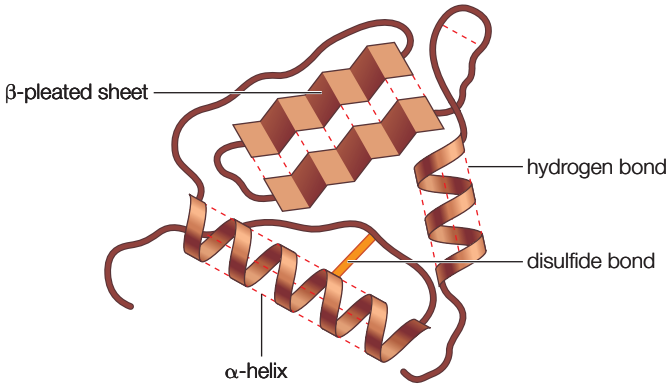
The peptide bond between amino acids is a strong bond. Other bonds are also made between the amino acids in a chain, to create the 3D structures of the protein. They depend on the atoms in the R group and include hydrogen bonds, **disulfide bonds** and ionic bonds.

HYDROGEN BONDS

You were introduced to hydrogen bonds in **Section 1A.1**. These same bonds are essential in protein structures. In amino acids, tiny negative charges are present on the oxygen of the carboxyl groups and tiny positive charges are present on the hydrogen atoms of the amino groups. When these charged groups are close to each other, the opposite charges attract, forming a hydrogen bond. Hydrogen bonds are weak but, potentially, they can be made between any two amino acids in the correct position, so there are many of them holding the protein together very firmly. They are very important in the folding and coiling of polypeptide chains (see **fig C**). Hydrogen bonds break easily and reform if pH or temperature conditions change.

DISULFIDE BONDS

Disulfide bonds form when two cysteine molecules are close together in the structure of a polypeptide (see **fig C**). An oxidation reaction occurs between the two sulfur-containing groups, resulting in a strong covalent bond known as a disulfide bond. These disulfide bonds are much stronger than hydrogen bonds but they happen much less often. They are important for holding the folded polypeptide chains in place.



▲ **fig C** Hydrogen bonds and disulfide bonds maintain the shape of protein molecules and this determines their function.

IONIC BONDS

Ionic bonds can form between some of the strongly positive and negative amino acid side chains which are sometimes found deep inside the protein molecules. They are strong bonds, but they are not as common as the other structural bonds.

Your hair is made of the protein keratin. Some methods of styling hair change the bonds within the protein molecules. Blow drying or straightening hair breaks the hydrogen bonds and temporarily reforms them with the hair curling in a different way until the hydrogen bonds reform in their original places.

Perming is a chemical treatment which is used in some hair salons to completely change the way hair looks for weeks or months. The chemicals break the disulfide bonds between the polypeptide chains and reform them in a different place. This effect is permanent – hair will stay styled in that particular way until it is cut off.

PROTEIN STRUCTURE

Proteins can be described by their primary, secondary, tertiary and quaternary structure (see **fig D**).

- The primary structure of a protein is the sequence of amino acids that make up the polypeptide chain, held together by peptide bonds.
- The secondary structure of a protein is the arrangement of the polypeptide chain into a regular, repeating three-dimensional (3D) structure, held together by hydrogen bonds. One example is the right-handed helix (α-helix), a spiral coil with the peptide bonds forming the backbone and the R groups protruding in all directions. Another is the ß-pleated sheet, in which the polypeptide chain folds into regular pleats held together by hydrogen bonds between the amino and carboxyl ends of the amino acids. Most **fibrous proteins** have this type of structure. Sometimes there is no regular secondary structure and the polypeptide forms a random coil.

LEARNING TIP

Remember that fibrous proteins have a simpler structure and so tend to be more stable to changes in temperature and pH.

LEARNING TIP

Remember that the primary structure of proteins is the result of peptide bonds between amino acids.

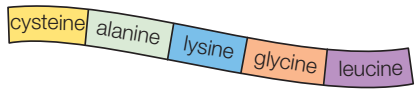
The secondary structure is the result of hydrogen bonding between nearby amino acids but R groups do not affect it.

Ionic bonds, hydrogen bonds and disulfide bridges are a result of interactions between the R groups and create the tertiary structure.

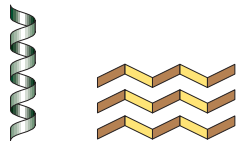
- The tertiary structure is another level of 3D organisation in addition to the secondary structure in many proteins. The amino acid chain, including any α-helices and β-pleated sheets, is folded further into complicated shapes. Hydrogen bonds, disulfide bonds and ionic bonds between the R groups of nearby amino acids hold these 3D shapes in place (see **page 17**). Globular proteins are an example of tertiary structures.
- The quaternary structure of a protein is only found in proteins consisting of two or more polypeptide chains. The quaternary structure describes the way these separate polypeptide chains fit together in three dimensions. Examples include some very important enzymes and the blood pigment haemoglobin.

Changes in conditions such as temperature or pH affect the bonds that keep the 3D shapes of proteins in place. Even small changes can cause the bonds to break, resulting in the loss of the 3D shape of the protein. This is called **denaturation**. Because the 3D structure of these proteins is important to the way they work, changing conditions inside the body can cause proteins such as enzymes to stop working properly.

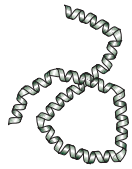
Primary structure the linear sequence of amino acids in a peptide.



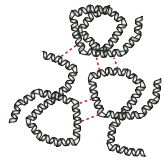
Secondary structure the repeating pattern in the structure of the peptide chains, such as an α-helix or β-pleated sheets.



Tertiary structure the three-dimensional folding of the secondary structure.



Quaternary structure the three-dimensional arrangement of more than one tertiary polypeptide.



▲ **fig D** The 3D structure of proteins

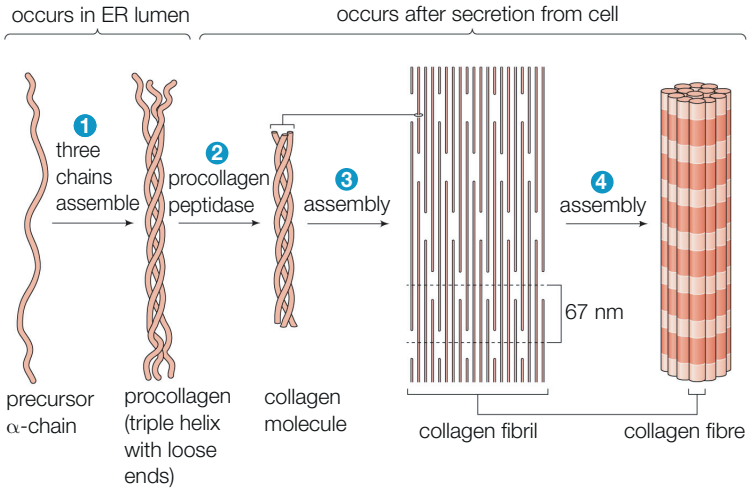
FIBROUS AND GLOBULAR PROTEINS

FIBROUS PROTEINS

The complex structures of large protein molecules relate closely to their functions in the body. Fibrous proteins have little or no tertiary structure. They are long, parallel polypeptide chains with occasional cross-linkages that form them into fibres. They are insoluble in water and are very tough, which makes them ideally suited to their structural functions within organisms. Fibrous proteins appear in the structure of connective tissue in tendons and the matrix of bones, as the silk of spiders' webs and silkworm cocoons, and as the keratin that makes up hair, nails, horns and feathers.

Collagen is a fibrous protein that gives strength to tendons, ligaments, bones and skin. It is the most common structural protein found in animals – up to 35% of the protein in your body is collagen. Collagen is extremely strong – the fibres have a tensile strength similar to that of steel. This is due to the unusual structure of the collagen molecule. Its quaternary structure has three polypeptide chains, each up to 1000 amino acids long. The primary structure of these chains is repeating sequences of glycine with two other amino acids – often proline and hydroxyproline. The three polypeptide α-chains are arranged in a unique triple helix, held together by a very large number of hydrogen bonds. Collagen molecules can be up to several millimetres long and are often found together in fibrils that are held together to form collagen fibres. You can see how collagen fibres are built up in **fig E**.

Collagen fibres combine with the bone tissue, giving it tensile strength, in the same way as the steel rods in reinforced concrete. In the genetic disease osteogenesis imperfecta, the collagen triple helix does not develop properly. Consequently, the bone does not have as much tensile strength; it is brittle and breaks very easily.



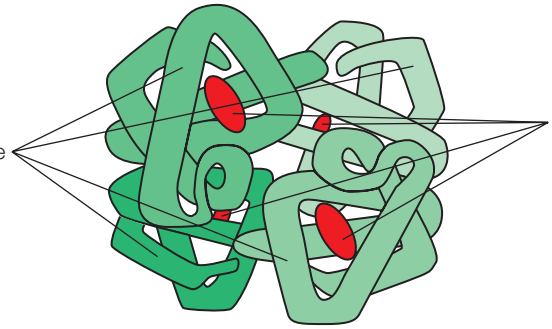
▲ **fig E** Collagen is a fibrous protein with an unusual triple helix structure and immense strength.

GLOBULAR PROTEINS

Globular proteins have complex tertiary and sometimes quaternary structures. They fold into spherical (globular) shapes. The character of the R groups on the amino acids plays an important role in the formation of globular proteins. Some R groups are **hydrophobic**. They repel water and will not mix or dissolve in it. They are usually found on the inside of globular proteins. Some R groups are **hydrophilic** – they have an affinity for water. These groups tend to be found on the outside of globular proteins. The large size of these globular protein molecules affects their behaviour in water.

The carboxyl and amino ends give them ionic properties, so you might expect them to dissolve in water and form a solution. Instead, the molecules are so big that they form a **colloid**. In a colloid, microscopic particles of one substance (in this case protein) are suspended throughout another substance (in this case water). They do not settle, and they cannot easily be separated. Globular proteins are important as they hold molecules in position in the cytoplasm. Globular proteins are also important in your immune system – for example, antibodies are globular proteins. Enzymes and some hormones are globular proteins and help maintain the structure of the cytoplasm (you will learn more about globular proteins as enzymes in **Sections 2B.1** and **2B.2**).

Haemoglobin is one of the best known globular proteins. It is a very large molecule with 574 amino acids arranged in four polypeptide chains which are connected by disulfide bonds. Each polypeptide chain surrounds an iron-containing haem group (see **fig F**). The iron enables the haemoglobin to bind and release oxygen molecules, and the arrangement of the polypeptide chains determines how easily the oxygen binds or is released (see **Section 1B.2** to find out how haemoglobin takes up and gives up oxygen in the tissues of your body).



▲ **fig F** The complex quaternary structure of haemoglobin produces a globular protein containing four haem groups which can carry oxygen to the tissues of the body.

LEARNING TIP

Remember that fibrous proteins are more stable than globular proteins and tend to create structures rather than being metabolically active.

EXAM HINT

Globular proteins have a specific 3D shape which means they can be metabolically active as enzymes or hormones. If the shape is altered slightly by changing conditions, they lose their ability to function.

CONJUGATED PROTEINS

The shape of a protein molecule is usually very important in its function. Some protein molecules are joined with (conjugated to) another molecule called a **prosthetic group** (see **fig F**). This structural feature usually affects the performance and functions of the molecules. These molecules are called **conjugated proteins**. Haemoglobin is a large protein with iron as the prosthetic group. It is a conjugated protein as well as a globular protein. **Lipoproteins** are formed when proteins are conjugated with lipids – you will find out more about these important biological molecules when you look at factors affecting the health of your heart in **Chapter 1B**.

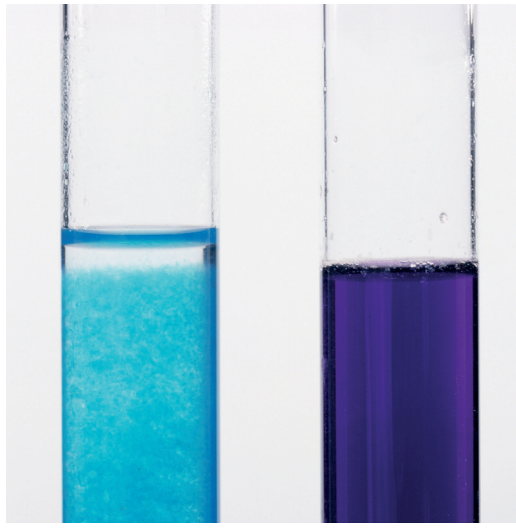
Glycoproteins are proteins with a carbohydrate prosthetic group. The carbohydrate part of the molecule helps them to hold a lot of water and also makes it harder for protein-digesting enzymes (**proteases**) to break them down. Lots of lubricants used by the human body – such as mucus and the synovial fluid in the joints – are glycoproteins. Their water-holding properties make them slippery and viscous, which reduces friction. This also helps to explain why the mucus produced in the stomach protects the protein walls from digestion.

Lipoproteins are very important in the transport of cholesterol in the blood. The lipid part of the molecule enables it to combine with the lipid cholesterol. There are two main forms of lipoproteins in your blood – low-density lipoproteins (LDLs) (around 22 nm in diameter) and high-density lipoproteins (HDLs) (approximately 8–11 nm in diameter). The HDLs contain more protein than LDLs, which is partly why they are denser – proteins are more compact molecules than lipids. You will discover the impact of different lipoproteins on the risk of developing cardiovascular diseases in **Section 1C.4**.

PRACTICAL SKILLS CP2

Testing for protein (RAP)

To test for the presence of protein, add Biuret reagent (ready-mixed 5% (w/v) sodium hydroxide solution and 1% (w/v) copper sulfate solution). A purple colour indicates the presence of protein (see **fig G**).



▲ **fig G** Biuret test for protein

EXAM HINT

Remember that amino acids are joined together by peptide bonds to make dipeptides and then polypeptides. However, the 3D structures of proteins are the result of hydrogen bonds, disulfide bonds, hydrophobic links and ionic bonds between amino acids within the polypeptide chains.

CHECKPOINT

SKILLS REASONING

1. Explain how the order of amino acids in a protein affects the structure of the whole protein.
2. Hydrogen bonds are weaker than disulfide bonds and ionic bonds, but they are more important in maintaining protein structure. Why is this?
3. The body uses many resources to maintain a relatively constant internal environment. With reference to proteins, explain why constant internal conditions are so important.

SUBJECT VOCABULARY

haemoglobin a red pigment that carries oxygen and gives the erythrocytes their colour
amino acids the building blocks of proteins consisting of an amino group ($-NH_2$) and a carboxyl group ($-COOH$) attached to a carbon atom and an R group that varies between amino acids
peptide bond the bond formed by condensation reactions between amino acids
dipeptide two amino acids joined by a peptide bond
polypeptide a long chain of amino acids joined by peptide bonds
disulfide bond a strong covalent bond produced by an oxidation reaction between sulfur groups in cysteine or methionine molecules, which are close together in the structure of a polypeptide
fibrous proteins proteins that have long, parallel polypeptide chains with occasional cross-linkages that produce fibres; they have little tertiary structure
denaturation the loss of the 3D shape of a protein (e.g. caused by changes in temperature or pH)
collagen a strong fibrous protein with a triple helix structure
globular proteins large proteins with complex tertiary and sometimes quaternary structures, folded into spherical (globular) shapes
hydrophobic a substance that tends to repel water and that will not mix with or dissolve in water
hydrophilic a substance with an affinity for water that will readily dissolve in or mix with water
colloid a suspension of molecules that are not fully dissolved
prosthetic group the molecule incorporated in a conjugated protein
conjugated proteins protein molecules joined with or conjugated to another molecule called a prosthetic group
lipoproteins conjugated proteins with a lipid prosthetic group
glycoproteins conjugated proteins with a carbohydrate prosthetic group
proteases protein-digesting enzymes

1A THINKING BIGGER

TREHALOSE: A SUGAR FOR DRY EYES?

SKILLS CRITICAL THINKING, ANALYSIS, CONTINUOUS LEARNING, INTELLECTUAL INTEREST AND CURIOSITY, COMMUNICATION, CREATIVITY

Dry eyes is a condition that is caused by dry air and over-use of air conditioning. Both of these environmental factors are common in Middle Eastern countries. Biological molecules have an amazing number of different roles in living organisms, including some you would not expect. In this activity, you will discover how current research shows that the disaccharide trehalose can protect proteins from damage in stressful conditions. This property is being used to make dry eyes more comfortable – and possibly protect the brain from the damage that can result from ageing.

MEDICAL JOURNAL ARTICLE

TREHALOSE: AN INTRIGUING DISACCHARIDE WITH POTENTIAL FOR MEDICAL APPLICATION IN OPHTHALMOLOGY

Abstract

Trehalose is a naturally occurring disaccharide comprising two molecules of glucose. The sugar is widespread in many species of plants and animals, where its function appears to be to protect cells against desiccation, but it is not found in mammals. Trehalose has the ability to protect cellular membranes and labile proteins against damage and denaturation as a result of desiccation and oxidative stress. Trehalose appears to be the most effective sugar for protection against desiccation. Although the exact mechanism by which trehalose protects labile macromolecules and lipid membranes is unknown, credible hypotheses do exist. As well as being used in large quantities in the food industry, trehalose is used in the biopharmaceutical preservation of labile protein drugs and in the cryopreservation of human cells. Trehalose is under investigation for a number of medical applications, including the treatment of Huntington's chorea [disease] and Alzheimer's disease. Recent studies have shown that trehalose can also prevent damage to mammalian eyes caused by desiccation and oxidative insult. These unique properties of trehalose have thus prompted its investigation as a component in treatment for dry eye syndrome. This interesting and unique disaccharide appears to have properties which may be exploited in ophthalmology and other disease states.

Trehalose, a naturally occurring alpha-linked disaccharide formed of two molecules of glucose (**fig A**) … is synthesized by many living organisms, including insects, plants, fungi, and micro-organisms as a response to prolonged periods of desiccation. This very useful property, known as anhydrobiosis, confers on an organism the ability to survive almost complete dehydration for prolonged periods and subsequently reanimate.

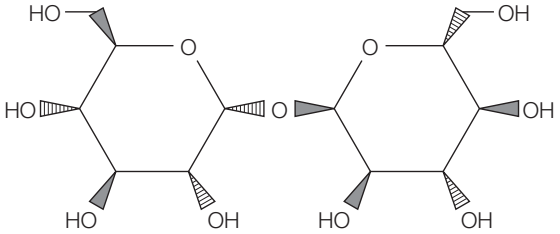


fig A Structure of trehalose; Registry number: 99-20-7; Molar mass: 342.296 g/mol (anhydrous); 378.33 g/mol (dihydrate); molecular structure: α-D-glucopyranosyl α-D-glucopyranoside (α,α-trehalose)

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From: Luyckx J., Baudouin C. Trehalose: an intriguing disaccharide with potential for medical application in ophthalmology. *Clinical ophthalmology* (Auckland, NZ) 5 (2011): 577

SCIENCE COMMUNICATION

SKILLS COMMUNICATION, CREATIVITY

This extract comes from a paper published in *Clinical Ophthalmology*, an online journal. Think about the type of writing being used and the audience it is intended for as you try and answer the following questions.

1 (a) What aspects of this writing tell you it is more like a scientific paper than a general interest article in a magazine?

(b) Many words in this article may be unfamiliar. But words are often made up of familiar components. Break up the word anhydrobiosis and it becomes an-hydro-biosis (an = non, hydro = water and biosis = life). So anhydrobiosis means life without water. Choose two other unfamiliar words used in the article. Find out what they mean and suggest why they have been used by the authors.

(c) How do you think these ideas about trehalose and the way it may be used to help human health might be presented in a newspaper or on a news or science website? Have a go at writing an article for a public interest website yourself.

(d) If trehalose can really help protect people's sight and prevent brain diseases such as Huntington's and Alzheimer's this would make a big difference to people's lives. Notice how careful the author is. Why are scientific papers so cautious in the way they report things?

INTERPRETATION NOTE

Think about the level of scientific detail that is suitable for your expected audience. How will you ensure your article is eye-catching and interesting?

BIOLOGY IN DETAIL

Now you are going to think about the science in the article. You will be surprised how much you know already, but if you choose to do so, you can return to these questions later in your course.

2 What do you know about the chemical nature of trehalose from the article? Can you work out what type of bond joins the subunits together?

3 Desiccation (drying out) is a major problem for living organisms. Suggest reasons why drying out is so hard to survive.

4 Scientists think that trehalose protects both lipid membranes and certain proteins from damage, both from drying out and oxidation. Explain why it is so important biologically to protect cell membranes and protein structures.

THINKING BIGGER TIP

Think about the chemistry of biological molecules you have learned already and use it to help you understand how trehalose works.

ACTIVITY

Which aspect of trehalose would you like to know more about? The way it prevents desiccation in many groups of organisms? The way it can protect human eyes from damage? The evidence that it could help reduce brain diseases in people?

Choose the area that interests you most and use as many resources as you can to produce a 3-minute presentation about that aspect of trehalose biology. Find interesting images and list all the references to help your colleagues decide if they can rely on the information you present.

fig B The desert plant *Selaginella lepidophylla* is a 'resurrection' plant – it can withstand almost complete dehydration and recover within about 24 hours, thanks to high levels of trehalose in the plant cells.

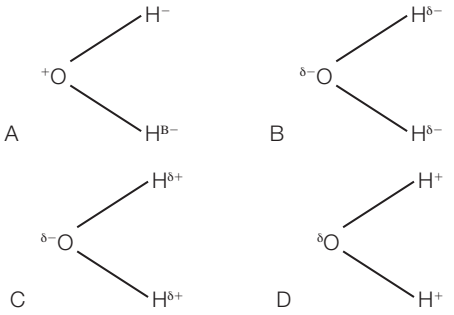
THINKING BIGGER TIP

You can refer to the full version of this paper, to the references listed at the end, to online encyclopaedias, to other scientific papers and to books. In each case, judge the reliability of your source before you use it.

1A EXAM PRACTICE

1 Water is one of the most essential molecules for life.

(a) Which diagram most accurately represents a water molecule?



[1]

(b) (i) Name the bond that occurs between two water molecules. [1]

(ii) State the property of water that enables these bonds to form. [1]

(iii) These intermolecular bonds give water a property called cohesion. Describe two ways in which cohesion is important to living things. [2]

(c) Water has a high specific heat capacity. Assess how important this property is to living things. [2]

(d) Explain how a molecule of sodium chloride can dissolve in water. [3]

(Total for Question 1 = 10 marks)

2 Water is a good solvent.

(a) Which of the following particles will not dissolve in water?

A Na^+ ion

B oxygen molecule

C maltose molecule

D starch molecule [1]

(b) Mosquito larvae live in water. They appear to be attached to the surface of the water. Which property of water enables the larvae to do this?

A Water is most dense at 4 °C

B Hydrogen bonds hold the water molecules together

C Water is a polar molecule

D Water cannot be compressed [1]

(c) Words written in water-based ink will smudge when water is spilled on the paper. Words written in ballpoint pen are not affected.

Explain this using your knowledge of the properties of water. [2]

(d) It is better to use a pencil for writing if the paper may get wet. Use your knowledge of solvents to justify this statement. [2]

(e) Draw two water molecules showing the bonding between the water molecules. [3]

(Total for Question 2 = 9 marks)

3 Carbohydrates include monosaccharides, disaccharides and polysaccharides.

(a) A disaccharide can be split by:

A hydrolysis of glycosidic bonds

B condensation of glycosidic bonds

C hydrolysis of ester bonds

D condensation of ester bonds. [1]

(b) Amylose is an example of a:

A monosaccharide

B disaccharide

C polysaccharide

D trisaccharide. [1]

(c) Complete this table to show the components and bonding within each carbohydrate.

	Lactose	**Amylose**	**Glycogen**
Component monosaccharides			
Bonds between monosaccharides			

[6]

(Total for Question 3 = 8 marks)

4 Disaccharides and polysaccharides consist of monosaccharides joined together.

(a) Name the bond holding the monosaccharides together.

A ionic

B ester

C glycosidic

D hydrogen [1]

(b) What is the function of starch molecules?

A provide a source of energy for plants

B store energy in all living organisms

C store energy in plants

D store energy in animals [1]

(c) A disaccharide can be hydrolysed to its two monosaccharides. Explain the term hydrolysis. [2]

(d) State the role of glycogen molecules and explain why they are well suited to the role. [5]

(Total for Question 4 = 9 marks)

5 (a) Which is the best description of an amino acid?

A contains the elements carbon, hydrogen and oxygen

B an amino group at one end and a carboxyl group at the other end

C a small molecule containing peptide bonds

D an amino group with an R group attached [1]

(b) Proteins are polymers of amino acids joined by peptide bonds formed between the:

A R groups

B R group and the amino group

C R group and the carboxyl group

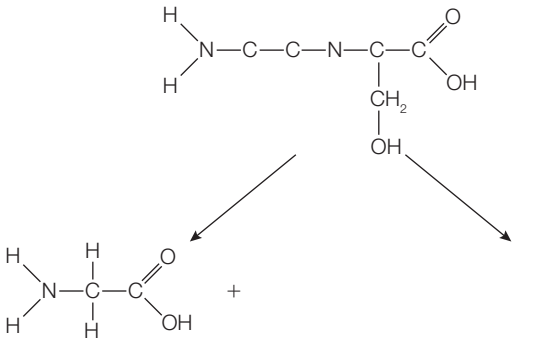
D carboxyl group and the amino group. [1]

(c) Collagen and haemoglobin are both proteins that have a primary structure consisting of amino acids joined together by peptide bonds.

(i) Explain what is meant by the term *primary structure* of a protein. [1]

(ii) Name the type of reaction that occurs when a peptide bond is broken causing a dipeptide to split into two amino acids. [1]

(d) Collagen contains the amino acids glycine and serine. The diagram below shows a dipeptide formed from these two amino acids.



Glycine Serine

Complete the diagram to show the structure of serine when the peptide bond breaks. [1]

(e) In the table below give three structural differences between the molecules of collagen and haemoglobin.

Difference	Collagen	Haemoglobin
1		
2		
3		

[3]

(Total for Question 5 = 8 marks)

6 (a) Complete the table below describing the different levels of protein structure (primary, secondary, tertiary, or quaternary structure). [4]

Description	Level of protein structure (primary, secondary, tertiary, or quaternary)
Hydrophobic amino acids such as proline are not found on the surface of protein molecule	
The molecule contains three polypeptide chains	
The protein molecule contains short helical sections separated by pleated sheets	
40% of the amino acids in the molecule are glutamine	

(b) Amino acids contain a residual or R group. Describe how the R group can affect the structure of a protein. [4]

(c) Explain, using examples, why globular proteins are more metabolically active than fibrous proteins. [4]

(Total for Question 6 = 12 marks)

TOPIC 1 MOLECULES, TRANSPORT AND HEALTH

CHAPTER 1B

MAMMALIAN TRANSPORT SYSTEMS

If a car breaks down, mechanics can replace worn-out parts, put in new oil and transmission fluid, or change perished or worn-out pipes. We do not expect doctors to be able to do the same for our bodies. But they can do a lot to replace or repair the various parts of the circulatory system. The heart can have new valves, new blood vessels to supply the muscle and can even be replaced in a transplant. The blood vessels can be opened up, unblocked or replaced with grafts from other healthy areas of the body. Blood can be replaced by transfusions, and the bone marrow that makes the blood cells can be replaced by transplants. Doctors have even developed techniques by which they can operate on the circulatory system of a fetus in the uterus, to give blood transfusions or repair some heart conditions long before birth.

In this chapter, you will be looking at mammalian transport systems. This involves studying the general principles of circulatory systems and why larger organisms need a complex circulatory system. You will learn about the details of the human blood, blood vessels and heart.

You will consider how blood fluid and blood cells help to transport gases and other substances in the blood and how haemoglobin – the pigment which carries oxygen – attracts oxygen and then releases it when and where it is needed. You will discover the way that the blood vessels are well adapted to their roles in different parts of the circulatory system and what can go wrong if they are not healthy. Finally, you will learn about the heart as a complex organ with a well-coordinated cycle of contraction.

MATHS SKILLS FOR THIS CHAPTER

- **Recognise and make use of appropriate units in calculations** (*e.g. work out the unit for the heart rate*)
- **Find arithmetic means** (*e.g. measuring mean heart rate*)
- **Construct and interpret frequency tables and diagrams, bar charts and histograms** (*e.g. explain volume and pressure changes in the heart chambers*)
- **Substitute numerical values into algebraic equations using appropriate units for physical quantities** (*e.g. calculating the volumes of cubes and spheres*)
- **Solve algebraic equations in a biological context** (*e.g. surface area to volume ratios*)
- **Calculate the circumferences, surface areas and volumes of regular shapes** (*e.g. work out the approximate surface area and volume of a single cell*)
- **Use ratios, fractions and percentages** (*e.g. calculate surface area to volume ratio of a single cell, compare the thickness of the wall of the heart chambers*)

What prior knowledge do I need?

- The human circulatory system and how it is related to the gas exchange system
- How the structure of the heart and the blood vessels are adapted to their functions
- How red blood cells, white blood cells, platelets and plasma are adapted to their functions in the blood
- How oxygen and carbon dioxide move between the air in the lungs and the blood
- Why specific transport systems are needed as organisms get larger and have higher metabolic rates

What will I study in this topic?

- The need for a circulatory system in larger and more complex organisms
- The importance of the surface area to volume ratio of larger organisms
- The advantages of a double circulation in mammals over the single circulatory system in fish
- The structure of the blood including the different cells, plasma and platelets and their functions in transport
- The role of platelets and plasma proteins in blood clotting
- The transport of oxygen in the blood, the roles of haemoglobin, fetal haemoglobin and the effect of carbon dioxide concentrations on the transport of oxygen
- The structure of the heart, arteries, veins and capillaries related to their functions
- The sequence of events of the cardiac cycle
- How blood vessels can become damaged by atherosclerosis and its effect on health

What will I study later?

Chapter 1C

- The risk factors for cardiovascular disease
- Treatments for cardiovascular disease

Chapter 2A

- Movement of gases into and out of the blood in the lungs
- Diffusion and osmosis

Chapter 2C

- Inheritance of blood groups

Chapter 3C

- Bone marrow as a source of blood cells and stem cells
- How stem cells from the bone marrow can have therapeutic uses

Chapter 4A

- Transport systems in plants

Chapter 6B (Book 2: IAL)

- Role of blood in immunity

Topic 7 (Book 2: IAL)

- The role of the blood in homeostasis
- The transport of heat in thermoregulation
- The movement of substances out of and into the blood in the nephrons of the kidney
- The role of the blood in transporting hormones
- The effect of hormones such as adrenaline on the circulatory system
- Coordination of the cardiac cycle
- The control of the heart rate by the nervous system
- Cardiac output

1 THE PRINCIPLES OF CIRCULATION

LEARNING OBJECTIVES

- Know why many animals have a heart and circulation which act as a mass transport system to overcome the limitations of diffusion.

THE NEED FOR TRANSPORT

- Within any organism, substances need to be moved from one place to another. One of the main ways substances move into and out of cells is by **diffusion**. Diffusion is the free movement of particles in a liquid or a gas down a **concentration gradient**. This movement is from an area where the particles are at a relatively high concentration to an area where they are at a relatively low concentration (see **Section 2A.2**).

In single-celled organisms and microscopic multicellular organisms, diffusion is sufficient to supply all their needs. However, when organisms reach a certain size, diffusion alone is not enough.

TRANSPORT IN SMALL ORGANISMS

For a single-celled organism like an amoeba and for very small multicellular organisms including many marine larvae, the nutrients and oxygen that they need can diffuse directly into the cells from the external environment and waste substances can diffuse directly out. This works well for the following reasons.

- The diffusion distances from the outside to the innermost areas of the cells are very small.
- The surface area in contact with the outside environment is very large when compared to the volume of the inside of the organism. Its **surface area to volume ratio (sa : vol)** is large, so there is a relatively big surface area over which substances can diffuse into or out of the organism (see **figs A** and **B**).
- The metabolic demands are low – the organisms do not regulate their own temperature and the cells do not use much oxygen and food or produce much carbon dioxide.

Single-celled organisms and very small multicellular organisms do not need specialised transport systems because diffusion is enough to supply their needs.

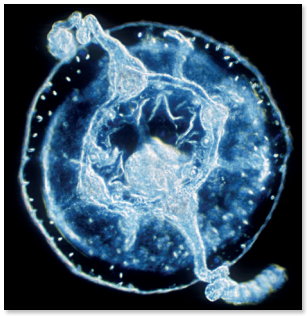


fig A The surface area : volume ratio of this tiny jellyfish larva is relatively large so simple diffusion can supply all its needs.

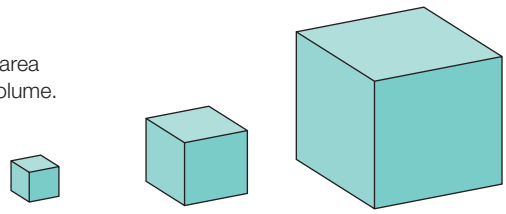
MODELLING SURFACE AREA : VOLUME RATIOS

The surface area to volume ratio of an organism is the key factor that determines whether diffusion alone will allow substances to move into and out of all the cells rapidly enough. However, it is not easy to calculate the surface area to volume ratio of organisms such as elephants, people and palm trees. It is difficult even for a single-celled *Amoeba* because of its irregular shape.

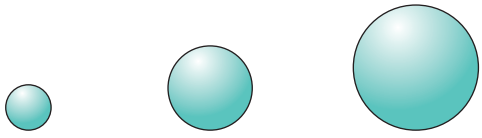
So scientists use models to help show what happens in the real situation (see **fig B**). A simple cube makes surface area to volume calculations easy. The bigger the organism gets, the smaller the surface area to volume ratio becomes. The distance from the outside of the organism to the inside gets longer, and there is proportionately less surface for substances to enter through. So it takes longer for substances to diffuse in, and they may not reach the individual cells quickly enough to supply all their needs.

Smaller surface area compared to volume.

Larger surface area compared to volume.



	1 mm cube	2 mm cube	4 mm cube
Surface area	6 sides × 1^2 = 6 mm^2	6 sides × 2^2 = 24 mm^2	6 sides × 4^2 = 96 mm^2
Volume	1^3 = 1 mm^3	2^3 = 8 mm^3	4^3 = 64 mm^3
Surface area to volume ratio	6 : 1	3 : 1	3 : 2



radius	0.5 µm	1 µm	2 µm
Surface area $4\pi r^2$	3.14 µm^2	12.57 µm^2	50.27 µm^2
Volume $\frac{4}{3}\pi r^3$	0.52 µm^3	4.19 µm^3	33.51 µm^3
Surface area to volume ratio	6 : 1	3 : 1	3 : 2

fig B In this diagram, the cubes and spheres represent models of organisms.

LEARNING TIP

Remember that small organisms have a small surface area. But this surface area is large compared to the volume inside the organism, so it has a large surface area to volume ratio.

THE NEED FOR TRANSPORT IN MULTICELLULAR ANIMALS

Within a large multicellular organism, many chemical reactions take place inside every microscopic cell. These cells require a supply of chemical substances such as glucose and oxygen for cellular respiration. These must be transported from outside a large organism into the cells. Respiration supplies energy for the other reactions of life, but it also produces the toxic waste product carbon dioxide. This and other waste products need to be removed from the cells before they cause damage to them.

Large multicellular organisms have internal transport systems that carry substances to every cell in the body. These systems deliver oxygen and nutrients and remove waste so that cells can carry out their functions efficiently. In large complex animals such as humans, chemicals made in a cell in one part of the body – such as a hormone like insulin or adrenaline – may influence a different type of cell elsewhere in the body. So substances made internally need to be moved around the body as well.

In many animals, including all the **vertebrates**, this transport system is the heart and circulatory system and the fluid that flows through it. This is an example of a **mass transport system** – substances are transported in the flow of a fluid with a mechanism for moving it around the body. All large complex organisms have some form of mass transport system which overcomes the limits of diffusion between the internal and external environments. Substances are delivered over short distances from the mass transport system to individual cells deep in the body by processes such as diffusion, osmosis and active transport.

FEATURES OF MASS TRANSPORT SYSTEMS

Mass transport systems are very effective for moving substances around the body. Most mass transport systems have certain features which are the same. They have:

- exchange surfaces to get materials into and out of the transport system
- a system of vessels that carry substances – these are usually tubes, sometimes following a very specific route, sometimes widespread and branching
- a way of making sure that substances are moved in the right direction (e.g. nutrients in and waste out)
- a way of moving materials fast enough to supply the needs of the organism – this may involve mechanical methods such as the pumping of the heart or ways of maintaining a concentration gradient so that substances move quickly from one place to another (e.g. using active transport)
- a suitable transport medium (e.g. fluid)
- in many cases, a way of adapting the rate of transport to the needs of the organism.

CIRCULATION SYSTEMS

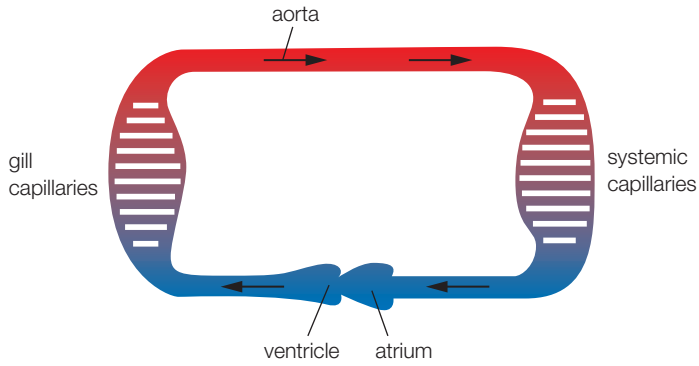
Many animals have a circulatory system in which a heart pumps blood around the body. Insects have an open circulatory system with the blood circulating in large open spaces. However, most larger animals, including mammals, have a closed circulatory system with the blood contained within tubes. The blood makes a continuous journey out to the most distant parts of the body and back to the heart.

LEARNING TIP

The main advantages of a closed system are:

- the pressure can be increased to make the blood flow more quickly
- the flow can be directed more precisely to the organs that need most oxygen and nutrients.

Animals such as fish have a **single circulation system** (see **fig C**). The heart pumps deoxygenated blood to the gills, the organs of gas exchange where the blood takes in oxygen (becomes oxygenated) and gives up carbon dioxide at the same time. The blood then travels on around the rest of the body of the fish, giving up oxygen to the body cells before returning to the heart.



▲ **fig C** The single circulation of a fish

LEARNING TIP

Remember that mass flow is like a stream with all the components flowing together.

Birds and mammals need much more oxygen than fish. Not only do they have to move around without the support of water, but they also maintain a constant body temperature that may be higher or lower than their surroundings. This takes a lot of resources, so their cells need plenty of oxygen and glucose and make waste products that need to be removed quickly. Birds and mammals have evolved the most complex type of transport system, known as a **double circulation** because it involves two separate circulation systems. The **systemic circulation** carries **oxygenated blood** (oxygen-rich blood) from the heart to the cells of the body where the oxygen is used. It also carries the **deoxygenated blood** (blood that has given up its oxygen to the body cells) back to the heart. The **pulmonary circulation** carries deoxygenated blood from the heart to the lungs to be oxygenated and then carries the oxygenated blood back to the heart (see **fig D**).

The separate circuits of a double circulatory system ensure that the oxygenated and deoxygenated blood cannot mix, so the tissues receive as much oxygen as possible. Another big advantage is that the fully oxygenated blood can be delivered quickly to the body tissues at high pressure. The blood going through the tiny blood vessels in the lungs is at relatively low pressure, so it does

not damage the vessels and allows gas exchange to take place. If this oxygenated blood at low pressure went straight into the big vessels that carry it around the body, it would move very slowly. However, the oxygenated blood returns to the heart, so it can be pumped hard and sent around the body at high pressure. This means it reaches all the tiny capillaries between the body cells quickly, supplying oxygen for an active way of life.

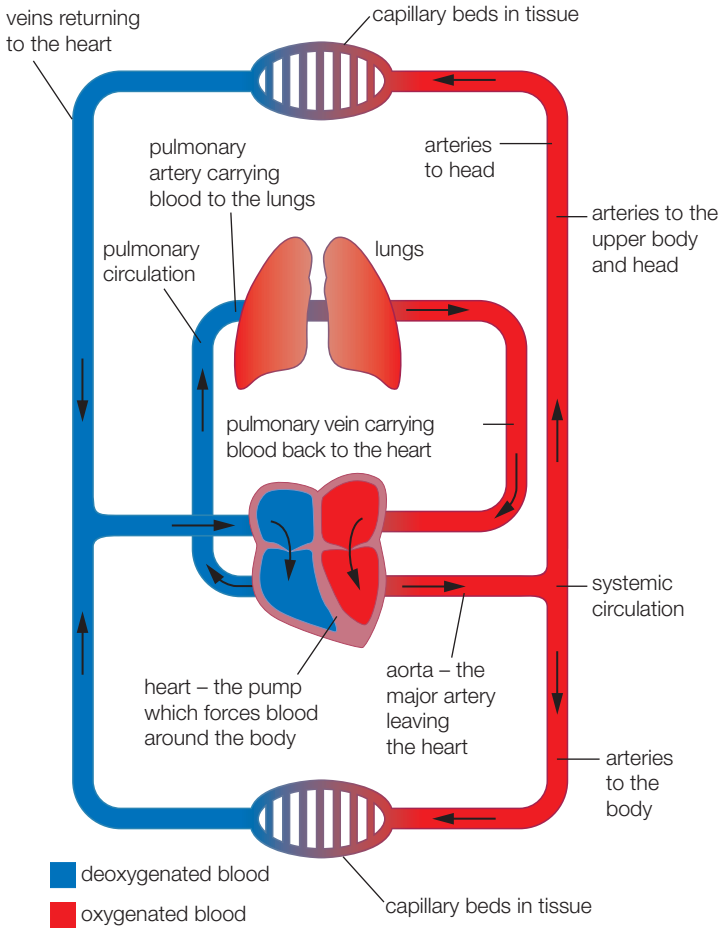


fig D A double circulation sends blood at high pressure, carrying lots of oxygen, to the active cells of the body. Take note: this is a schematic diagram. In a real double circulation, all of the blood vessels enter and leave from the top of the heart.

EXAM HINT

When you write about mass transport systems, make it clear that they are needed to overcome the limits of diffusion in organisms with a small surface area : volume ratio.

CHECKPOINT

SKILLS ADAPTIVE LEARNING

1. Explain why large animals cannot take in all the substances they need from outside the body through their skin.
2. What are the main characteristics of a mass transport system?
3. In fish, blood is supplied to the body tissues at low pressure. Why is low pressure sufficient in organisms such as fish?
4. Explain why a double circulation is ideal for an active animal that maintains its own body temperature independently of the environment.

SUBJECT VOCABULARY

diffusion the movement of the particles in a liquid or a gas down a concentration gradient from an area where they are at a relatively high concentration to an area where they are at a relatively low concentration

concentration gradient the change in the concentration of solutes present in a solution between two regions; in biology, this typically means across a cell membrane

surface area to volume ratio (sa : vol) the relationship between the surface area of an organism and its volume

vertebrates animals with a backbone or spinal column; they include mammals, birds, reptiles, amphibians and fish

mass transport system an arrangement of structures by which substances are transported in the flow of a fluid with a mechanism for moving it around the body

single circulation system a circulation in which the heart pumps the blood to the organs of gas exchange and the blood then travels on around the body before returning to the heart

double circulation system a circulation that involves two separate circuits, one of deoxygenated blood flowing from the heart to the gas exchange organs to be oxygenated before returning to the heart, and one of oxygenated blood leaving the heart and flowing around the body, returning as deoxygenated blood to the heart

systemic circulation carries oxygenated blood from the heart to the cells of the body where the oxygen is used, and carries the deoxygenated blood back to the heart

oxygenated blood blood that is carrying oxygen

deoxygenated blood blood that has given up its oxygen to the cells in the body

pulmonary circulation carries deoxygenated blood to the lungs and oxygenated blood back to the heart

1B 2 THE ROLES OF THE BLOOD

SPECIFICATION REFERENCE
1.9(i) 1.9(ii) 1.11

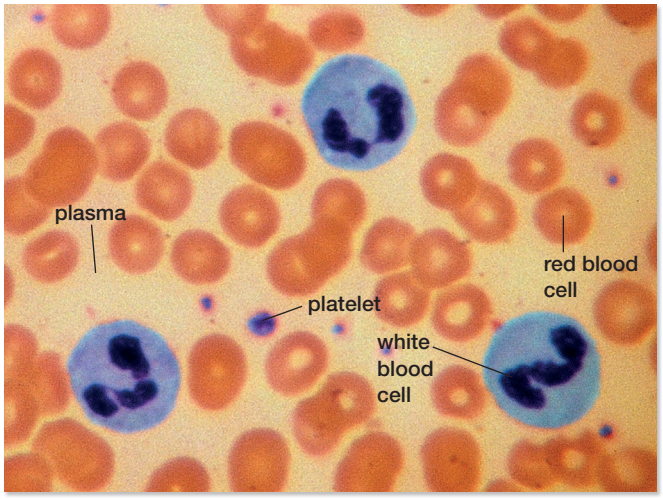
LEARNING OBJECTIVES

- Understand the role of haemoglobin in the transport of oxygen and carbon dioxide.
- Understand the oxygen dissociation curve of haemoglobin, the Bohr effect and the significance of the oxygen affinity of fetal haemoglobin compared with adult haemoglobin.
- Understand the blood clotting process.

In mammals, the mass transport system is the **cardiovascular system**. This is made up of a series of vessels with the heart as a pump to move blood through the vessels. The blood is the transport medium and its passage through the vessels is called the **circulation**. The system delivers the materials needed by the cells of the body, and carries away the waste products of their metabolism. Substances move between the plasma or red blood cells and the body cells by diffusion or by **active transport** (see **Section 2A.4**). The tiniest blood vessels have walls only one cell thick, so diffusion distances are short and substances pass easily across these into other cells. Every cell in the body is near one of these small vessels. The blood also carries out other functions, such as carrying hormones (chemical messages) from one part of the body to another, forming part of the defence system of the body and distributing heat.

THE COMPONENTS OF THE BLOOD AND THEIR MAIN FUNCTIONS

You are going to study all three parts of the cardiovascular system, starting with the transport medium – the blood. Your blood is a complex mixture carrying a wide variety of cells and substances to all areas of your body (see **fig A**).



▲ **fig A** This light micrograph shows red blood cells, white blood cells and platelets.

PLASMA

Your blood plasma is the fluid part of your mass transport system. Over 50% of your blood volume is plasma, and it carries all of your blood cells and everything else that needs transporting around your body. This includes:

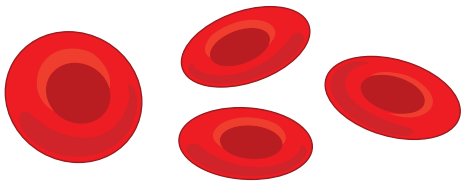
- digested food products (e.g. glucose and amino acids) from the small intestine to the liver and then to all the parts of the body where they are needed either for immediate use or storage
- nutrient molecules from storage areas to the cells that need them
- excretory products (e.g. carbon dioxide and urea) from cells to the organs such as the lungs or kidneys that excrete them from the body
- chemical messages (hormones) from where they are made to where they cause changes in the body.

The plasma helps to maintain a steady body temperature by transferring heat around the system from internal organs (e.g. the gut) or very active tissues (e.g. leg muscles in someone running) to the skin, where it can be lost to the surroundings. It also acts as a **buffer** to regulate pH changes.

ERYTHROCYTES (RED BLOOD CELLS)

There are approximately 5 million erythrocytes per mm^3 of blood (4–5 million per mm^3 in women, 5–6 million per mm^3 in men). They contain haemoglobin, a red pigment that carries oxygen and gives them their colour (see **Section 1A.5**). They are made in the bone marrow. Mature erythrocytes do not contain a nucleus and have a limited life of about 120 days.

The erythrocytes transport oxygen from the lungs to all the cells. They are well adapted for their function. The biconcave disc shape of the cells means that they have a large surface area to volume ratio, so oxygen can diffuse into and out of them rapidly (see **fig B**). Having no nucleus leaves much more space inside the cells for the haemoglobin molecules that carry the oxygen. In fact, each red blood cell contains around 250–300 million molecules of haemoglobin and can carry approximately 1000 million molecules of oxygen. Haemoglobin also carries some of the carbon dioxide produced in respiration back to the lungs. The rest is transported in the plasma.



▲ **fig B** Healthy red blood cells have a biconcave disc shape.

LEUCOCYTES (WHITE BLOOD CELLS)

Leucocytes or white blood cells are much larger than erythrocytes, but can also squeeze through tiny blood vessels because they can change their shape. There are around 4000–11 000 per mm^3 of blood and there are several different types. They are made in the bone marrow, although some mature in the thymus gland. Their main function is to defend the body against infection. Leucocytes are also very important in the inflammatory response of the body when an area of tissue is damaged. They all contain a nucleus and have colourless cytoplasm, although some types contain granules which can be stained. There are several different types of leucocyte, which you will study further in **Book 2 Chapter 6B**.

PLATELETS

Platelets are tiny fragments of large cells called **megakaryocytes**, which are found in the bone marrow. There are about 150 000–400 000 platelets per mm^3 of blood. They are involved in blood clotting (see **page 35**).

TRANSPORT OF OXYGEN

The many haemoglobin molecules that are in the red blood cells transport oxygen. Each haemoglobin molecule is a large globular protein consisting of four peptide chains, each with an iron-containing prosthetic group. Each group can collect four molecules of oxygen in a reversible process to form **oxyhaemoglobin**:

$$Hb + 4O_2 \rightleftharpoons Hb.4O_2$$

haemoglobin + oxygen ⇌ oxyhaemoglobin

The first oxygen molecule that binds to the haemoglobin changes the arrangement of the molecule making it easier for the following oxygen molecules to bind. The final oxygen molecule binds several hundred times faster than the first. The same process happens in reverse when oxygen dissociates from haemoglobin – it gets progressively harder to remove the oxygen.

EXAM HINT

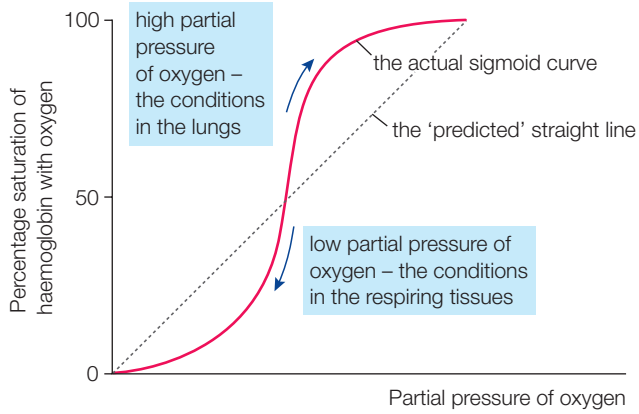
Always use suitable scientific terms. This is important because it can help to focus a response clearly.

When the blood enters the lungs, the concentration of oxygen in the red blood cells is relatively low. Oxygen moves into the red blood cells from the air in the lungs by diffusion. The oxygen is collected and bound to the haemoglobin, so the free oxygen concentration in the cytoplasm of the red blood cells stays low. This maintains a steep concentration gradient from the air in the lungs to the red blood cells, so more and more oxygen diffuses in and joins onto the haemoglobin.

The oxygen levels are relatively low in the body tissues. The concentration of oxygen in the cytoplasm of the red blood cells is higher than in the surrounding tissue. As a result, oxygen moves out into the body cells by diffusion down its concentration gradient. The haemoglobin molecules give up some of their oxygen. When you are at rest or exercising gently, only about 25% of the oxygen carried by the haemoglobin is released into your cells. There is another 75% in reserve in the transport system for when you are very active.

The strong affinity of haemoglobin for oxygen means that a small change in the proportion of oxygen in the surrounding environment can have a big effect on the saturation of the blood with oxygen. So in the lungs, the haemoglobin rapidly gains oxygen and in the tissues, as the oxygen saturation of the environment falls, oxygen is released rapidly (see **fig C**).

As deoxygenated blood approaches the lungs, the steep part of the curve means that a *small* increase in partial pressure causes a *large* increase in % saturation.



As oxygenated blood approaches the tissues, a *small* decrease in partial pressure causes a *large* decrease in % saturation (i.e. a large release of oxygen).

▲ **fig C** Oxygen dissociation curve for human haemoglobin

TRANSPORT OF CARBON DIOXIDE

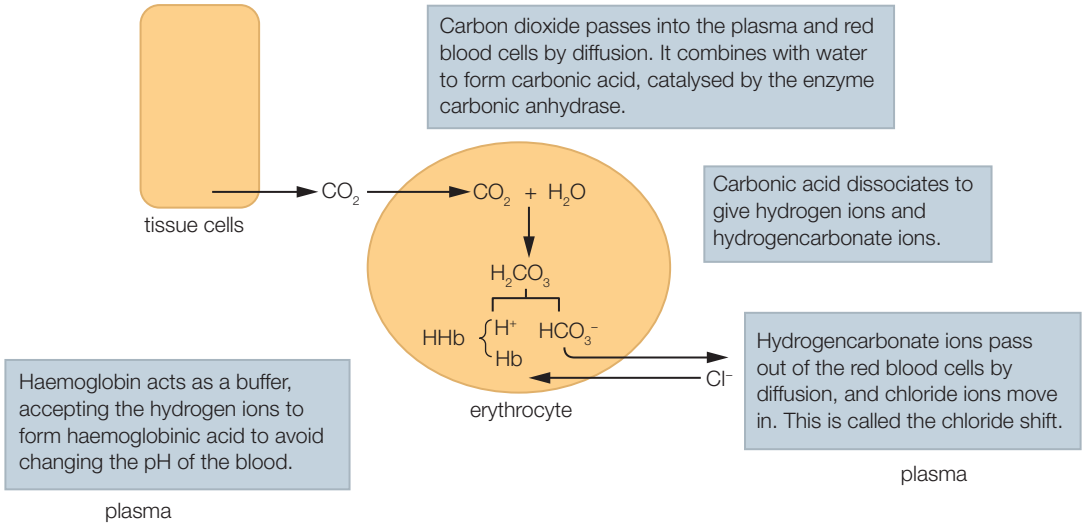
Waste carbon dioxide diffuses from the respiring cells of the body tissues into the blood along a concentration gradient. The reaction of the carbon dioxide with water is crucial. When carbon dioxide is dissolved in the blood it reacts slowly with the water to form carbonic acid, H_2CO_3. The carbonic acid separates to form hydrogen ions H^+ and hydrogencarbonate ions HCO_3^-:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

About 5% of the carbon dioxide is carried in solution in the plasma. A further 10–20% combines with haemoglobin molecules to make **carbaminohaemoglobin**. Most of the carbon dioxide is transported in the cytoplasm of the red blood cells as hydrogencarbonate ions. The enzyme **carbonic anhydrase** controls the rate of the reaction between carbon dioxide and water to produce carbonic acid.

In the body tissues, there is a high concentration of carbon dioxide in the blood, so carbonic anhydrase catalyses the formation of carbonic acid.

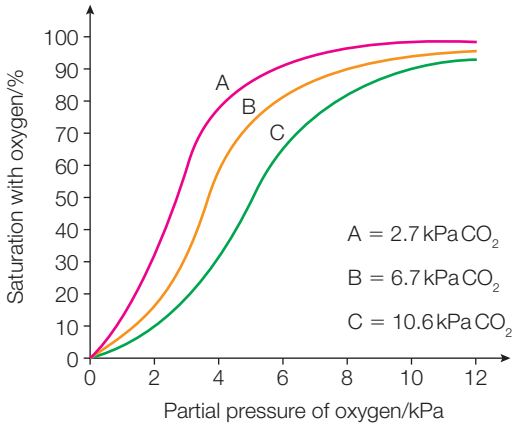
In the lungs, the carbon dioxide concentration is low, so carbonic anhydrase catalyses the reverse reaction and free carbon dioxide diffuses out of the blood and into the lungs (see **fig D**).



▲ **fig D** The transport of carbon dioxide from the tissues to the lungs depends on the reaction of carbon dioxide with water, controlled by an enzyme in the red blood cells.

THE BOHR EFFECT

The way in which haemoglobin collects and releases oxygen is also affected by the proportion of carbon dioxide in the tissues (see **fig E**). When the proportion of carbon dioxide in the tissues is high, the affinity of haemoglobin for oxygen is reduced. In other words, haemoglobin needs higher levels of oxygen to become saturated and releases oxygen much more easily. So in active tissues with high carbon dioxide levels, haemoglobin releases oxygen more readily. Carbon dioxide levels in the lung capillaries are relatively low, which makes it easier for oxygen to bind to the haemoglobin. The changes in the oxygen dissociation curve that result as the carbon dioxide level changes are known as the **Bohr effect**.



▲ **fig E** As the proportion of carbon dioxide in the environment rises, the haemoglobin curve moves down and to the right, so it gives up oxygen more easily. This is known as the Bohr effect.

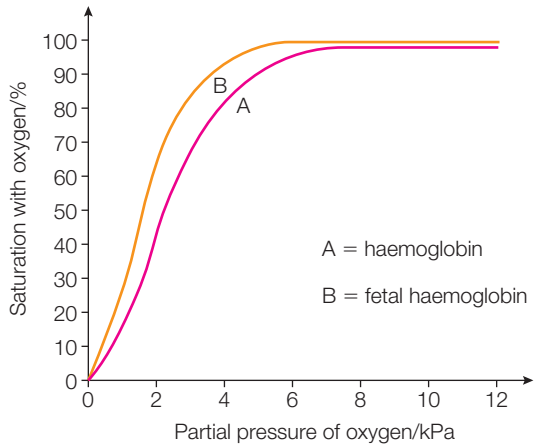
LEARNING TIP

Remember that as CO_2 builds up it affects the pH and this has an effect on the protein structure, so haemoglobin does not work as well (i.e. it has a lower affinity for oxygen).

FETAL HAEMOGLOBIN

A fetus in the uterus depends on its mother to supply it with oxygen. Oxygenated blood from the mother flows through the placenta close to the deoxygenated fetal blood. If the blood of the fetus had the same affinity for oxygen as the blood of the mother, very little oxygen would be transferred. Fortunately, the blood of the fetus contains a special form of the oxygen-carrying pigment called **fetal haemoglobin**. Fetal haemoglobin has a higher affinity for oxygen than the adult haemoglobin of the mother. Consequently, the fetal haemoglobin can remove oxygen from the maternal blood even when the proportion of oxygen is relatively low (see **fig F**). The maternal and fetal blood also run in

opposite directions. This makes the oxygen concentration gradient between the mother's blood and that of her fetus as steep as possible, maximising the oxygen transfer to the blood of the fetus.



▲ **fig F** Fetal haemoglobin has a higher affinity for oxygen than the adult haemoglobin of the mother, so it can take oxygen from the mother's blood and deliver it to the cells of the growing fetus.

EXAM HINT

Be precise with your descriptions e.g. fetal *haemoglobin* has a higher affinity for oxygen than maternal haemoglobin – it is not the fetus or the blood that has a higher affinity.

DID YOU KNOW?

Down into the depths!

Elephant seals can dive to depths of almost 2 km and stay underwater for up to 2 hours, swimming and hunting, although most do not dive so deep or for so long (see **fig G**). While underwater, the seals cannot breathe but they have three adaptations of the blood that allow them to stay underwater for a long time.

- They have up to twice the blood volume of a land mammal of the same size, with extra spaces in their circulatory system to store oxygenated blood.
- They have more erythrocytes per unit of blood than land mammals, and scientists think the erythrocytes also contain more haemoglobin. As a result, they have up to three times as much haemoglobin as a land mammal of a similar size.
- They have over 10 times more myoglobin in their muscles than humans. Myoglobin is another pigment with an affinity for oxygen which is higher than either haemoglobin or fetal haemoglobin. In elephant seals, the myoglobin is so dense their muscles look almost black.

These adaptations mean that elephant seals have an enormous oxygen store in their bodies when they dive, which helps to explain why they are such masters of the underwater world.

▲ **fig G** Elephant seal underwater

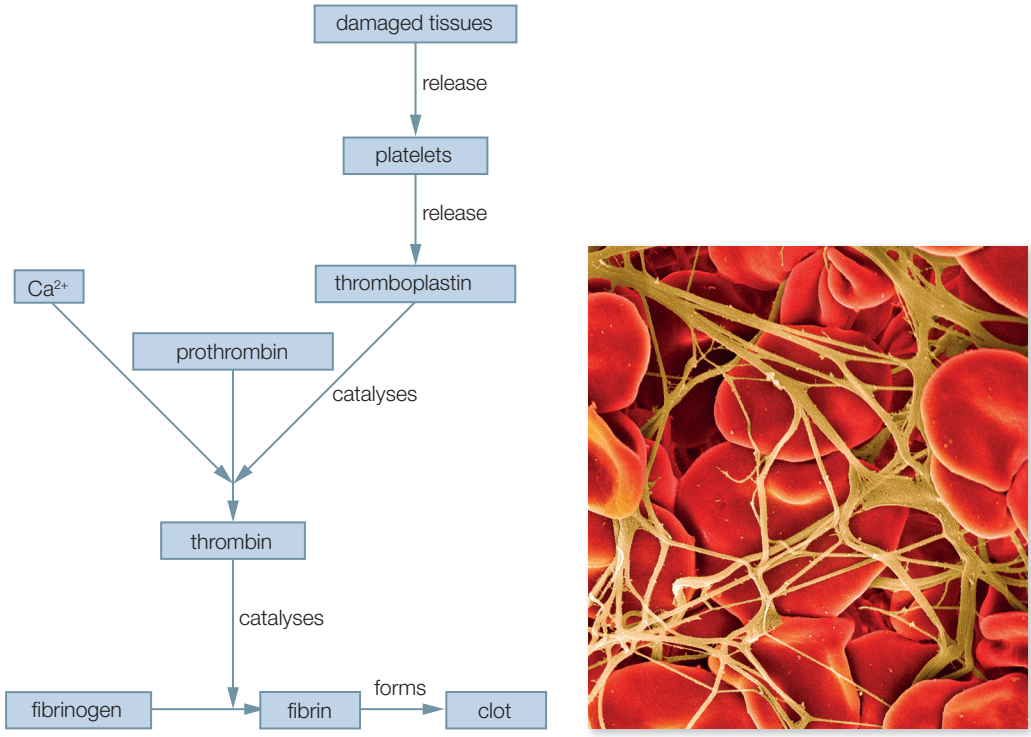
THE CLOTTING OF THE BLOOD

You have a limited volume of blood. In theory, a minor cut could endanger life as the torn blood vessels allow blood to escape. First, your blood volume will reduce and if you lose too much blood, you will die. Second, pathogens can get into your body through an open wound. In normal circumstances, your body protects you through the clotting mechanism of the blood. This mechanism seals damaged blood vessels to minimise blood loss and prevent pathogens getting in.

FORMING A CLOT

Plasma, blood cells and platelets flow from a cut vessel. Contact between the platelets and components of the tissue (e.g. collagen fibres in the skin) causes the platelets to break open in large numbers. They release several substances, two of which are particularly important.

- **Serotonin** causes the smooth muscle of the blood vessel to contract. This narrows the blood vessels, cutting off the blood flow to the damaged area.
- **Thromboplastin** is an enzyme that starts a sequence of chemical changes that clot the blood (see **fig H**).



▲ **fig H** The cascade of events that results in a life-saving or life-threatening clot. When you cut yourself, this is the process which seals the blood vessels and protects the delicate new tissues that form underneath.

THE BLOOD CLOTTING PROCESS

The blood clotting process is a very complex sequence of events in which there are many different clotting factors. Vitamin K is important in the production of many of the compounds needed for the blood to clot, including prothrombin. Here is a simple version of the events in the blood clotting process.

1 Thromboplastin catalyses the conversion of a large soluble protein called **prothrombin** found in the plasma into another soluble protein, the enzyme called **thrombin**. Prothrombin is biologically inactive while thrombin is biologically active – prothrombin is a **precursor** of thrombin. This conversion happens on a large scale at the site of a wound. Calcium ions need to be present in the blood at the right concentration for this reaction to happen.

2 Thrombin acts on another soluble plasma protein called **fibrinogen**, converting it to an insoluble substance called **fibrin**. Again, fibrinogen is the biologically inactive precursor of biologically active fibrin. The fibrin forms a mesh of fibres to cover the wound.

LEARNING TIP

Remember that '*pro*' means before. Prothrombin is a precursor that will form an active molecule.

3 More platelets and red blood cells pouring from the wound get trapped in the fibrin mesh. This forms a clot.

4 Special proteins in the structure of the platelets contract, making the clot tighter and tougher to form a scab that protects the skin and vessels underneath as they heal.

In a sequence such as clot formation, a small event is amplified through a series of steps. However, sometimes the body's clotting mechanism is started in the wrong place, and this can lead to serious problems in the blood vessels. A clot in the vessels that supply your heart muscle with blood can cause a heart attack and a clot in the brain can cause a stroke (see **Section 1B.5**).

CHECKPOINT

SKILLS CRITICAL THINKING

1. Red blood cells are unusual because they do not have a nucleus. Explain how this is an adaptation for their role in carrying oxygen, and why they have a limited life.
2. Describe how oxygen is transported in the blood.
3. Explain why fetal haemoglobin needs to have a higher affinity for oxygen than adult haemoglobin.
4. Prothrombin and fibrinogen are both precursors. Discuss the similarities and differences between these two proteins.
5. There is a rare condition in babies that causes excessive internal bleeding, which can cause brain damage and even death. Newborn babies in most countries in the world are routinely given vitamin K either by injection or orally. Suggest how these two facts might be linked.

SUBJECT VOCABULARY

cardiovascular system the mass transport system of the body made up of a series of vessels with a pump (the heart) to move blood through the vessels
circulation the passage of blood through the blood vessels
active transport the movement of substances into or out of the cell using ATP produced during cellular respiration
buffer a solution which resists changes in pH
leucocytes white blood cells; there are several different types which play important roles in defending the body against the entry of pathogens and in the immune system
platelets cell fragments involved in the clotting mechanism of the blood
megakaryocytes large cells that are found in the bone marrow and produce platelets
oxyhaemoglobin the molecule formed when oxygen binds to haemoglobin
carbaminohaemoglobin the molecule formed when carbon dioxide combines with haemoglobin
carbonic anhydrase the enzyme that controls the rate of the reaction between carbon dioxide and water to produce carbonic acid
Bohr effect the name given to changes in the oxygen dissociation curve of haemoglobin that occur due to a rise in carbon dioxide levels and a reduction of the affinity of haemoglobin for oxygen
fetal haemoglobin a form of haemoglobin found only in the developing fetus with a higher affinity for oxygen than adult haemoglobin
serotonin a chemical that causes the smooth muscle of the blood vessels to contract, narrowing them and cutting off the blood flow to the damaged area
thromboplastin an enzyme that sets in progress a cascade of events that leads to the formation of a blood clot
prothrombin a large, soluble protein found in the plasma that is the precursor to an enzyme called thrombin
thrombin an enzyme that acts on fibrinogen, converting it to fibrin during clot formation
precursor a biologically inactive molecule which can be converted into a closely related biologically active molecule when needed
fibrinogen a soluble plasma protein which is the precursor of the insoluble protein fibrin
fibrin an insoluble protein formed from fibrinogen by the action of thrombin that forms a mesh of fibres that trap erythrocytes and platelets to form a blood clot

1B 3 CIRCULATION IN THE BLOOD VESSELS

SPECIFICATION REFERENCE 1.7

LEARNING OBJECTIVES

- Understand how the structures of blood vessels (arteries, veins and capillaries) relate to their functions.

THE BLOOD VESSELS

The blood vessels that make up the circulatory system can be thought of as the biological equivalent of a road transport system. The **arteries** and **veins** are like the large roads carrying heavy traffic while the narrow town streets and tracks are represented by the vast area of branching and spreading **capillaries** called the capillary network. In the capillary network, substances carried by the blood are exchanged with cells in the same way that products are transported from factories, oil refineries or farms and distributed into shops and homes. The structures of the different types of blood vessel closely reflect their functions in your body.

ARTERIES

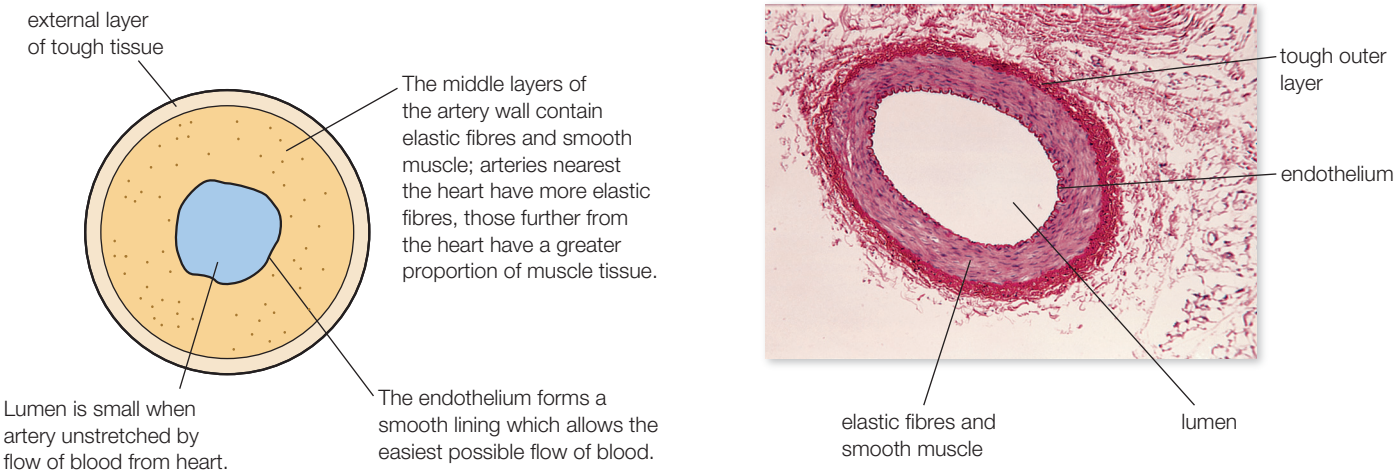
Arteries carry blood away from your heart towards the cells of your body. The structure of an artery is shown in **fig A**. Almost all arteries carry oxygenated blood. The exceptions are:

- the pulmonary artery – carrying deoxygenated blood from the heart to the lungs
- the umbilical artery – during pregnancy, this carries deoxygenated blood from the fetus to the placenta.

The arteries leaving the heart branch off in every direction, and the diameter of the **lumen**, the central space inside the blood vessel, gets smaller the further away it is from the heart. The very smallest branches of the **arterial system**, furthest from the heart, are the **arterioles**.

LEARNING TIP

Remember that all arteries carry blood away from the heart, so they have thick walls and lots of collagen to withstand the high pressure.



▲ **fig A** The structure of an artery means it is adapted to cope with the surging of the blood as the heart pumps.

Blood is pumped out from the heart in a regular rhythm, about 70 times a minute. Each heartbeat sends a high-pressure flow of blood into the arteries. The major arteries close to the heart must withstand these pressure surges. Their walls contain a lot of elastic fibres, so they can stretch to accommodate the greater volume of blood without being damaged (see **fig B**). Between surges, the elastic fibres return to their original length, squeezing the blood to move it along in a continuous flow. The pulse you can feel in an artery is the effect of the surge each time the heart beats. The blood pressure in all arteries is relatively high, but it falls in arteries further away from the heart. These are known as the **peripheral arteries**.

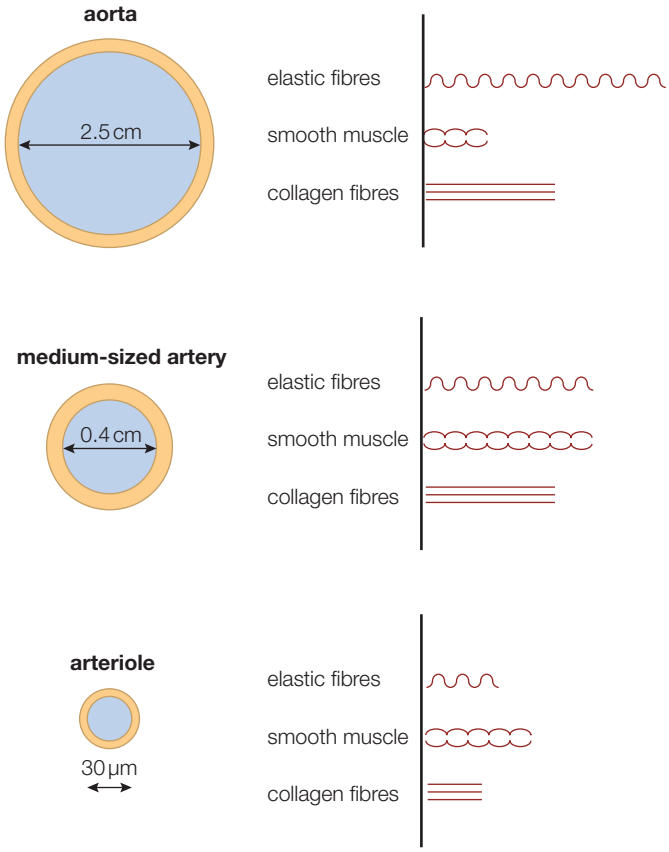
EXAM HINT

You will study the structure and the function of the types of blood vessel separately. However, you should remember that the vessels do not exist separately – they are all interlinked within the whole circulatory system.

EXAM HINT

The role of the elastic fibres in artery walls is to return to their original length to help maintain the pressure. This is called recoil. The elastic recoil does not help to increase pressure, it simply helps to maintain the pressure – so do not suggest that the recoil helps pump blood along.

In the peripheral arteries, the muscle fibres in the vessel walls contract or relax to change the size of the lumen, controlling the blood flow. The smaller the lumen, the harder it is for blood to flow through the vessel. This controls the amount of blood that flows into an organ, so regulating its activity. You will find out more about this important response in **Book 2 Topic 7**.



▲ **fig B** The relative proportions of different tissues in different arteries. Collagen gives general strength and flexibility to both arteries and veins.

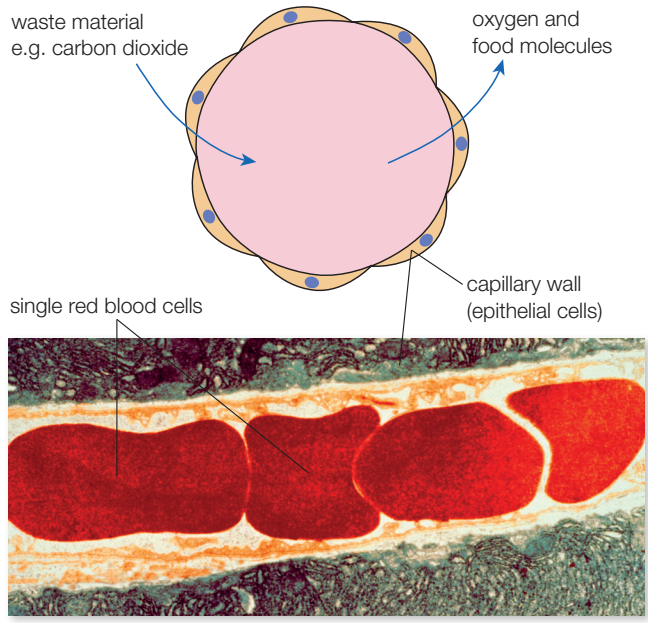
LEARNING TIP

The role of the muscles in the wall of the arterioles is to reduce the size of the lumen to increase resistance – this can reduce blood flow to areas that do not need so much blood and will cause the oxygenated blood to flow to other tissues. Remember to link this to things you may learn later such as how blood flow to the skin changes when you are too hot or too cold.

CAPILLARIES

Arterioles lead into networks of capillaries. These are very small vessels that spread throughout the tissues of the body. The capillary network links the arterioles and the **venules**. Capillaries branch between cells – no cell is far from a capillary, so substances can diffuse between cells and the blood quickly. Also, because the diameter of each individual capillary is small, the blood travels relatively slowly through them, giving more opportunity for diffusion to occur (see **fig C**). The smallest capillary is no wider than a single red blood cell.

Capillaries have a very simple structure which is well adapted to their function. Their walls are very thin and contain no elastic fibres, smooth muscle or collagen. This helps them fit between individual cells and allows rapid diffusion of substances between the blood and the cells. The walls consist of just one very thin cell. Oxygen and other molecules, such as digested food molecules and hormones, quickly diffuse out of the blood in the capillaries into the nearby body cells, and carbon dioxide and other waste molecules diffuse into the capillaries. Blood entering the capillary network from the arteries is oxygenated. When it leaves, it carries less oxygen and more carbon dioxide.



▲ **fig C** The very thin walls of capillaries allow rapid diffusion of oxygen, carbon dioxide and digested food molecules. The lumen is just wide enough for red blood cells to pass through.

VEINS

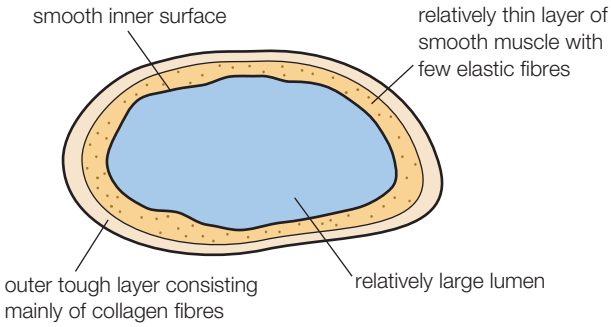
Veins carry blood back towards the heart. Most veins carry deoxygenated blood. The exceptions are:

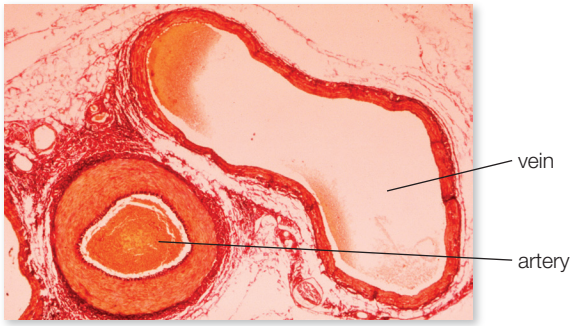
- the pulmonary vein – carrying oxygen-rich blood from the lungs back to the heart for circulation around the body
- the umbilical vein – during pregnancy, it carries oxygenated blood from the placenta into the fetus.

Tiny venules lead from the capillary network, combining into larger and larger vessels going back to the heart (see **fig D**).

LEARNING TIP

Remember that all veins carry blood back to the heart so they have low pressure and do not need a thick wall.





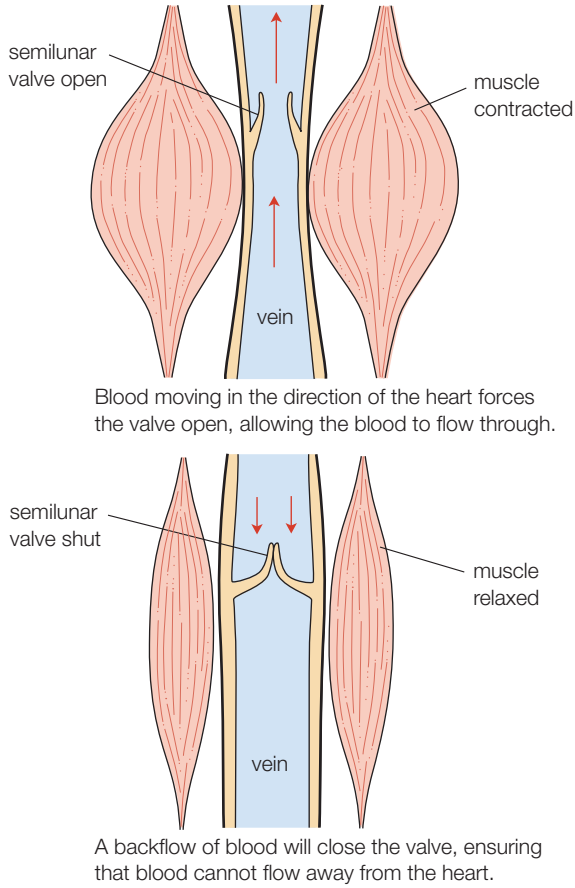
▲ **fig D** The arrangement of tissues in a vein reflects the pressure of blood in the vessel.

Eventually only two veins (sometimes called the great veins) carry the blood from the body tissues back to the heart – the **inferior vena cava** from the lower parts of the body and the **superior vena cava** from the upper parts of the body.

Veins can hold a large volume of blood – in fact more than half of the body's blood volume is in the veins at any one time. They act as a blood reservoir. The blood pressure in the veins is relatively low – the pressure surges from the heart are eliminated before the blood reaches the capillary system. This blood at low pressure must be returned to the heart and lungs to be oxygenated again and recirculated.

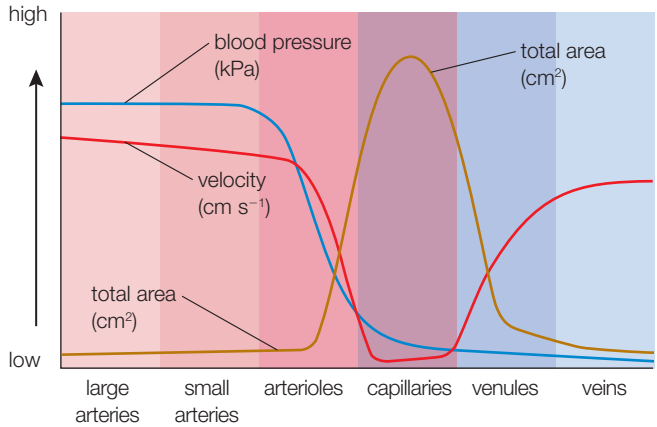
The blood is not pumped back to the heart, it returns to the heart by means of muscle pressure and one-way valves.

- Many of the larger veins are situated between the large muscle blocks of the body, particularly in the arms and legs. When the muscles contract during physical activity they squeeze these veins. The valves (see below) keep the blood travelling in one direction and this squeezing helps to return the blood to the heart.
- There are one-way valves at frequent intervals throughout the **venous system**. These are called **semilunar valves** because of their half-moon shape. They develop from infoldings of the inner wall of the vein. Blood can pass through towards the heart, but if it starts to flow backwards the valves close, preventing any backflow (see **fig E**).



▲ **fig E** Valves in the veins make sure blood only flows in one direction – towards the heart. The contraction of large muscles encourages blood flow through the veins.

The main types of blood vessel – the arteries, veins and capillaries – have very different characteristics. These affect the way the blood flows through the body, and what the vessels do in the body. Some of these differences are summarised in **fig F**.



▲ **fig F** Graph to show the surface area of each major type of blood vessel in your body, along with the velocity and pressure of the blood travelling in them.

CHECKPOINT

1. Why are valves important in veins but unnecessary in arteries?
2. Compare the main structures of arteries, veins and capillaries to their functions.
3. SKILLS ANALYSIS Look at the graph in **fig F**. Explain carefully what the different lines on the graph show you. How is this information linked to the functions of the different regions of the circulatory system?

SUBJECT VOCABULARY

arteries vessels that carry blood away from the heart
veins vessels that carry blood towards the heart
capillaries tiny vessels that spread throughout the tissues of the body
lumen the central space inside the blood vessel
arterial system the system of arteries in the body
arterioles the very smallest branches of the arterial system, furthest from the heart
peripheral arteries arteries further away from the heart but before the arterioles
venules the very smallest branches of the venous system, furthest from the heart
inferior vena cava the large vein that carries the returning blood from the lower parts of the body to the heart
superior vena cava the large vein that carries the returning blood from the upper parts of the body to the heart
venous system the system of veins in the body
semilunar valves half-moon shaped, one-way valves found at frequent intervals in veins to prevent the backflow of blood

1B 4 THE MAMMALIAN HEART

SPECIFICATION REFERENCE 1.8

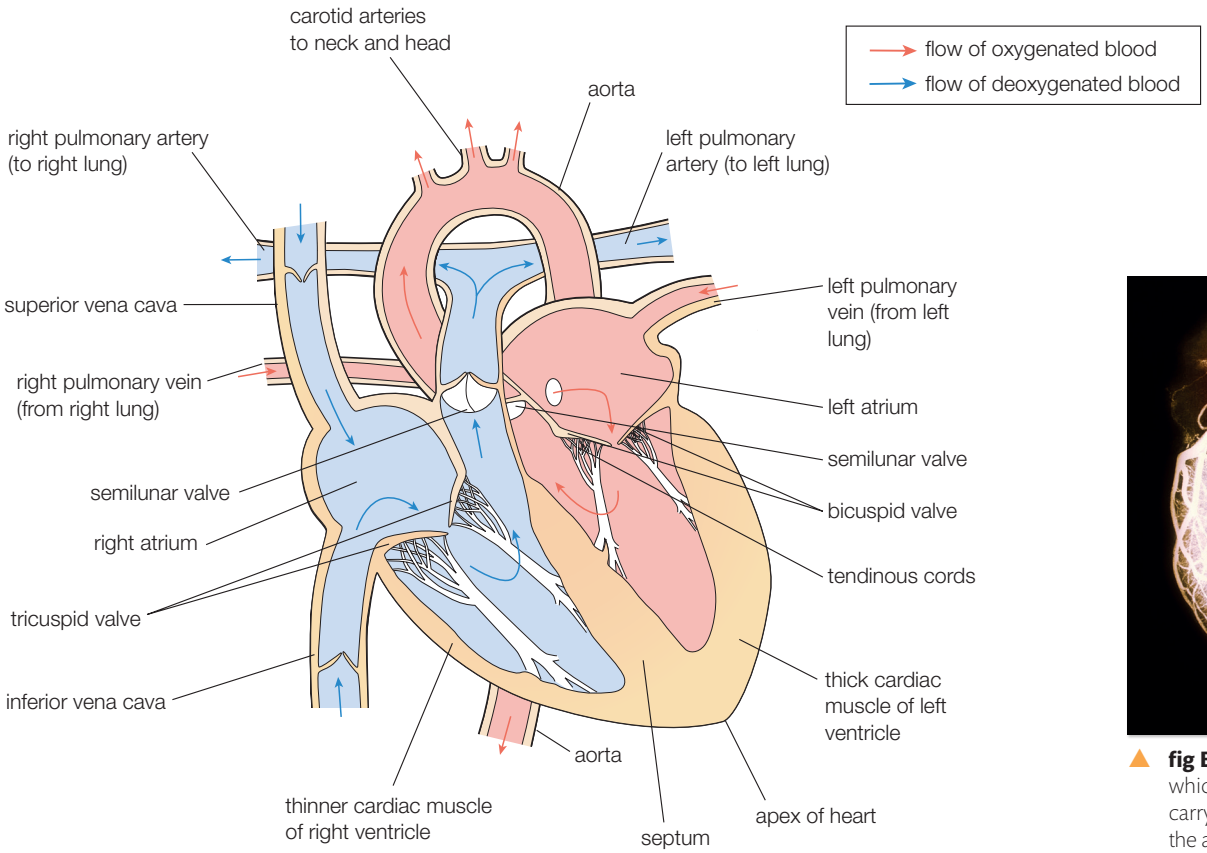
LEARNING OBJECTIVES

- Relate the structure and operation of the mammalian heart, including the major blood vessels, to its function.
- Know the cardiac cycle.

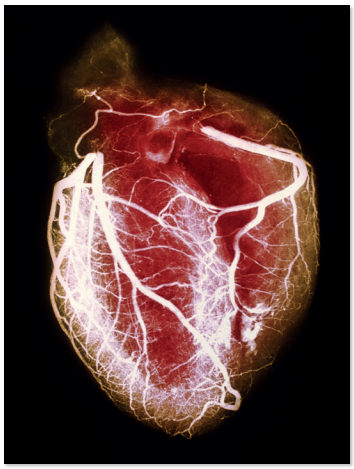
In most animal transport systems, the heart is the organ that moves the blood around the body. In mammals, the heart is a complex, four-chambered muscular organ that sits in the chest protected by the ribs and sternum. In an average lifetime, the heart beats about 3 000 000 000 (3×10^9) times and will pump over 200 million litres of blood – quite a workload.

THE STRUCTURE OF THE HEART

The human heart, like other mammalian hearts (see **fig A**), is not a single muscular pump but two pumps, joined and working in time together. The right side of the heart receives blood from the body and pumps it to the lungs. The left side of the heart receives blood from the lungs and pumps it to the body. The blood in each side of the heart does not mix with the blood from the other side. The two sides are separated by a thick, muscular **septum**. The heart is made of a unique type of muscle, known as **cardiac muscle**, which has special properties – it can carry on contracting regularly without resting or getting fatigued. You will study this in more detail in **Book 2 Topic 7**. Cardiac muscle has a good blood supply – the coronary arteries bring oxygenated blood to the tissue (see **fig B**). It also contains lots of **myoglobin**, a respiratory pigment which has a stronger affinity for oxygen than haemoglobin. This myoglobin stores oxygen for the respiration needed to keep the heart contracting regularly.



▲ **fig A** The structure of the human heart



▲ **fig B** The coronary arteries, which you can clearly see here, carry oxygenated blood from the aorta to the heart muscle, providing it with oxygen and digested food and removing carbon dioxide.

THE ACTION OF THE HEART

EXAM HINT

When describing the action of the heart, remember that blood flows through both sides at the same time. Make it clear that both atria pump at the same time and both ventricles pump at the same time.

1 The inferior vena cava collects deoxygenated blood from the lower parts of the body, while the superior vena cava receives deoxygenated blood from the head, neck, arms and chest. Deoxygenated blood is delivered to the **right atrium**.

2 The right atrium receives the blood from the great veins. As it fills with blood, the pressure builds up and opens the tricuspid valve, so the **right ventricle** starts to fill with blood too. When the atrium is full it contracts, forcing more blood into the ventricle. The atrium has thin muscular walls because it receives blood at low pressure from the inferior vena cava and the superior vena cava and it needs to exert relatively little pressure to move the blood into the ventricle. One-way semilunar valves (like the valves in veins described in **Section 1B.3**) at the entrance to the atrium stop a backflow of blood into the veins.

3 The **tricuspid valve** consists of three flaps and is also known as an **atrioventricular valve** because it separates an atrium from a ventricle. The valve allows blood to pass from the atrium to the ventricle, but not in the other direction. The tough **tendinous cords**, also known as valve tendons or heartstrings, make sure the valves are not turned inside out by the pressure exerted when the ventricles contract.

4 The right ventricle is filled with blood under some pressure when the right atrium contracts, then the ventricle contracts. Its muscular walls produce the pressure needed to force blood out of the heart into the **pulmonary arteries**. These carry the deoxygenated blood to the capillaries in the lungs. As the ventricle starts to contract, the tricuspid valve closes to prevent blood flowing into the atrium. Semilunar valves, like those in veins, prevent the blood flowing back from the arteries into the ventricle.

5 The blood returns from the lungs to the left side of the heart in the **pulmonary veins**. The blood is at relatively low pressure after passing through the extensive capillaries of the lungs. The blood returns to the **left atrium**, another thin-walled chamber that performs the same function as the right atrium. It contracts to force blood into the **left ventricle**. Backflow is prevented by another atrioventricular valve known as the **bicuspid valve**, which has only two flaps.

6 As the left atrium contracts, the bicuspid valve opens and the left ventricle is filled with blood under pressure. As the left ventricle starts to contract the bicuspid valve closes to prevent backflow of blood to the left atrium. The left ventricle pumps the blood out of the heart and into the **aorta**, the major artery of the body. This carries blood away from the heart at even higher pressure than the major arteries that branch off from it.

The muscular wall of the left side of the heart is much thicker than that of the right. The right side pumps blood to the lungs, which are relatively close to the heart. The delicate capillaries of the lungs need blood delivered at relatively low pressure. The left side must produce sufficient force to move the blood under pressure to all the extremities of the body and overcome the elastic recoil of the arteries. Semilunar valves prevent the blood flowing back from the aorta into the ventricle.

LEARNING TIP

Remember that the valves do not operate on their own. They open and close as blood pressure changes in the chambers on either side of the valve. When the pressure is higher on one side it will push the valve open. When it is higher on the other side, it will close the valve.

The septum is a thick wall of muscle and connective tissue between the two sides of the heart. It prevents the oxygenated blood mixing with the deoxygenated blood.

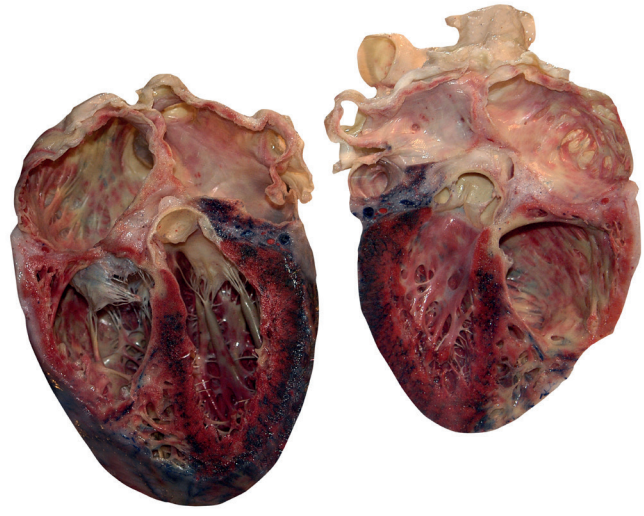
DID YOU KNOW?

In an embryo, there is a gap in the septum called the *foramen ovale* and the blood from the two sides of the heart can mix. This does not matter because the lungs of the fetus do not function and little blood flows to them. At birth, this hole closes over as the lungs begin to function. If it does not, the baby has a condition called patent *foramen ovale* or 'hole in the heart'. This may be so small it does not really matter. If it is large, it must be closed by surgery.

DID YOU KNOW?

Inside the heart

The diagrams we use of the inside of a mammalian heart make it look very clean and simple (see **fig A**). But when you dissect the heart of a mammal such as a sheep or a cow, you can see that it is much more complicated. Cutting open a heart and exploring the connections between the blood vessels and the chambers of the heart, and seeing the structure of the valves, helps you understand how it works as a three-dimensional pump (see **fig C**).



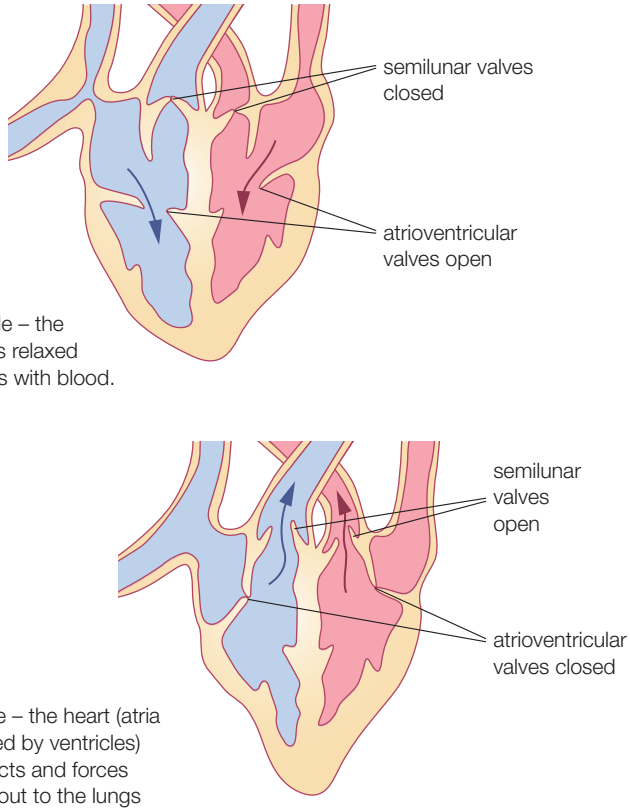
▲ **fig C** A dissected mammalian heart

HOW YOUR HEART WORKS

The beating of your heart produces the sounds that are your heartbeat. The sounds are not made by the contracting of the heart muscle but by the heart valves closing. The two sounds of a heartbeat are often described as 'lub-dub'. The first sound ('lub') comes when the ventricles contract and the blood is forced against the atrioventricular valves. The second sound ('dub') comes when the ventricles relax and a backflow of blood hits the semilunar valves in the pulmonary artery and aorta. The rate of your heartbeat shows how frequently your heart is contracting.

THE CARDIAC CYCLE

Your heart is continuously contracting then relaxing. The contraction of the heart is called **systole**. Systole can be divided into **atrial systole**, when the atria contract together forcing blood into the ventricles, and **ventricular systole**, when the ventricles contract. Ventricular systole happens about 0.13 seconds after atrial systole, and forces blood out of the ventricles into the pulmonary artery and the aorta. Between contractions the heart relaxes and fills with blood. This relaxation stage is called **diastole**. One cycle of systole and diastole makes up a single heartbeat, which lasts about 0.8 seconds in humans. This is known as the **cardiac cycle** (see **fig D**). You will learn more about how the rate of the heartbeat is controlled in **Book 2 Topic 7**.



▲ **fig D** The cardiac cycle

CHECKPOINT

1. Describe the path of blood around the human body, identifying at which points the blood is oxygenated and where it is deoxygenated. Explain how this system efficiently supplies cells with the oxygen they need.
2. Discuss the relationship between structure and function for these parts of the heart:
   (a) semilunar valves
   (b) atria
   (c) ventricles including the thickness of the muscle walls
   (d) tendinous cords.

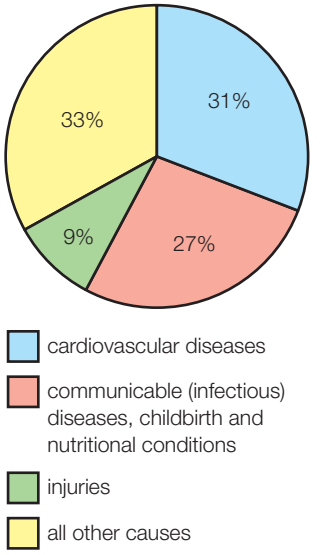
SUBJECT VOCABULARY

septum the thick muscular dividing wall through the centre of the heart that prevents oxygenated and deoxygenated blood from mixing
cardiac muscle the special muscle tissue of the heart, which has an intrinsic rhythm and does not fatigue
myoglobin a respiratory pigment with a stronger affinity for oxygen than haemoglobin.
right atrium the upper right-hand chamber of the heart that receives deoxygenated blood from the body
right ventricle the lower chamber that receives deoxygenated blood from the right atrium and pumps it to the lungs
tricuspid valve (atrioventricular valve) the valve between the right atrium and the right ventricle that prevents backflow of blood from the ventricle to the atrium when the ventricle contracts
tendinous cords (valve tendons, heartstrings) cord-like tendons thatmake sure the valves are not turned inside out by the large pressure exerted when the ventricles contract
pulmonary arteries the blood vessels that carry deoxygenated blood from the heart to the lungs
pulmonary veins the blood vessels that carry oxygenated blood back from the lungs to the heart
left atrium the upper left-hand chamber of the heart that receives oxygenated blood from the lungs
left ventricle the chamber that receives oxygenated blood from the left atrium and pumps it around the body
bicuspid valve (atrioventricular valve) the valve between the left atrium and the left ventricle that prevents backflow of blood into the atrium when the ventricle contracts
aorta the main artery of the body; it leaves the left ventricle of the heart carrying oxygenated blood under high pressure
systole the contraction of the heart
atrial systole when the atria of the heart contract
ventricular systole when the ventricles of the heart contract
diastole when the heart relaxes and fills with blood
cardiac cycle the cycle of contraction (systole) and relaxation (diastole) in the heart

SPECIFICATION REFERENCE
1.10 1.11

LEARNING OBJECTIVES

- Understand the course of events that lead to atherosclerosis.



▲ **fig A** This WHO data from 2017 shows cardiovascular disease is the biggest single cause of death around the world.

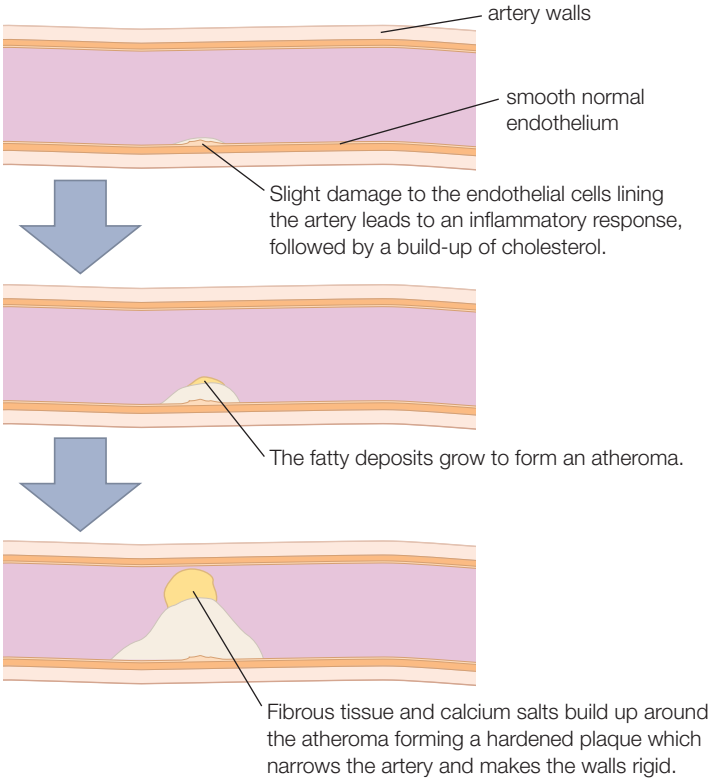
CARDIOVASCULAR DISEASES

Problems with the cardiovascular system have serious consequences. Globally, almost 18 million people die from cardiovascular diseases each year. World Health Organization (WHO) data from 2017 show that **cardiovascular diseases** were responsible for 31% of all global deaths – it is the single biggest cause of death and disability (see **fig A**). What is more, around a third of these deaths were in people younger than 70.

Many cardiovascular diseases are linked to a condition called **atherosclerosis**.

ATHEROSCLEROSIS

Atherosclerosis, a hardening of the arteries, is a disease in which **plaques** (made of a yellowish fatty substance) build up on the inside of arteries. It can begin in late childhood and continues throughout life. A plaque can continue to develop until it restricts the flow of blood through the artery or even blocks it completely. Plaques are most likely to form in the arteries of the heart (coronary arteries) and neck (carotid arteries). The typical development of a plaque is summarised in **fig B**.



▲ **fig B** The development of atherosclerosis

We can now look at this development in more detail. Atherosclerosis begins with damage to the endothelial lining of blood vessels. This damage can be caused by several factors, including high blood pressure and substances in tobacco smoke. Atherosclerosis usually occurs in arteries rather than in veins. This is because the blood in the arteries flows fast under relatively high pressure, which puts more strain on the endothelial lining of the vessels and can cause small areas of damage. In the veins, the pressure is lower so damage to the endothelium is much less likely.

LEARNING TIP

Remember that damage to the endothelium occurs first and this is often caused by high blood pressure, often as a result of smoking.

EXAM HINT

Learn the stages of the development of atherosclerosis: damage to the endothelium of the arteries → inflammatory response → accumulation of cholesterol → atheroma → fibrous tissue/calcium salts → plaque → narrowing/loss of elasticity of the artery.

Once damage to the endothelium has occurred, the body's inflammatory response begins and white blood cells arrive at the site of the damage. These cells accumulate chemicals from the blood, especially cholesterol. This leads to a plaque (also known as an **atheroma**) forming on the endothelial lining of the artery (see **fig C**). Fibrous tissue and calcium salts also build up (increase in amount) around the atheroma, turning it into a hardened plaque. This hardened area means that part of the artery wall is less elastic and narrower than it should be. This is atherosclerosis and is summarised in **fig B**.

The plaque causes the lumen of the artery to become much smaller. This increases the blood pressure, making it harder for the heart to pump blood around the body. The raised blood pressure makes damage more likely in other areas of the endothelial lining and more plaques will form. This will make the blood pressure even higher, and so the problem gets worse. There are many factors that are linked to the development of atherosclerosis. You will look at these in more detail in **Chapter 1C**.

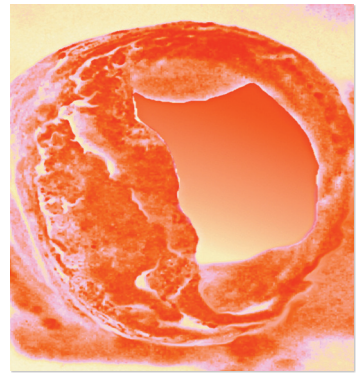


fig C Fatty deposits like these in an artery cause disease and death in millions of people every year.

EFFECT OF ATHEROSCLEROSIS ON HEALTH

Atherosclerosis can have many serious effects on the health of an individual. The development of atherosclerosis can be summarised as: damage to the endothelium of the arteries → inflammatory response → accumulation of cholesterol → atheroma → fibrous tissue/calcium salts → plaque → narrowing/loss of elasticity of the artery.

ANEURYSMS

If an area of an artery is narrowed by plaque, blood tends to collect behind the blockage. The artery bulges and the wall is put under more pressure than usual, so it becomes weakened. This is known as an **aneurysm**. The weakened artery wall may split open, leading to massive internal bleeding. Aneurysms frequently happen in the blood vessels supplying the brain or in the aorta, especially when it passes through the abdomen. The massive blood loss and drop in blood pressure are often fatal, but if aneurysms are diagnosed they can be treated by surgery before they burst.

RAISED BLOOD PRESSURE

The arteries narrowed due to plaques on the walls cause raised blood pressure. This can lead to severe damage in a number of organs, including the kidneys, the eyes and the brain. The high pressure damages the tiny blood vessels where your kidney filters out urea and other substances from the blood. If the vessels feeding the kidney tubules become narrowed, the pressure inside them gets even higher and proteins may be forced out through their walls. If you have high blood pressure, your doctors can test for protein in your urine as a sign of kidney damage.

Similarly, the tiny blood vessels supplying the retina of your eye are easily damaged. If they become blocked or leak, the retinal cells are starved of oxygen and die and this can cause blindness.

Bleeding from the capillaries into the brain results in one type of stroke (see below).

EXAM HINT

Make sure you are clear about all of the different terms. Atherosclerosis can cause aneurysms, angina and myocardial infarctions.

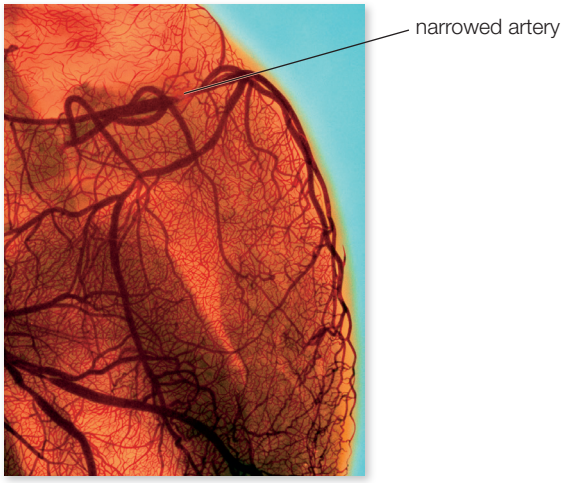
HEART DISEASE

There are many kinds of heart disease, but the two most common ones are **angina** and **myocardial infarction (heart attack)**; both are closely linked to atherosclerosis (see **figs B** and **D**).

In angina, plaques build up slowly in the coronary arteries, reducing blood flow to the parts of the heart muscle beyond the plaques. Often symptoms are first noticed during exercise, when the cardiac muscle is working harder and needs more oxygen. The narrowed coronary arteries cannot supply enough oxygenated blood and the heart muscle resorts to **anaerobic respiration**. This causes a gripping pain in the chest that can extend into the arms, particularly the left one, and the jaw, and often also causes breathlessness. The symptoms of angina subside once exercise stops, but the experience is painful and frightening.

Fortunately, most angina is relatively mild. It can be helped by taking regular exercise, losing weight and not smoking. The symptoms can be treated by drugs that cause rapid dilation of the coronary blood vessels so that they supply the cardiac muscle with the oxygen it needs. However, if the blockage of the coronary arteries continues to get worse, so will the symptoms of the angina. Other drugs are then used to dilate the blood vessels and reduce the heart rate. Unfortunately, drugs cannot

solve a severe problem permanently. A small tube called a **stent** may be inserted into the coronary arteries to hold them open, or heart bypass surgery may be carried out.



▲ **fig D** Injecting the blood vessels with special dye allows doctors to see where the coronary arteries are narrowing due to atherosclerosis so they can treat the problem.

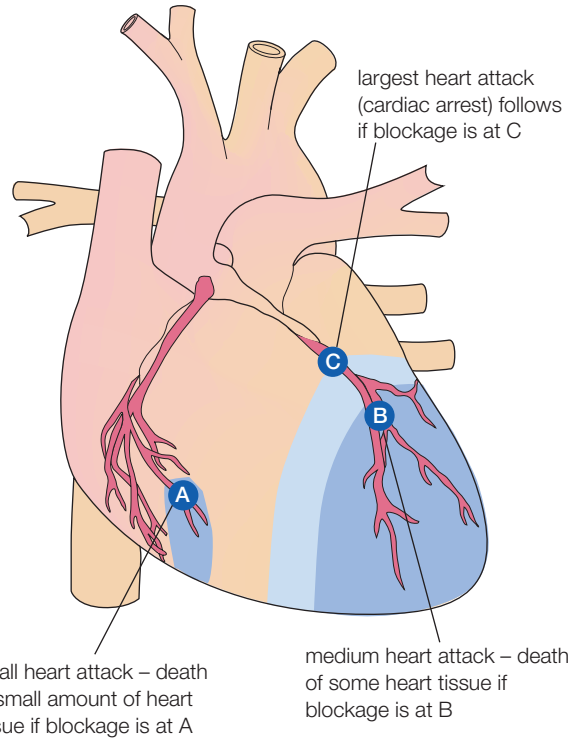
EXAM HINT

Be clear that angina and myocardial infarction are caused by reduced blood flow to the cardiac muscle – if you say 'to the heart' this suggests reduced flow in the veins carrying blood into the atria rather than arteries carrying oxygenated blood to the muscle itself.

In a myocardial infarction, often called a heart attack, one of the branches of the coronary artery becomes completely blocked and part of the heart muscle is permanently starved of oxygen.

Many heart attacks are caused by a blood clot resulting from atherosclerosis. As you have seen, the wall of an artery affected by a plaque is stiffened, making it much more likely to suffer cracks or damage. Platelets touch the damaged surface of the plaque and the clotting process is triggered (see **Section 1B.2**). The plaque itself may rupture and break open, and the cholesterol that is released will also cause the platelets to trigger the blood clotting process. A clot may also develop because the endothelial lining is damaged, for example by high blood pressure or smoking.

A clot that forms in a blood vessel is known as a **thrombosis**. The clot can rapidly block the whole blood vessel, particularly if it is already narrowed by a plaque. A clot that gets stuck in a coronary artery is known as a coronary thrombosis. The clot can block the artery, starving the heart muscle beyond that point of oxygen and nutrients, and this often leads to a heart attack (see **fig E**).



▲ **fig E** The size and severity of a heart attack is closely related to the position of the blockage in the coronary artery.

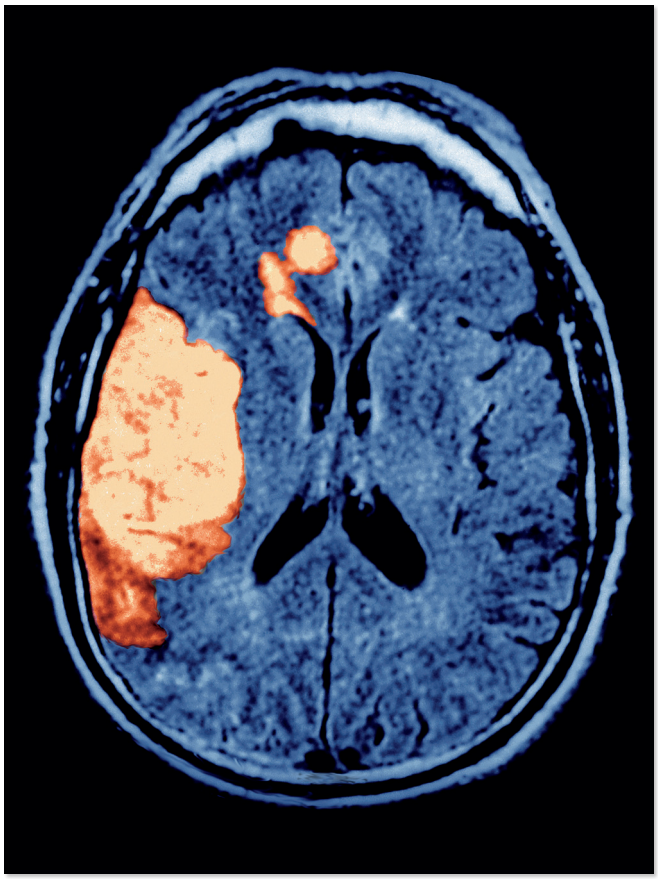
During a heart attack, there is chest pain in the same areas as in an angina attack, but it is much more severe. The pain may occur at any time, although exercise may start it, and it often lasts for several hours. Death may occur very rapidly with no previous symptoms, or it may happen after several days of feeling tired and suffering symptoms mistaken for indigestion.

It is very important to react quickly if you suspect someone is having a heart attack. Give them two full-strength aspirin tablets to help stop the blood clotting, and get them to hospital as fast as you can.

STROKES

A **stroke** is caused by an interruption to the normal blood supply to an area of the brain. This may be due to bleeding from damaged capillaries or a blockage cutting off the blood supply to the brain. A blockage is usually caused by a blood clot, an atheroma or a combination of the two. Sometimes, the blood clot forms somewhere else in the body and is carried in the bloodstream until it gets stuck in an artery in the brain. The damage happens very quickly. A blockage in one of the main arteries leading to the brain causes a very serious stroke that may lead to death. In one of the smaller arterioles leading into the brain, the effects may be less disastrous.

The symptoms of strokes vary, depending on how much of the brain is affected. Very often, the blood is cut off from one part or one side of the brain only (see **fig F**). Symptoms include dizziness, confusion, slurred speech, blurred vision or partial loss of vision (usually one eye) and numbness. In more severe strokes, there can be paralysis, usually on one side of the body.



▲ **fig F** The damage caused in the brain by a major stroke resulting from a blood clot in the wrong place can be seen on the left of this MRI scan. The healthy part of the brain is shown in blue.

The outcome of either a heart attack or a stroke usually depends on how soon the person is treated. The sooner the patient is given treatment, including clot-busting drugs that break down or dissolve the blood clot, the more likely they are to survive. For example, if treatment is given rapidly, 75% of patients who survive the first week after a heart attack can expect to be alive five years later.

CHECKPOINT

1. When a plaque starts to form on the endothelium (lining) of an artery, it usually gets worse and worse. Unless the person changes their lifestyle or gets medical treatment, the lining of the artery does not return to normal. Explain why this happens, and why it is so dangerous.

2. (a) Describe in detail the role of atherosclerosis in cardiovascular disease.

(b) Summarise the similarities and differences between a heart attack and a stroke.

SKILLS INNOVATION

3. The build-up of a fatty plaque in the artery leads to changes in the blood flow and an increase in the blood pressure. Plan a way of modelling this that could be used on a television programme to explain high blood pressure to young people.

SUBJECT VOCABULARY

cardiovascular diseases diseases of the heart and circulatory system, many of which are linked to atherosclerosis

atherosclerosis a condition in which yellow fatty deposits build up (increase in amount) on the lining of the arteries, causing them to be narrowed and resulting in many different health problems

plaques yellowish fatty deposits that form on the inside of arteries in atherosclerosis

atheroma another term for a plaque formed on the arterial lining

aneurysm a weakened, bulging area of artery wall that results from blood collecting behind a blockage caused by plaques

angina a condition in which plaques are deposited on the endothelium of the arteries and reduce the blood flow to the cardiac muscle through the coronary artery; it results in pain during exercise

myocardial infarction (heart attack) the events which take place when atherosclerosis leads to the formation of a clot that blocks the coronary artery entirely and deprives the heart muscle of oxygen, so it dies; it can stop the heart functioning

anaerobic respiration cellular respiration that takes place in the absence of oxygen

stent a metal or plastic mesh tube that is inserted into an artery affected by atherosclerosis to hold it open and allow blood to pass through freely

thrombosis a clot that forms in a blood vessel

stroke an event caused by an interruption to the normal blood supply to an area of the brain which may be due to bleeding from damaged capillaries or a blockage cutting off the blood supply to the brain, usually caused by a blood clot

1B EXAM PRACTICE

1 (a) Which statement is incorrect?

A All arteries carry oxygenated blood.

B All veins carry blood at low pressure.

C All veins carry blood towards the heart.

D All arteries carry blood away from the heart. [1]

(b) Draw a labelled diagram to show the structure of an artery wall. [3]

(c) Explain how the structure of an artery wall relates to its function. [2]

(d) Give **two** differences between the structure of a vein and the structure of a capillary. [2]

(Total for Question 1 = 8 marks)

2 Many animals have hearts that pump blood through a network of blood vessels.

(a) What is the correct term for the circulation of a mammal?

A closed single circulation

B open single circulation

C closed double circulation

D open double circulation [1]

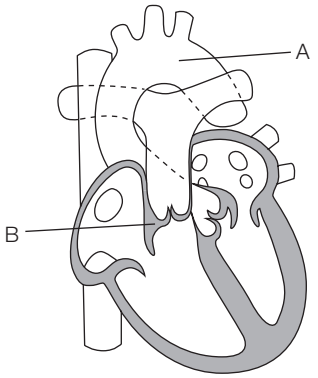
(b) The table below refers to blood flow in the four major blood vessels of the human heart. If the statement is correct, place a tick (✓) in the appropriate box and if the statement is incorrect, place a cross (✗) in the appropriate box.

Name of blood vessel	Carries blood away from the heart	Carries oxygenated blood
aorta		
vena cava		
pulmonary artery		
pulmonary vein		

[4]

(c) The diagram below shows a section through the heart of a mammal.

Name the parts labelled A and B. [2]

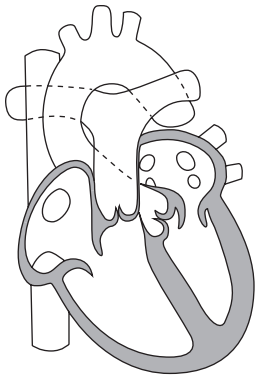


(d) Heart muscle has a high demand for oxygen. Describe how heart muscle is supplied with oxygen. [3]

(e) The volume of blood pumped by the ventricles is 0.07 dm^3. Calculate the cardiac output when the heart rate is 72 bpm. [2]

(Total for Question 2 = 12 marks)

3 (a) The diagram below shows a mammalian heart during atrial systole.



What evidence can be seen in the diagram to confirm it is in atrial systole?

A Both the semilunar valves and the atrioventricular valves are open.

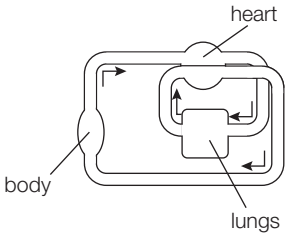
B Both the semilunar valves and the atrioventricular valves are closed.

C The semilunar valves are open and the atrioventricular valves are closed.

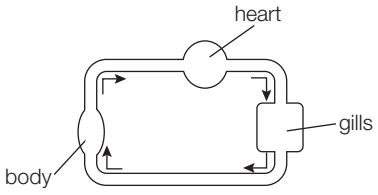
D The semilunar valves are closed and the atrioventricular valves are open. [1]

(b) Humans and fish are both animals that have a heart and a network of blood vessels. However, there are some differences in their circulatory systems. The diagrams below illustrate a human circulatory system and a fish circulatory system.

Human circulatory system



Fish circulatory system



The arrows show the direction of blood flow.

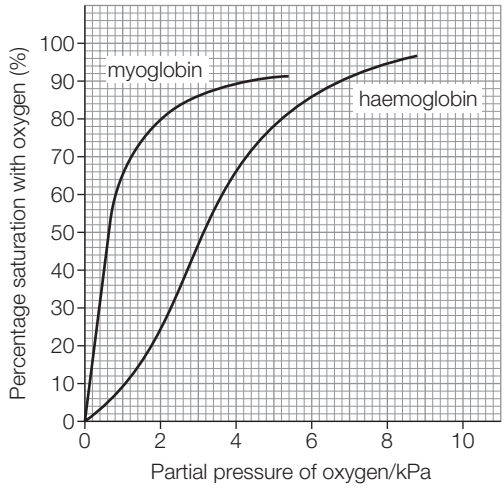
(i) Describe the circulation of blood in a fish using the information in the diagram. [3]

(ii) Using the information in both diagrams, evaluate the advantages that the human circulatory system has compared with that of the fish. [2]

(c) Describe the cardiac cycle. [5]

(Total for Question 3 = 11 marks)

4 (a) The graph below shows oxygen dissociation curves for human myoglobin and human haemoglobin.



(i) Using the graph, state the partial pressures of oxygen at which myoglobin and haemoglobin are 50% saturated with oxygen. [2]

(ii) Calculate the increase in percentage saturation for haemoglobin between 2 kPa of oxygen and 8 kPa of oxygen. Show your working. [2]

(b) The muscle of diving mammals such as elephant seals contains a lot of myoglobin. Use the information in the graph to explain how the myoglobin can help an elephant seal to dive for longer. [3]

(c) At increased partial pressures of carbon dioxide, the oxygen dissociation curve for haemoglobin moves to the right. This is known as the Bohr effect.

Explain the importance of the Bohr effect. [4]

(Total for Question 4 = 11 marks)

5 (a) During a dissection of a mammalian heart a student measured the thickness of the ventricular walls. The left ventricle wall was 32 mm thick and the right wall was 11 mm thick.

(i) Calculate the thickness of the right ventricle wall as a percentage of the left ventricle wall thickness. Show your working and state your answer to three significant figures. [2]

(ii) Explain the difference in the thickness of the ventricle walls. [2]

(b) Describe and explain the function of the semilunar valves. [3]

(c) Explain the function of the tendinous cords in the atrioventricular valves. [2]

(Total for Question 5 = 9 marks)

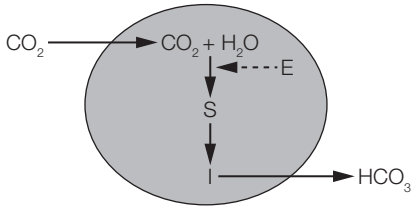
6 (a) Platelets are fragments of cells that are involved in blood clotting. Describe how blood clots. [4]

(b) Describe two conditions that are caused by blood clots that form inside the blood vessels. [4]

(c) State the meaning of the term *aneurysm* and explain how an aneurysm is caused. [3]

(Total for Question 6 = 11 marks)

7 (a) The diagram below shows how most carbon dioxide is transported.



(i) What is the name of the cell represented by the circle. [1]

A leucocyte
B neutrophil
C erythrocyte
D stem cell

(ii) What is the name of enzyme E. [1]

A catalase
B carbonase
C anhydrous carbonase
D carbonic anhydrase

(iii) Name substance S. [1]

(iv) Identify ion I. [1]

(b) If ion I is allowed to accumulate inside the cell it could affect the functioning of the cell.

(i) Describe how the accumulation of ion I is prevented. [2]

(ii) Explain the effect that accumulation of ion I has on the transport of oxygen. [2]

(Total for Question 7 = 8 marks)

TOPIC 1 MOLECULES, TRANSPORT AND HEALTH

CHAPTER 1C

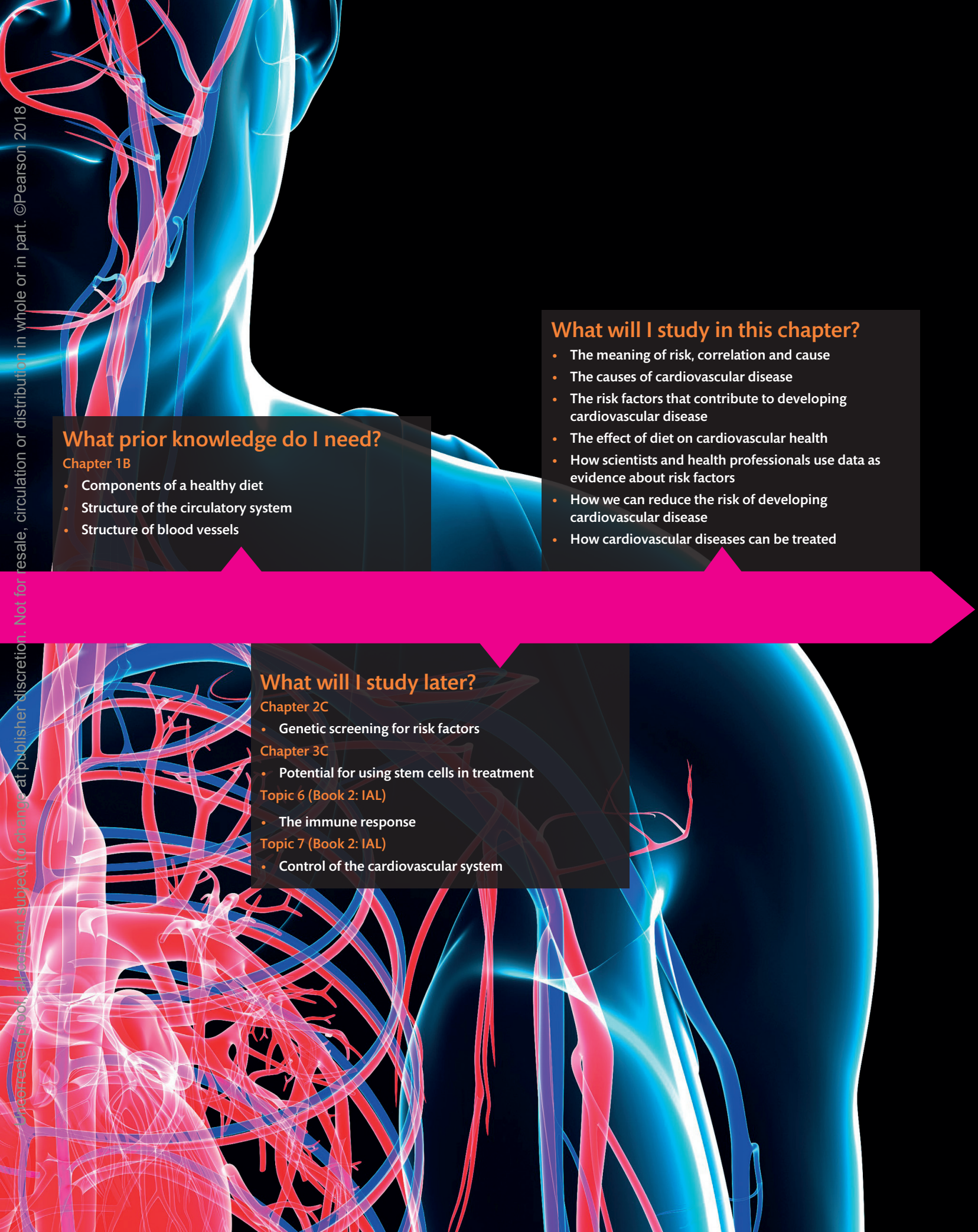
CARDIOVASCULAR HEALTH AND RISK

What do you do with your spare time? Do you like to watch TV, read, use the internet or spend time on social media? According to a recent poll of professionals in the Middle East and North Africa, a third of people spend more than five hours a day using the internet for leisure. One fifth of people spend at least one hour a day relaxing online. Compare that to only 4.6% who prefer to play sport and only 2.2% who prefer outdoor pursuits. Over 35% of people eat out nearly every day. People enjoy an affluent lifestyle – eating well, using a car instead of walking, relaxing at home or spending time with family and friends. Unfortunately, many people do not realise that these are also risk factors that increase the probability that they will develop a serious disease of the heart or blood vessels.

In this topic, you will learn about the meaning of risk and how we perceive risk. Cardiovascular diseases are those of the heart and blood vessels. You will learn how we can determine what causes cardiovascular diseases and what increases the chances of us developing such diseases. Diet is an important factor and the things we choose to eat can increase the risk of developing these life-threatening diseases. Fortunately, making the right choices can also significantly decrease the risks. You will learn how scientists and health professionals can use evidence to analyse the risks and how these diseases can be treated.

MATHS SKILLS FOR THIS CHAPTER

- **Recognise and make use of appropriate units in calculations** (*e.g. calculating a BMI in kg m^{-2}*)
- **Recognise and use expressions in decimal and standard form** (*e.g. calculating a person's BMI*)
- **Use ratios, fractions and percentages** (*e.g. calculating proportions of the population with certain risk factors*)
- **Construct and interpret frequency tables and diagrams, bar charts and histograms** (*e.g. interpreting data about incidence of disease or the effect of reducing risk factors*)
- **Understand simple probability** (*e.g. considering the chances of developing a particular cardiovascular disease*)
- **Use a scatter diagram to identify a correlation between two variables** (*e.g. comparing risk of developing a disease with risk factors such as diet or blood pressure*)
- **Translate information between graphical, numerical and algebraic forms** (*e.g. draw graphs from data tables or select data from graphs about various risk factors*)
- **Calculate rate of change from a graph showing a linear relationship** (*e.g. calculate how quickly the proportion of people who are obese has increased over the last 50 years*)



What will I study in this chapter?

- The meaning of risk, correlation and cause
- The causes of cardiovascular disease
- The risk factors that contribute to developing cardiovascular disease
- The effect of diet on cardiovascular health
- How scientists and health professionals use data as evidence about risk factors
- How we can reduce the risk of developing cardiovascular disease
- How cardiovascular diseases can be treated

What prior knowledge do I need?

Chapter 1B

- Components of a healthy diet
- Structure of the circulatory system
- Structure of blood vessels

What will I study later?

Chapter 2C

- Genetic screening for risk factors

Chapter 3C

- Potential for using stem cells in treatment

Topic 6 (Book 2: IAL)

- The immune response

Topic 7 (Book 2: IAL)

- Control of the cardiovascular system

1 RISK, CORRELATION AND CAUSE

LEARNING OBJECTIVES

- Understand why people's perception of risks is often different from the actual risks, including underestimating and overestimating the risks due to diet and other lifestyle factors in the development of heart disease.
- Be able to distinguish between correlation and causation.

Every country has diseases which affect its people and may even kill them. Some of these diseases affect you randomly – there is nothing you can do to change whether you are affected or not. However, for many diseases, especially **non-communicable** (non-infectious) **conditions** such as heart disease and cancer, you can increase or lower your **risk** of becoming ill, based on factors in your lifestyle. If you understand the risk factors, you can help to make yourself and your family healthier.

WHAT IS RISK?

fig A The risk, chance or probability that you will pick a blue ball out of the black bag is 1 in 6. If you return the ball to the bag each time, you will have exactly the same probability of picking a blue ball again the next time. The probability will always be 1 in 6.

The word *risk* is used regularly in everyday conversation, but in science it has a very specific meaning. In science, risk describes the **probability** that an event will happen. Probability means the chance or likelihood of the event, calculated mathematically. For example, imagine you have six coloured balls – red, blue, green, yellow, orange and purple – in a black cloth bag (see **fig A**). If you reach in and pull out a single ball, the probability (risk) of getting, say, a green ball can be expressed in one of three ways:

- 1 in 6
- 0.166 66 recurring (0.17)
- 17%.

This is the case for any one of the six colours in the bag. In the same way, it is possible to work out your risk of developing certain specified diseases or of dying from a specified cause.

HOW DO WE PERCEIVE RISK?

The actual risk of doing something is not always the same as the sense of risk one feels. Most people don't think twice before getting into their car – but globally you have an annual risk of 1 in 5747 of being killed in a road traffic accident. On the other hand, many people get very worried before flying, but commercial flights have a 1 in 4.5–5.5 million risk of crashing. Personal perception of risk is based on a variety of factors which include:

- how familiar you are with the activity
- how much you enjoy the activity
- whether or not you approve of the activity.

The actual mathematical risk may play very little part in developing your personal perception of risk. People often overestimate the benefits, or minimise the risk, of behaviour that they want to continue. For example, there is now strong evidence from around the world that obesity is linked to a range of diseases such as diabetes, cardiovascular disease and some cancers. However, people like eating and so they still become overweight. On the other hand, they will over-emphasise the risks of activities if they want to avoid them or prevent others from doing them. For example, parents over-emphasise the risk of wandering away to small children, to help make the child behave and stay close.

In another example, there is good scientific evidence that smoking affects our risk of developing diseases such as atherosclerosis, as well as lung cancer. However, knowledge of the mathematical risk of an early death if you smoke cigarettes doesn't always stop people from smoking.

EPIDEMIOLOGY

If you know the number of people in a population who are affected by a disease, it is possible to calculate the average risk of developing that disease for a person within that population. But the risk is higher for some people than others, depending on their lifestyle and which genes they inherit.

It is possible to identify the **risk factors** that may contribute to the cause of a disease. You can look at people who have the same factors (e.g. smoking) and compare their risk of the disease with the average risk for the whole population. Using these techniques, it appears that there are a number of factors that increase the likelihood that a person will develop atherosclerosis. If many factors influence your chance of having a disease, it is called a **multifactorial disease**. The study of the patterns of diseases and their causes is called **epidemiology**.

When two different sets of data change together, there may be a link, which is called a **correlation**. For example, mortality data from a disease such as atherosclerosis may change in a similar pattern to a lifestyle factor such as smoking or lack of exercise. However, this does not prove that one is the cause of the other. They could both be caused by something else which would explain why they change in the same way. Correlation is not the same as **causation** – further research is always needed to demonstrate a causal link.

For example, **fig B** shows the percentage of deaths in the UAE from cardiovascular disease each year. It also shows the statistics for obesity and diabetes. This data suggests a possible correlation between obesity and heart disease.

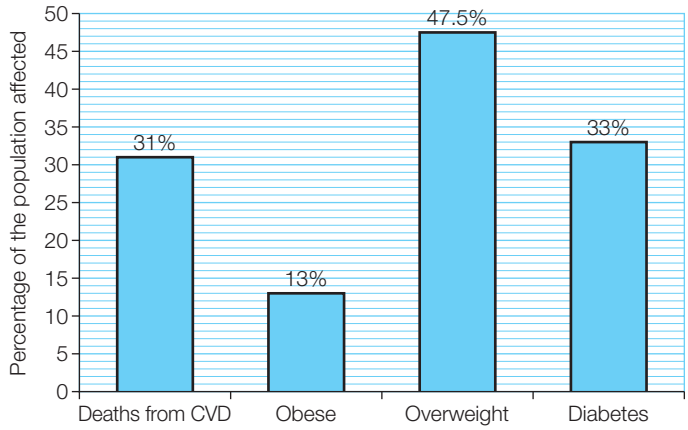


fig B This data shows a possible correlation between obesity, diabetes and death from cardiovascular disease (CVD). It needs more data from other sources to show that obesity can cause diabetes and CVD.

EXAM HINT

When provided with data in the form of a graph, make sure you read the axis titles carefully so that you know what the data refers to.

You cannot base conclusions on a single set of data. However, these UAE data agree with findings from countries around the world that suggest obesity is closely linked to the development of diabetes and cardiovascular diseases. Dr Raghib Ali, principle investigator in the UAE Healthy Future Study, has set up a long-term study in Abu Dhabi. The team is aiming to collect the data needed to confirm the pattern of increased disease risk in the UAE – and so to find ways of reducing the risk of diabetes and cardiovascular diseases.

CHECKPOINT

1. Explain the difference between risk, correlation and causation.
2. In most areas of the world, the risk of dying from heart disease is about three times greater for smokers than for non-smokers. Explain why this does not mean that an individual person who smokes will die from heart disease.

SKILLS PERSONAL AND SOCIAL RESPONSIBILITY

3. The risks of developing diabetes and heart disease linked to obesity are well known. Suggest reasons why people stay obese, and why more people are becoming obese.
4. In the Maldives, 39% of deaths are the result of cardiovascular disease. 25% of the population smoke and around 12.9% are obese. Draw a bar chart to show this information. How does it compare with the information in **fig B** on the UAE? Suggest any other information you might need to make accurate comparisons between the causes of disease in the two countries.

SUBJECT VOCABULARY

non-communicable conditions diseases which are not caused by pathogens and cannot be spread from one person to another
risk the probability that an event will take place
probability a measure of the chance or likelihood that an event will take place
risk factors factors which affect the risk of an event happening
multifactorial disease a disease which results from the interactions of many different factors – not from one simple cause
epidemiology the study of patterns of health and disease, to identify causes of different conditions and patterns of infection
correlation a strong tendency for two sets of data to change together
causation when a factor directly causes a specific effect

2 INVESTIGATING THE CAUSES OF CVDs

LEARNING OBJECTIVES

- Be able to evaluate the design of studies used to determine health risk factors, including sample selection and sample size used to collect data that are both valid and reliable.
- Know how factors such as genetics, age and gender increase the risk of cardiovascular diseases (CVDs).

Everywhere you look, on television, in newspapers and on the internet, there are reports of factors which affect your health. Eat fruit and vegetables, drink orange juice, take lots of exercise, enjoy these foods – how do we know which advice is based on good science, and which is given to us because someone wants to sell us something? There are many ways in which you can evaluate the design of studies to decide if the data are meaningful.

DESIGNING STUDIES

Most epidemiological studies are based on a very big sample size – usually, the bigger the study, the more meaningful the results.

The ideal is to investigate one factor or variable, keeping all other variables the same (controlled). However, controlling variables is almost impossible when you are working with human beings. The way people live is complex and varies a lot, so it is hard to detect how any one factor affects people. When a larger number of people are studied, it is more likely that patterns may emerge, even with all the other differences between the people involved. Evidence based on large amounts of data is more likely to be statistically significant than evidence based on small studies.

Some epidemiological studies are carried out over a long time. These **longitudinal studies** are very valuable because they follow the same group of individuals over many years (see **fig A**). This means the impact of their known lifestyle on their health can be tracked over time. For example, the Münster Heart Study looked at cardiovascular disease in 10 856 men aged 36–65 in Europe, following them from the start of the study well into the 21st century. The results from this study are still seen as important because so many people were involved over a long period of time. The Framingham Study in the US also provided much data – but was limited because they were all from similar American citizens. The study started in 1948 and it is still going on – the scientists have widened the population they gather data from, so it is more relevant now.

An ambitious new study called the National Children's Study has been set up in the US to follow 100 000 children from birth until they are 21 years old. From 2008–2012, children were selected to be representative of the whole of the US population. One major objective of the study is to examine how environmental inputs and genetic factors interact to affect the health and development of children. This is believed to be the biggest longitudinal study ever set up. Similarly, the UAE Healthy Future Study will be longitudinal, looking at the same group of volunteers over a number of years.

Sometimes, scientists look at all the available studies in a subject area and analyse the available data in a massive literature study. This combines small and large studies and can give more reliable evidence than any one of the studies alone. This is called a **metadata analysis (meta-analysis)**.

EVALUATING SCIENTIFIC STUDIES

When considering a study, you need to examine the methodology to see if it is **valid**. That means that it is properly designed to answer the question or questions being asked. You also need to see if the measurements have been carried out with **precision**. It is important to find out if other scientists have been able to repeat the methodology and have had similar results – if so, the results are considered more **reliable**.

It is also important to know who carried out the research, who funded it and where it was published. Then to decide whether or not any of these factors might have affected or **biased** the study. You need to **evaluate** the data and conclusions from the study in the light of all these factors.

EXAM HINT

Remember the meaning of the following terms.
Valid: answers the question the scientists are asking
Precise: measurements with little difference between them
Reliable: the investigation is repeatable by other scientists who get similar results
They are important in evaluating all practical work and research.

In the next few pages, you are going to look at some of the evidence that scientists have collected suggesting factors that may – or may not – affect your risk of developing cardiovascular diseases (CVDs). In each case, you need to look carefully at the type of evidence that is presented and think about what else you need to know to make firm conclusions.

RISK FACTORS FOR CVDs

The results from many epidemiological studies have identified a range of risk factors linked to CVDs. These factors divide into two main groups – those you can't change and those you can do something about (see **Section 1C.3**).

NON-MODIFIABLE RISK FACTORS FOR ATHEROSCLEROSIS

There are three main risk factors for CVDs which cannot (at the present time) be changed.

- **Genes**: studies show that there is a genetic tendency (trend) in some families, and also in some ethnic groups, to develop CVDs. These trends can include
  – arteries which are easily damaged

  - a tendency to develop hypertension which can cause arterial damage and make CVDs more likely
  - problems with the cholesterol balance of the body.
- **Age**: as you get older, your blood vessels begin to lose their elasticity and to narrow slightly. This can make you more likely to suffer from CVDs, particularly heart disease.
- **Gender**: statistically, under the age of 50, men are more likely to suffer from heart disease (and other CVDs) than women. The female hormone oestrogen, which is an important factor in the woman's menstrual cycle, appears to reduce the build-up of plaque. This gives women some protection against CVDs until they go through the menopause when oestrogen levels fall.

LEARNING TIP

Remember that risk factors do not cause the disease, they contribute to the chances of developing the disease.

LOOKING AT THE DATA

Identical twin studies are an excellent resource when investigating whether there is a genetic factor at work, because identical twins have exactly the same genes. Any differences should therefore be due to the environment in which they live. A major twin study was conducted in Sweden and was based on over 21 000 pairs of twins, both identical and non-identical. This study showed that (for male twins) if one twin died of heart disease between the ages of 36 and 55, then the risk of the other twin also dying of heart disease was eight times higher than if neither was affected (see **fig A**). However, as the twins got older, one dying of heart disease had less of a correlation with the other twin also dying of heart disease. In other words, there appears to be a clear genetic link to heart disease in younger men, but it gets less in much older men.

Epidemiological studies have also identified several lifestyle factors linked to CVDs, some of which you will look at in the following pages. These lifestyle factors are important for health because they are the factors that we can change.

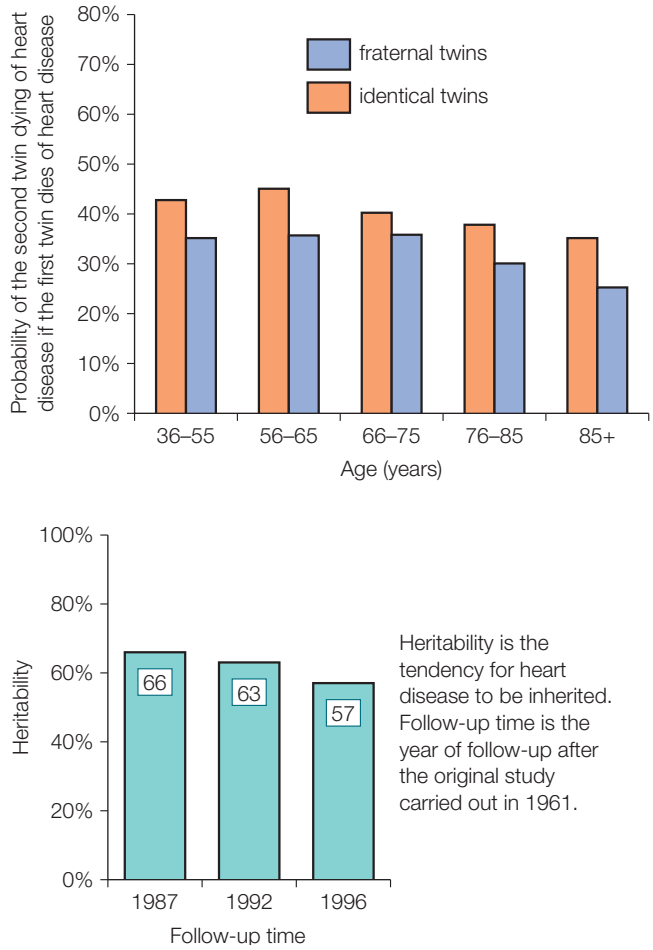


fig A These are results from an epidemiological study of male twins in Sweden published in 1994. Although this study was carried out a long time ago, the findings are still important, because of the large number of twin pairs who took part and the length of the study.

CHECKPOINT

SKILLS EXECUTIVE FUNCTION

1. When scientists design a major study, what can they do to try and make sure their results will be both valid and reliable?
2. Using the data in **fig A**, answer the following questions.
   (a) How do the figures for identical and fraternal twins differ in the top graph? What does this suggest about a genetic link to heart disease?
   (b) What does the bottom graph show you about the apparent heritability of heart disease in men? What might affect the fall in apparent heritability as the men got older?

SUBJECT VOCABULARY

longitudinal studies scientific studies which follow the same group of individuals for many years
metadata analysis (meta-analysis) when data from all the available studies in a particular area are analysed
valid an investigation which is well designed to answer the question being asked
precision measurements with only slight variation between them
reliable evidence which can be repeated by several different scientists
biased when someone is unfairly for or against an idea (e.g. when a scientist is paid by someone with a vested interest in a specific result – they may receive benefit from the outcome)
evaluate to assess or judge the quality of a study and the significance of the results

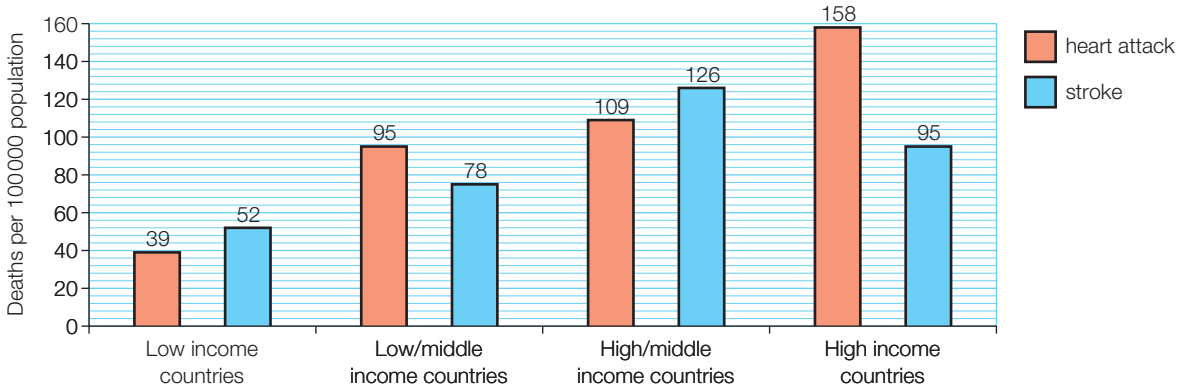
3 RISK FACTORS FOR CARDIOVASCULAR DISEASE

SPECIFICATION REFERENCE
1.12 1.16

LEARNING OBJECTIVES

- Be able to evaluate the design of studies used to determine health risk factors, including sample selection and sample size used to collect data that are both valid and reliable.
- Know how factors such as diet, high blood pressure, smoking and inactivity increase the risk of cardiovascular disease (CVD).

The non-modifiable factors affecting your risk of developing CVDs – age, genetics and gender – are the same all over the world. However, the numbers of people who die of CVDs varies enormously, depending on where you live, as you can see in **fig A**. This tells us that other factors are involved – factors which vary with your lifestyle. In the rest of this topic, you will find out more about the lifestyle factors which affect us and influence our risk of developing – or dying from – heart disease.



▲ **fig A** Deaths from CVDs in different countries (based on 2012 data)

EXAM HINT

When you are given a graph, try to analyse it briefly before looking at the question. Find trends and obvious comparison points. This will help you to understand what the question is asking for.

MODIFIABLE (LIFESTYLE) RISK FACTORS FOR CVDs

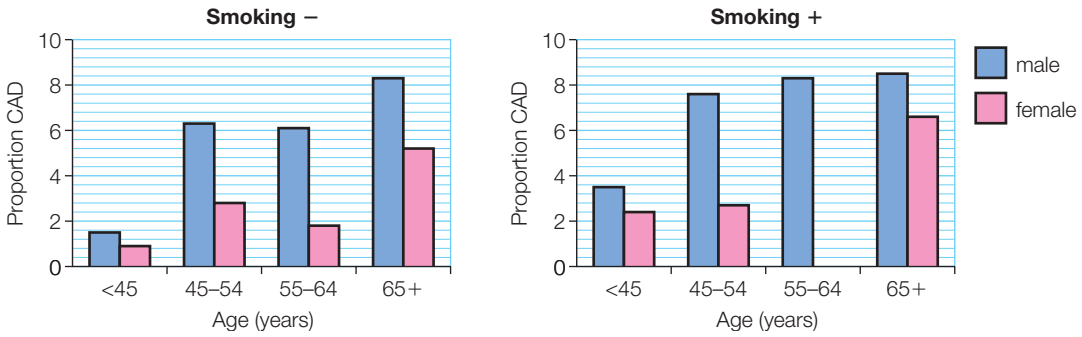
The development of atherosclerosis is linked to many types of CVD. Your lifestyle can affect your risk of developing atherosclerosis in the future. Epidemiological studies have shown links with smoking, diet and weight, lack of activity and high blood pressure. These are the factors we can change, so we can change our risk of developing CVDs by the lifestyle choices we make.

SMOKING AND ATHEROSCLEROSIS

Studies have shown that smokers are far more likely to develop atherosclerosis than non-smokers with a similar lifestyle. Nine out of ten people who need heart bypass surgery or stents as a result of atherosclerosis are smokers. In 2007, a Spanish study showed a clear correlation between smoking and the incidence of death from atherosclerotic heart disease. Causation was established by further research. For example, studies found that the substances in tobacco smoke:

- can damage the artery linings, which makes the build-up of plaques more likely
- can cause the arteries to narrow, raise the blood pressure and increase the risk of atherosclerosis.

Similar findings were made in a study on adults with heart disease in Jordan in 2017 (see **fig B**).



▲ **fig B** Proportion of adults with coronary artery disease (CAD) depending on whether they smoke or not based on a Jordanian study in 2017.

INACTIVITY AND CVDs

Regular exercise helps lower blood pressure, prevent obesity and diabetes, lower blood cholesterol levels, balance lipoproteins and reduce stress. These also lower your risk of developing atherosclerosis and CVDs. A study of 10 269 male Harvard University (USA) graduates aged between 45 and 84 showed that the men who changed from being inactive to taking regular exercise had a 23% lower mortality over the life of the study than those who did not exercise. Moreover, the main cause of the deaths was atherosclerosis and the linked CVDs. A study of 72 488 female nurses showed the same benefits for women – the more active women had a significantly lower risk of developing atherosclerosis and other CVDs.

A 2013 study from Sri Lanka showed a similar pattern – high levels of inactivity were linked to an increased risk of obesity, diabetes, **high blood pressure** and CVDs. High levels of activity were linked to a reduced risk of all these conditions. Several studies have shown that exercise both reduces the formation of plaques in the arteries and also keeps plaques that are present more stable and less likely to break.

HIGH BLOOD PRESSURE AND ATHEROSCLEROSIS

As you saw in **Section 1B.4**, the heart pumps blood out into your arteries in a regular rhythm. The blood travels through your arterial system at pressures which change as your heart beats and which are easily measured (see **fig C**). At systole, when the blood is forced out of the heart, a healthy blood pressure is around 120 mmHg. When the heart is relaxed and filling during diastole, a healthy blood pressure is around 80 mmHg. Measuring blood pressure is used as an indicator of the health of both your heart and your blood vessels. Your blood pressure goes up and down naturally during the day – but it shouldn't be constantly raised. If your blood pressure is regularly above 140/90 mmHg, you have high blood pressure or **hypertension**. Raised blood pressure can be a sign of atherosclerosis. The blood pressure goes up when the walls of the arteries become less flexible due to the build-up of plaque, and when the lumen of the arteries get narrower as they are blocked by the plaques. This means that raised blood pressure can be the result of atherosclerosis and can be used to help diagnose the disease.

▲ **fig C** Doctors can use a blood pressure monitor like this to check that your blood pressure is in the healthy range. Some people buy and use their own monitor, so they can check their blood pressure regularly to help prevent them getting CVDs.

However, other factors can also raise the blood pressure. For example, smoking narrows the blood vessels and raises the blood pressure. Obesity, inactivity, a high level of salt in the diet and stress can also narrow the arteries or affect the way the heart is pumping and raise the blood pressure. When the blood pressure is constantly high, the lining of the arteries is more likely to be damaged, leading to atherosclerosis and ultimately CVDs. So high blood pressure can also contribute to CVDs. If a doctor discovers you have high blood pressure, they will try to help you reduce the level by making lifestyle changes or with medication, to try to reduce your risk of developing CVDs.

DIET, OBESITY AND ATHEROSCLEROSIS

An increasing number of studies suggest that being overweight does not directly affect your risk of developing CVDs, but it is a very important indicator of risk. Most scientists think that the best predictors of future CVDs are:

- where fat is stored on your body
- how much exercise you do
- the levels of different fats in your blood.

Two other factors which are often a direct result of being overweight do increase the risk of atherosclerosis and CVDs. These are:

- high blood pressure – increases the risk of damage to blood vessel linings, and so of plaque formation
- type 2 diabetes – this can result in damage to the lining of the blood vessels which increases the risk of plaque formation.

There have been many studies on how diet is linked to atherosclerosis and CVDs, some looking at general diet, some looking at the role of diet in becoming overweight or obese, and some looking at specific foods. The evidence is very mixed and very difficult to interpret. You can find out more about this in **Section 1C.4**.

EXAM HINT

Remember that atherosclerosis is a multifactorial disease – there is no single cause but there are many factors that contribute to the chances of it occurring.

Smoking is one important factor that increases the chances of atherosclerosis. Inactivity and diet are other factors.

LINKS BETWEEN FACTORS

Many epidemiological studies are starting to find that an increased risk of developing a disease is often due to a combination of factors. For example, it is known that smoking increases your risk of atherosclerosis because of its effect on your blood vessels and blood pressure. Evidence now suggests that smoking also changes the balance of lipoproteins in your blood in a way which raises your risk of dying from atherosclerosis-related CVDs. You will find out more about lipoproteins and their effect on cardiovascular risk in **Section 1C.4**.

PREVENTING ATHEROSCLEROSIS AND CVDs

The advice about what is 'good' for us and what is 'bad' changes. This happens because epidemiological studies of links between risk factors and CVDs become more sophisticated and scientific research discovers more reasons why some factors can contribute to atherosclerosis. Current evidence suggests that eating a balanced diet with a variety of fats and plenty of fruit and vegetables helps prevent atherosclerosis. It helps not to smoke, to maintain a healthy weight to avoid high blood pressure and type 2 diabetes, to reduce constant stress and get plenty of exercise. It is important to take action as early as possible because there is clear evidence of the early signs of atherosclerosis in teenagers and even young children, if known risk factors are already in place.

CHECKPOINT

1. (a) What is the difference between modifiable and non-modifiable risk factors for CVDs?

(b) Give **two** non-modifiable and **two** modifiable risk factors for atherosclerosis.

(c) For each factor you have chosen, explain how it increases the risk of developing atherosclerosis and CVDs.

2. (a) Take the data from **fig A** and combine the information on deaths from heart attacks and strokes for each group of countries. Record your answers in a table. This will give you the total number of deaths from CVDs in each.

(b) Using your answer to part (a), draw a bar chart of the total numbers of deaths from CVDs in the different groups of countries in 2012.

SKILLS PERSONAL AND SOCIAL RESPONSIBILITY

3. The numbers of deaths from CVDs in poorer countries are much lower than in wealthier countries. Using what you know about the risk factors for CVDs, suggest at least **three** reasons for these differences.

SUBJECT VOCABULARY

high blood pressure blood pressure that is regularly more than 140/90 mmHg; this increases your risk of developing CVDs

hypertension high blood pressure, regularly measuring over 140/90 mmHg, which increases your risk of developing CVDs

1C 4 DIET AND CARDIOVASCULAR HEALTH

SPECIFICATION REFERENCE
1.12 1.18(i) 1.18(ii)

LEARNING OBJECTIVES

- Know how factors such as diet increase the risk of cardiovascular disease.
- Be able to analyse data on the possible significance for health of blood cholesterol levels and levels of high-density lipoproteins (HDLs) and low-density lipoproteins (LDLs).
- Know the evidence for a causal relationship between blood cholesterol levels (total cholesterol and LDL cholesterol) and cardiovascular disease.
- Understand how people use obesity indicators such as BMI and waist-to-hip ratios.

There is strong evidence from around the world that the food we eat has a big effect on our health in many different ways. It certainly has a big impact on the health of our cardiovascular system. However, our understanding of what the effect is and how our food affects our risk of developing cardiovascular diseases keeps changing as scientists learn more.

WEIGHT ISSUES

There is plenty of food in the developed world and people can easily eat more than they need to supply the metabolic needs of the body. This means that many people have a positive energy balance. The excess food energy is converted into a store of fat so these people become overweight and then obese. All the evidence suggests that being obese increases your risk of developing many different diseases, including CVDs.

MEASURING A HEALTHY WEIGHT: THE BODY MASS INDEX

What do we mean by 'overweight'? It isn't just how much you weigh. Doctors and scientists look at your **body mass index (BMI)** to decide if you are unhealthily heavy (see **fig A**). This compares your weight to your height in a simple formula:

$$\text{BMI} = \frac{\text{weight in kilograms}}{(\text{height in metres})^2}$$

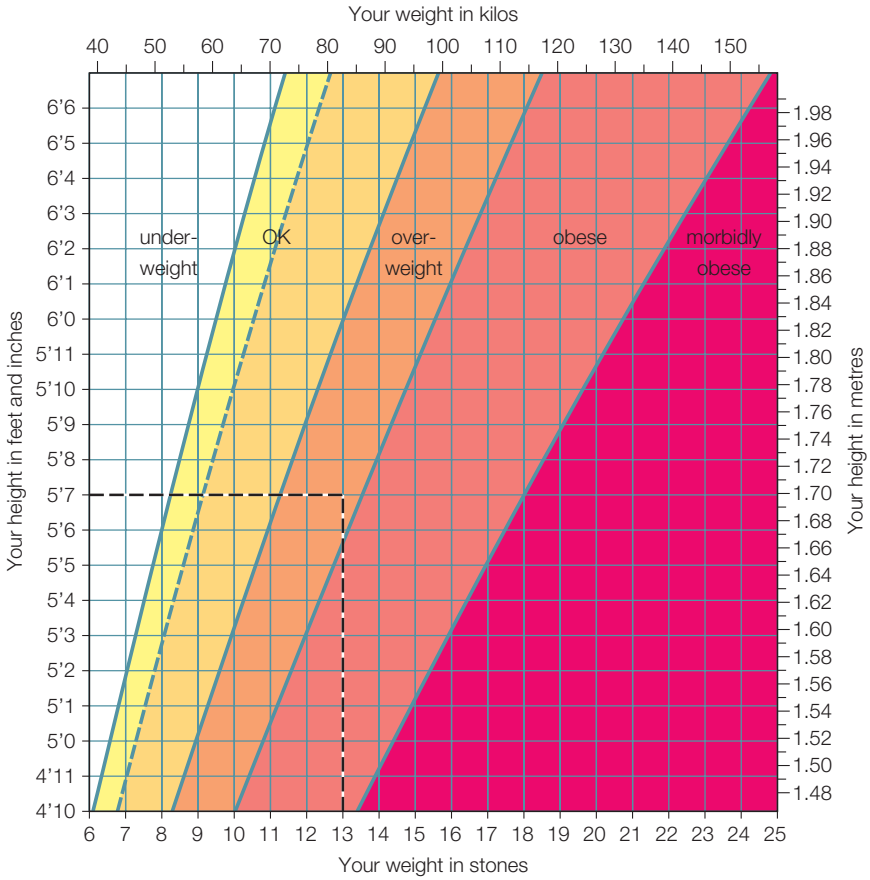
For an adult, the following definitions apply:

- a BMI of less than 18.5 $kg\,m^{-2}$ means you are underweight
- a BMI of 18.5–25 $kg\,m^{-2}$ is the ideal range
- a BMI over 25 and up to 30 $kg\,m^{-2}$ means you are overweight
- a BMI of 30–40 $kg\,m^{-2}$ is considered obese
- a BMI over 40 $kg\,m^{-2}$ defines you as morbidly obese.

EXAM HINT

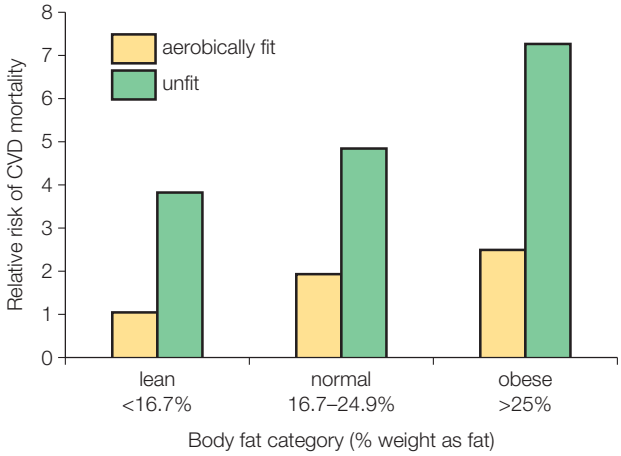
Using numbers in examinations has always been a weak point with biology students.

If you can apply your maths skills accurately, you will gain marks easily. When calculating BMI, candidates often forget to square the height, or they use height in centimetres rather than metres.



▲ **fig A** Using a graph like this gives an adult a good idea of whether or not their BMI is in the healthy range.

The BMI measure was developed in the mid-1800s and it was originally used to classify normal, relatively inactive people of average body composition. The normal charts apply to adults only – there are special charts for children and teenagers. Young people grow and their body composition changes as they mature, so both age and gender are important in calculating what is normal until they become adults. The BMI became widely used for deciding whether people are a healthy weight for their height and even for predicting the likelihood of CVDs – but doctors increasingly feel it is a very limited tool. Most top athletes would have BMIs in the obese range, because BMI makes no allowance for the difference in composition of people's bodies. The reason athletes often have BMIs that suggest they are obese is because BMI does not recognise the difference between fat and muscle. BMI values also underestimate body fat in older people who have lost a lot of their muscle mass. There are also international differences, with some groups having a greater or lower than average risk of obesity-related diseases. More and more, the evidence suggests that BMI is not a good predictor of CVDs on its own – but combined with other factors it is part of the picture (see **fig B**).



▲ **fig B** The risk of dying of CVDs differs for people in different weight and fitness categories. Being overweight or obese does increase the risk – but it is not the whole story.

MEASURING A HEALTHY WEIGHT: THE WAIST-TO-HIP RATIO

Increasingly, scientists are finding that a simple waist:hip ratio is the best measure of obesity, and also the best way to predict an increased risk of CVDs. The waist is measured just above the navel, and the hips at the widest point of the hips. The size of the waist is then divided by the size of the hips:

$$\frac{\text{waist size (cm)}}{\text{hip size (cm)}}$$

Waist size gives a good indication of the amount of fat a person is carrying.

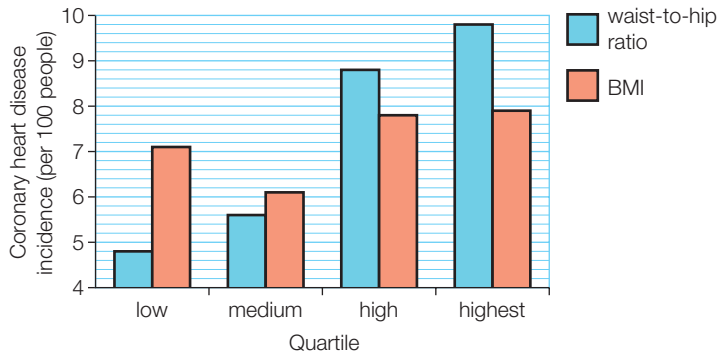
GENDER	WAIST:HIP RATIO INDICATING OBESITY
Male	>0.9
Female	>0.85

A simple measurement like this can be used easily by individuals to monitor their own health and well-being. Simple measures can lower the waist:hip ratio. These include eating less and taking more exercise to reduce the fat stores and reduce the size of the waist. Keeping the waist:hip ratio at a healthy level reduces your overall risk of CVDs, as well as the many other conditions linked to obesity.

Being seriously underweight is not good for you either and can lead to muscle wasting, heart damage and other health problems. However, it is the other end of the scale that is causing the most concern. The available data show that around 61% of all adults in England (that's almost 24 million people) are either overweight or obese, and that the proportion of the population affected is continuing to rise. The trend towards obesity is being seen across the developed world. For example, Gulf Cooperation Council countries face challenges with health problems related to obesity. Saudi Arabia (35.2%), Qatar (33.1%) and UAE (33%) face similar concerns.

TACKLING OBESITY

Evidence from around the world suggests that the change in energy balance is linked to modern lifestyles rather than simply to poor individual choices. Energy-rich food is widely available and cheap. The 21st century way of life in many countries involves almost no exercise – relatively few jobs now require manual labour, household tasks are often automated and people drive instead of walking or cycling. So, as the average energy input has increased (or stayed the same), the energy output has decreased and people are gaining weight. Solutions include taxes on fatty foods, town planning to make walking and cycling easier and educating children to prevent childhood obesity – but there is no clear scientific evidence that any of these solutions work. One thing we do know – since 2006, the number of overweight people in the world is greater than the number of people who do not get enough to eat. The importance of reducing obesity is shown in the graph in **fig C**. This also shows that waist:hip ratio is a better predictor of heart disease than BMI.

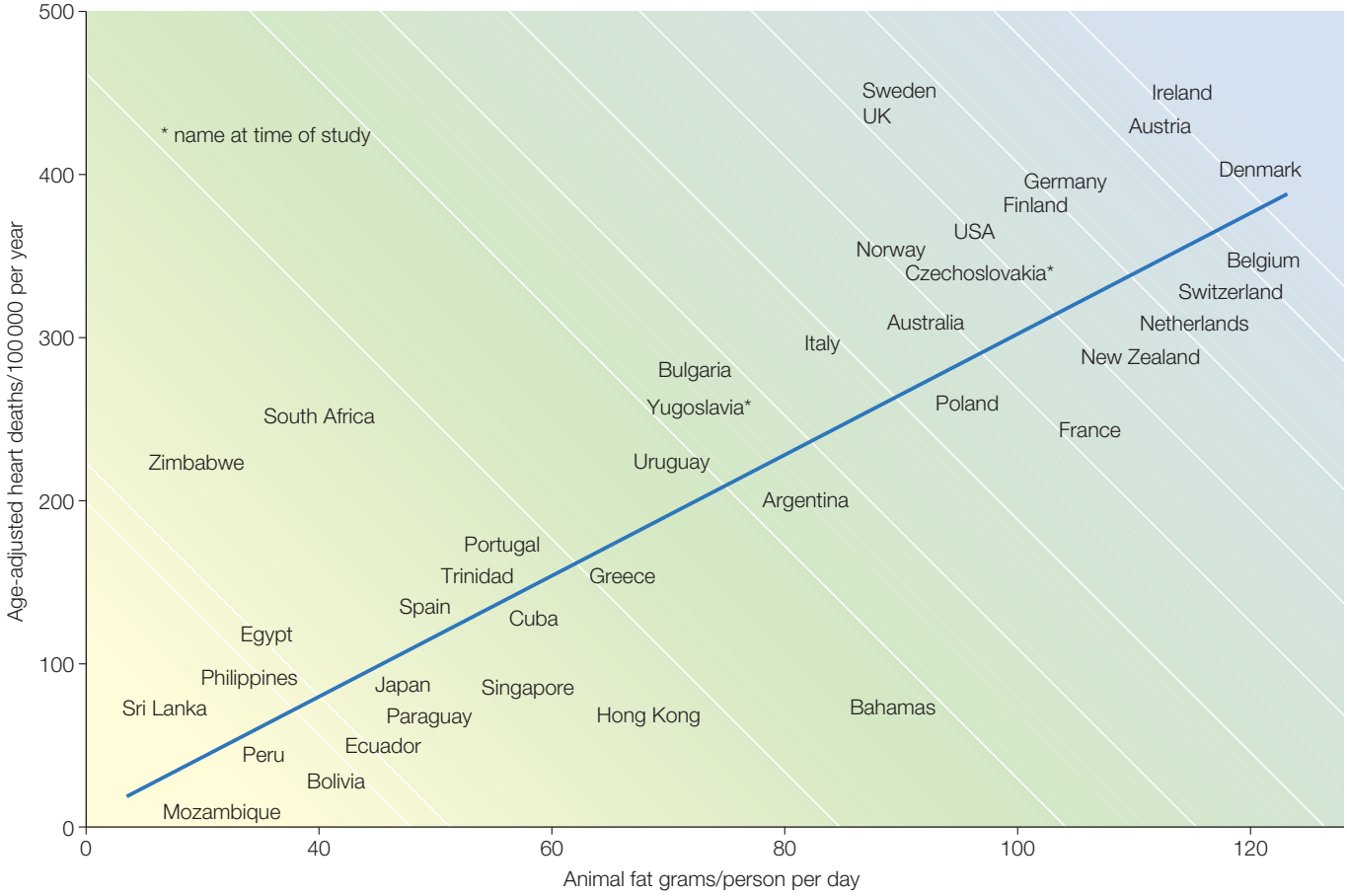


▲ **fig C** This graph shows that as men become more obese, their risk of developing coronary heart disease also increases. It also shows that waist:hip ratio is a better predictor than BMI.

DIET AND CVDs

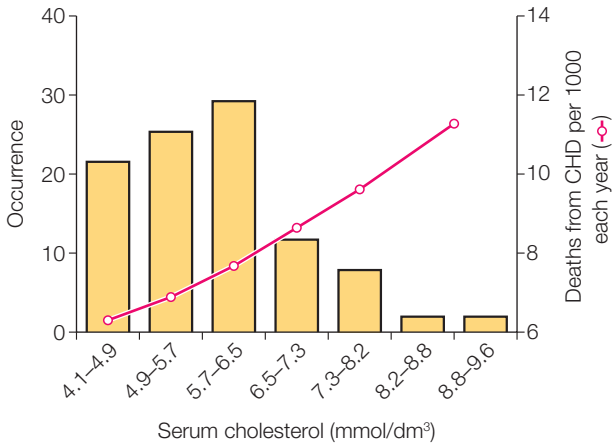
The effect of diet on the risk of developing CVDs isn't simply about becoming obese. What you eat, as well as how much you eat, seems to be very important. Many studies have looked at the general diet people eat and at the incidence of heart disease. For example, one study produced the graph in **fig D**. This shows that

in countries where people eat a lot of fatty meat and dairy foods (mostly saturated fats), many people die of heart disease. This suggests that high levels of saturated fats in the diet may be a risk factor.



▲ **fig D** Data from the early 21st century showing the death rates per 1000 men and women from heart attacks in different countries compared with the average intake of animal (saturated) fats.

The link between a diet high in saturated fats and a raised incidence of CVDs shows a correlation, but not a cause. Over the last 50 years or so, many scientific studies showed that a high intake of saturated fats was often associated with high blood cholesterol levels. Cholesterol is involved in plaque formation in atherosclerosis, so this suggested a cause for the link between a high-fat diet and CVDs (see **fig E**).



▲ **fig E** The relationship between blood cholesterol levels and death from coronary heart disease (CHD) in men in the UK. The bars show the frequency with which the different cholesterol concentrations are found, while the line graph shows the number of heart attacks per 1000 men each year.

LEARNING TIP

Remember that it is saturated fats that are harmful. These are the animal fats that are solid at room temperature.

Then, in 2014, a major study was published by scientists from prestigious institutions including the universities of Cambridge, Oxford and Bristol, Imperial College and the Medical Research Council in the UK. The results suggested that the links found between diets high in saturated fats and atherosclerosis and CVDs had been a correlation and nothing more. Looking at all of the data from 72 studies they found that diets high in saturated fats did not appear to be linked directly with increases in atherosclerosis and CVDs.

Our picture of the relationship between fat in the diet and cholesterol in the blood is further complicated by lipoproteins, conjugated proteins (see **Section 1B.5**) which transport lipids around the body.

- **Low-density lipoproteins (LDLs)** are made from *saturated* fats, cholesterol and protein and bind to cell membranes before being taken into the cells. If there are high levels of some LDLs, your cell membranes become saturated and so more LDL cholesterol remains in your blood.
- **High-density lipoproteins (HDLs)** are made from *unsaturated* fats, cholesterol and protein. They carry cholesterol from body tissues to the liver to be broken down, lowering blood cholesterol levels. HDLs can even help to remove cholesterol from fatty plaques on the arteries which reduces the risk of atherosclerosis.

Scientists are now confident that the balance of these lipoproteins in your blood is a good indication of your risk of developing atherosclerosis and the associated CVDs (see **fig F**).

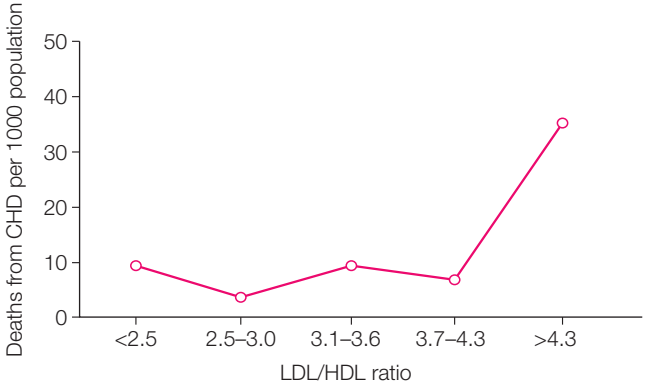


fig F This evidence from a well-known European study into heart disease appears to show a clear link between the LDL/HDL ratio and deaths from coronary heart disease (CHD).

Blood cholesterol and LDL/HDL levels are not simply related to diet. The way your body metabolises the fats you eat and manages the levels of cholesterol and balance of lipoproteins in your blood are all linked to your genetic make-up. Some people can metabolise almost any amount of fat and maintain a good balance of LDLs and HDLs. Other people cannot cope so well and even small amounts of fat in the diet are reflected in raised blood cholesterol levels.

LEARNING TIP

Remember that it is the ratio of LDL : HDL that seems to have the greatest effect on cardiovascular disease. A healthy ratio is about 3 : 1 LDL : HDL.

CHECKPOINT

1. What is meant by the term BMI?
2. Ali weighs 65 kg and is 1.68 m tall. Calculate Ali's BMI. What does this tell you about him?
3. Using the graph in **fig A**, what are the highest and lowest weights that would be healthy for an individual who is:
   (a) 6 feet tall
   (b) 1.58 metres tall?
   (c) At what weight would these individuals be defined medically as obese?

SKILLS REASONING

4. (a) What are the limitations of using BMI as a predictor of cardiovascular health?
   (b) What is the waist-to-hip ratio and why is it often used to indicate obesity and predict heart health?
5. (a) Explain the apparent link between dietary fats, blood cholesterol, LDLs and HDLs.
   (b) Why do scientists look at a whole range of indicators including your BMI or waist-to-hip ratio, your blood cholesterol and HDLs and LDLs, and your history of smoking and exercise when they try to decide your risk of developing heart disease?
6. In 2014, a report was published which suggested that the link between fat in the diet and the risk of atherosclerosis and CVDs was a correlation but that it was **not** causative. Many ordinary people felt confused and upset when this report was discussed on news programmes. Others were very pleased. Suggest reasons for both of these responses.

SUBJECT VOCABULARY

body mass index (BMI) a calculation to determine if you are a healthy weight by comparing your weight to your height in a simple formula

low-density lipoproteins (LDLs) lipoproteins which transport lipids around the body

high-density lipoproteins (HDLs) lipoproteins which transport cholesterol from body tissues to the liver and can help reduce risks of CVDs

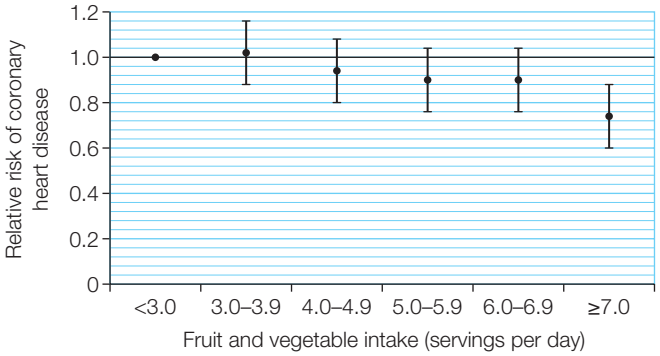
5 DIETARY ANTIOXIDANTS AND CARDIOVASCULAR DISEASE

SPECIFICATION REFERENCE
1.13 1.14 1.15
CP2

LEARNING OBJECTIVES

- Understand the link between dietary antioxidants and the risk of cardiovascular disease.
- Be able to distinguish between correlation and causation and recognise conflicting evidence.

Your diet is not all about the fats you eat. Lots of studies show that eating lots of fruit and vegetables benefits your health in many ways – including reducing your risk of developing CVDs. The graph in **fig A** is one piece of evidence which shows how eating five or more portions of fruit or vegetables a day can lower your risk of having a heart attack. It was based on data from a longitudinal study of more than 84 000 women and 42 000 men over eight years, looking at their fruit and vegetable intake and cardiac health.



▲ **fig A** This graph shows the impact of eating increasing amounts of fruit and vegetables on the risk for coronary heart disease.

EXAM HINT

Remember to look closely at the data you are given. This graph shows the relative risk of developing coronary heart disease compared to a person eating fewer than three servings of fruit and vegetables per day.

ANTIOXIDANTS AND HEART HEALTH

However, as you know, it isn't enough to show a correlation between two things. We need to show how one thing causes another and we still don't really know how fruit and vegetables have their effect. They are very varied in their chemistry. For some time, it was thought that the **antioxidants** found in fruit and vegetables might be the answer. Vitamins, such as vitamin A found in carrots, vitamin C from citrus fruits and vitamin E from leafy green vegetables, almonds and sunflower oil, are antioxidants and they are found in fruits and vegetables. Several studies appeared to show that antioxidants were the answer and many people started taking antioxidant supplements to protect their hearts. However, recent studies, including some very large metadata analyses (studies where scientists have looked at the results of many different investigations), have shown that the evidence for antioxidants being good for your heart is inconclusive. There is some evidence that some antioxidants may cause harm.

VITAMIN C: A CASE STUDY

Vitamin C is important in the formation of connective tissue in the body, such as in the bones, teeth, skin and many internal body surfaces including the endothelial lining of blood vessels. A severe lack of vitamin C in the diet causes scurvy, which can result in bleeding gums, bruising easily and painful joints. As you have seen, if the lining of an artery is damaged, atherosclerosis is more likely to develop. So, it makes sense, in theory, that if your diet is low in vitamin C, your arteries are more likely to be damaged and you are more likely to be affected by CVD.

A study published in the *British Medical Journal* in 1997 looked at the association between concentration of vitamin C in the blood and risk of heart attack in 1605 men from eastern Finland. The men had no sign of coronary artery disease when they were tested between 1984 and 1989. Their vitamin C levels were also tested. Between 1984 and 1992 a total 70 of the men had a heart

attack (some fatal, some not). Of the men who showed low vitamin C levels, 13.2% had heart attacks, compared with 3.8% of the men who showed no sign of vitamin C deficiency. Many people began eating lots of vitamin C rich foods, and taking vitamin C supplements, in the belief that they were reducing their risk of having heart disease.

Then, in 2016, a major metadata study was published in the *International Journal of Molecular Sciences*. It looked at all the evidence for the antioxidant properties of vitamin C as an explanation of the known benefits of fruit and vegetables on heart health. The conclusions were that there was no relationship between them. The study even showed that taking vitamin C supplements could damage heart health. This is a good example of where there is contradictory evidence – and where scientists must look at all of that evidence to avoid coming to the wrong conclusions.

PRACTICAL SKILLS CP2

Testing for vitamin C

There is a simple laboratory test for the presence of vitamin C in foods. It involves a reagent called DCPIP, which stands for 2,6-dichlorophenol-indophenol. DCPIP solution is blue. When it reacts with vitamin C, it turns colourless (although in a very acidic solution such as lemon juice, it may turn pink).

You can estimate the concentration of vitamin C in different foods and drinks by recording the volume of DCPIP which is added before it remains blue – at this point all the vitamin C has been used up.

▲ **fig B** Citrus fruit contains vitamin C, which can be tested for with DCPIP.

EXAM HINT

Ensure that you know about measuring vitamin C levels – there could be questions directly about the experimental procedure and how to make it valid, precise and reliable.

CHECKPOINT

1. Look at **fig A**. Calculate the percentage reduction in deaths from heart disease if everyone ate:
   (a) five portions of fruit and vegetables every day
   (b) seven or more portions of fruit and vegetables every day.
2. What is the difference between the data that show a link between the amount of fruit and vegetables eaten and heart health, and the evidence looking at the effect of antioxidants on heart health?

SKILLS EXECUTIVE FUNCTION

3. Plan an investigation to compare the vitamin C content of two fruits.

SUBJECT VOCABULARY

antioxidants molecules that inhibit the oxidation of other molecules which can lead to chain reactions that may damage cells

6 USING THE EVIDENCE

SPECIFICATION REFERENCE 1.19

LEARNING OBJECTIVES

- Understand how people use scientific knowledge about the effects of diet, including obesity indicators, exercise and smoking to reduce their risk of coronary heart disease.

There is much scientific evidence about the main factors that increase the risk of heart disease. A lot of that evidence is used by governments and health organisations to produce advice on how to improve our health. Why do they do this?

PREVENTION IS BETTER THAN CURE

Cardiovascular disease has a negative effect on individuals, on families and on society. It costs a lot of money to treat people in hospital. When people are too ill to work, they are losing money for their families, and also for the companies where they work. Treating people with drugs to prevent them from needing surgery is cheaper for health service providers. It is even cheaper (and better for the individual) if we can stop ourselves needing the drugs. So, prevention is better than treatment for CVDs for many reasons (see **fig A**). However, persuading people to change their lifestyle habits is often difficult.

For example, there is a lot of reliable evidence to show that smoking is one of the highest risk factors for CVDs. However, if you stop smoking, your risk of developing heart disease is almost halved after just one year. Moreover, research carried out by a team led by Azra Mahmud from Trinity College Dublin and published in 2007 suggests that after 10 years, the arteries of smokers who stop smoking are the same as if they had never smoked. There is a lot of support available for people who want to stop smoking. Yet, despite all this, almost 1 billion people around the world smoke cigarettes and millions of them die each year of CVDs and cancers linked to their smoking.

Health education programmes in schools and communities can help to make sure that everyone is aware of the risks associated with different lifestyle choices. However, each individual has to make their own choices and take their own risks.

OVERWEIGHT OR UNDERFIT?

Most people are aware that obesity is linked to CVDs, and many go on slimming diets to try to lose weight. Most people also know that taking regular exercise helps protect against CVDs – but more people choose to go on a diet than choose to take regular exercise. The results of a study carried out over an average of eight years on 20 000 men aged from 30 to 83 years are given in **Section 1C.4 fig B**. Fitness was defined by how much oxygen they used during exercise. The results show that if you are obese and fit you have a lower risk of dying from CVDs than someone who is not obese but unfit. Obviously, being the correct weight and fit is best of all!

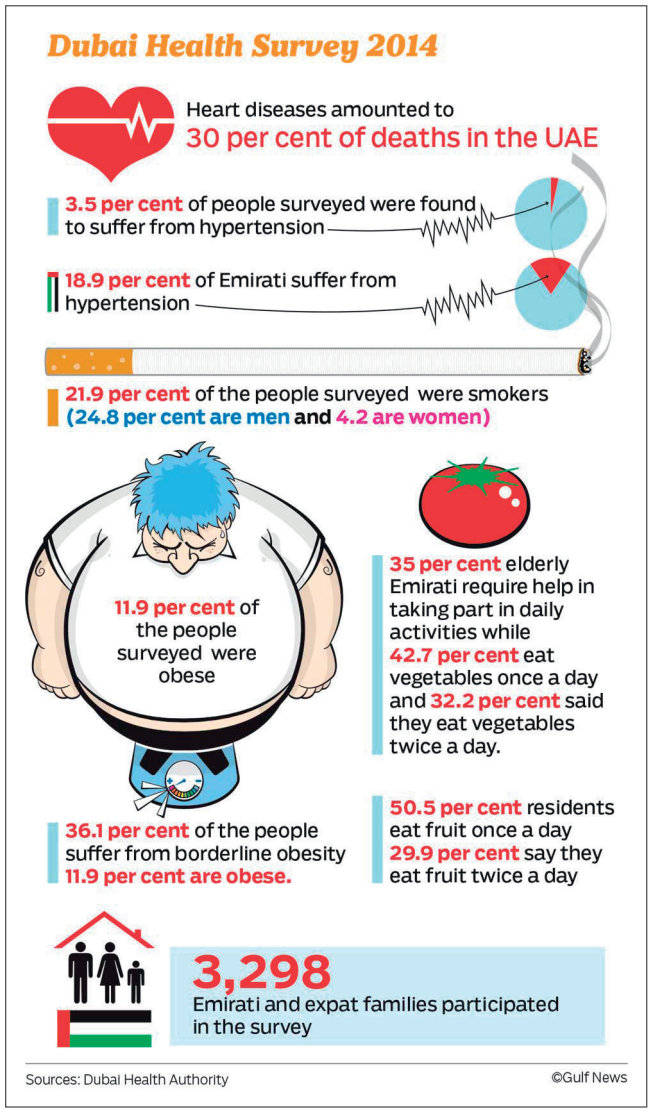


fig A Infographics like this one published in *Gulf News* help people understand the factors which affect their heart health.

The problem is that many people enjoy their food, and don't take sufficient exercise. It takes a lot of effort to cut down the amount of food you eat and change to eating healthier foods including lots of fruit and vegetables.

LEARNING TIP

Remember to read all the information in graphics.

DID YOU KNOW?

SALT AND CVDs

The Yanomami Indians in Brazil eat far less salt than people in the developed world and have much lower blood pressure levels. This evidence was used to draw a link between high salt levels, high blood pressure and CVDs. After much more research, there is wide agreement among scientists that high levels of dietary salt increase blood pressure in many people in the developed world. Processed foods typically have high levels of salt, and often people add salt to their food. If people eat less processed food, add less salt to their own cooking, and food manufacturers add less salt to their products, we might be able to lower our salt intake from the current daily average of 9–12 g to the recommended level of less than 5–6 g of salt per day.

▲ **fig B** If everyone in richer countries ate less salt, it would result in a global drop in high blood pressure and cardiovascular disease.

SO WHY DON'T PEOPLE CHANGE THEIR LIFESTYLE?

Part of the problem is that people find it difficult to distinguish between perceived risk and actual risk. They can see a risk applies to an average of a group, but not to themselves as individuals. If you see people smoking, eating a high-fat, high-salt diet, never exercising and yet appearing well, the evidence of your own experience contradicts and overrides the evidence from research reported in the media. People then underestimate the risk of CVDs associated with smoking, obesity, lack of exercise or a high-salt diet.

There are other reasons that lead to mistakes when people assess risk. Sometimes people will continue smoking because they don't want to gain weight. Smoking speeds up the metabolism and reduces the appetite, which both help to control body mass. Here, the health risks of obesity are overestimated in comparison with those of smoking. In other words, the risks of smoking are ignored because people do not want to get fat. Also, the nicotine in tobacco smoke is addictive to many people, and this makes it very difficult to give up smoking.

When people calculate their personal risk/benefit situation, it is easy to think that the immediate benefit (pleasure in eating high-fat food, smoking, not wanting to make the effort to exercise) is more important than the apparently low risk of heart disease.

CHECKPOINT

1. Why do you think people are more likely to try to lose weight than to take more exercise?

SKILLS DECISION MAKING

2. What are the limitations of drawing conclusions about the effect of salt on blood pressure from a study comparison of the Yanomami in Brazil and the population of a country such as the UK or Qatar? Do you think people in developed countries under- or overestimate the risk of eating too much salt, and what influences these perceptions?
3. Many governments spend millions of pounds on health advertising each year. Discuss whether or not this is a waste of money.

7 THE BENEFITS AND RISKS OF TREATMENT

LEARNING OBJECTIVES

- Know the benefits and risks of treatments for CVDs including antihypertensives, statins, anticoagulants and platelet inhibitors.

Once a patient has signs of cardiovascular disease, there are a number of different treatment options available. Changing lifestyle, such as improving diet, giving up smoking and taking more exercise can help but there are also various drugs that can be given. The drugs aim to reduce the risks associated with CVDs by helping to prevent problems developing. However, all medicines carry some risk.

CONTROLLING BLOOD PRESSURE

As you have seen, hypertension or high blood pressure is a major risk factor for cardiovascular diseases.

ANTIHYPERTENSIVES

Drugs that reduce blood pressure are known as **antihypertensives**. Some commonly prescribed antihypertensive drugs are described below.

- Treatment often begins with **diuretics**, which increase the volume of urine produced. This eliminates excess fluids and salts, so that the blood volume decreases. With less blood, a smaller volume is pumped from the heart and the blood pressure falls.
- **Beta blockers** interfere with the normal system for controlling the heart. They block the response of the heart to hormones such as adrenaline, which normally act to speed up the heart and increase the blood pressure (you will find out more in **Book 2 Topic 7**). So, beta blockers make the heart rate slower and the contractions less strong, so the blood pressure is lower.

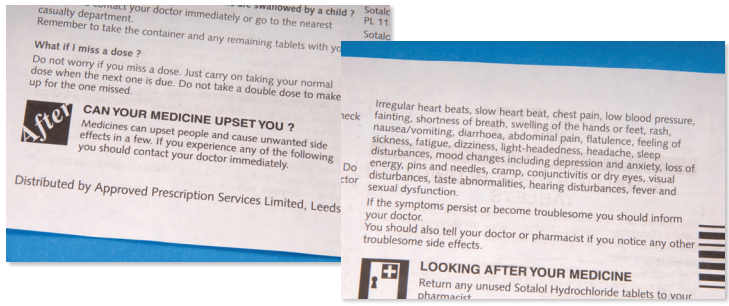
Sympathetic nerve inhibitors affect the sympathetic nerves which go from your central nervous system to all parts of your body (you will find out more in **Book 2 Topic 7**). Sympathetic nerves stimulate your arteries to constrict, which raises your blood pressure. The inhibitors prevent these nerves signalling to the arteries, which helps to keep the arteries dilated and your blood pressure lower.

- Angiotensin is a hormone which stimulates the constriction of your blood vessels and so causes the blood pressure to rise. **ACE inhibitors** block the production of angiotensin, which reduces the constriction of your blood vessels and so keeps your blood pressure lower.

The benefits of these drugs in reducing blood pressure are clear. They reduce the risk of CVDs, and also reduce the risk of damage to the kidneys and eyes from the high blood pressure.

But there are risks. The risks of these treatments are twofold. If the treatment is not monitored carefully, your blood pressure may become too low. That can lead to falls and injuries which, particularly in elderly patients, can be serious and even life-threatening. The second major risk is the **side-effects** that may result from the way your body reacts to the drugs. Each type of drug has its own possible side-effects (see **fig A**). For a drug to be given a licence for use, the benefits of the treatment must be judged to outweigh any side-effects.

The side-effects from commonly used antihypertensives include coughs, swelling of the ankles, impotence, tiredness and fatigue, and constipation. These are not serious compared with the health risks from high blood pressure – but to the patient they may feel very significant. High blood pressure often doesn't make you feel ill, but the medication needed to control it can affect your quality of life. Doctors find many patients stop taking their medication – the side-effects make them ignore the much larger but invisible risk of CVDs.



▲ **fig A** All medically licensed drugs come with instructions and information which includes possible side-effects known to be caused by the drug.

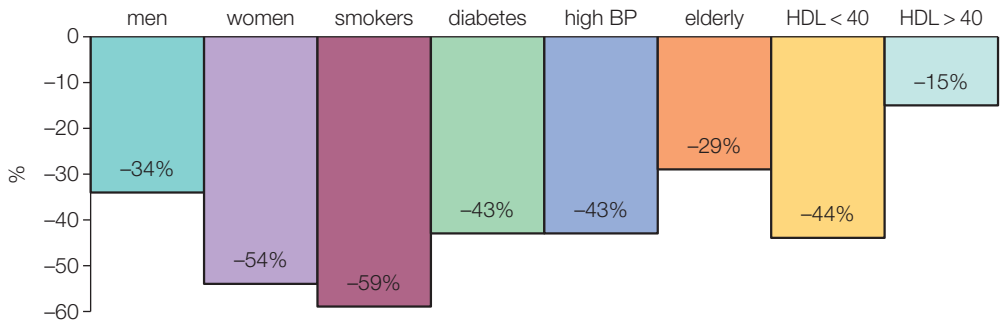
EXAM HINT

If you are asked to discuss or evaluate the use of medication or some other treatment, you must remember to include both the benefits and the potential risks associated with the treatment.

STATINS

Statins are a group of drugs that lower the level of cholesterol in your blood. They block the enzyme in the liver that is responsible for making cholesterol, and are very effective at blocking the production of LDLs. Statins also improve the balance of LDLs to HDLs and reduce inflammation in the lining of the arteries. Both functions reduce the risk of atherosclerosis developing.

Fig B shows the results from a trial using statins with a group of 6605 Asian Indians in the US. This shows the results for men and women, and other groups who are high-risk categories for cardiovascular disease. Statins reduce the incidence of serious cardiovascular disease in all categories, but they seem to have a greater effect for some groups than for others.



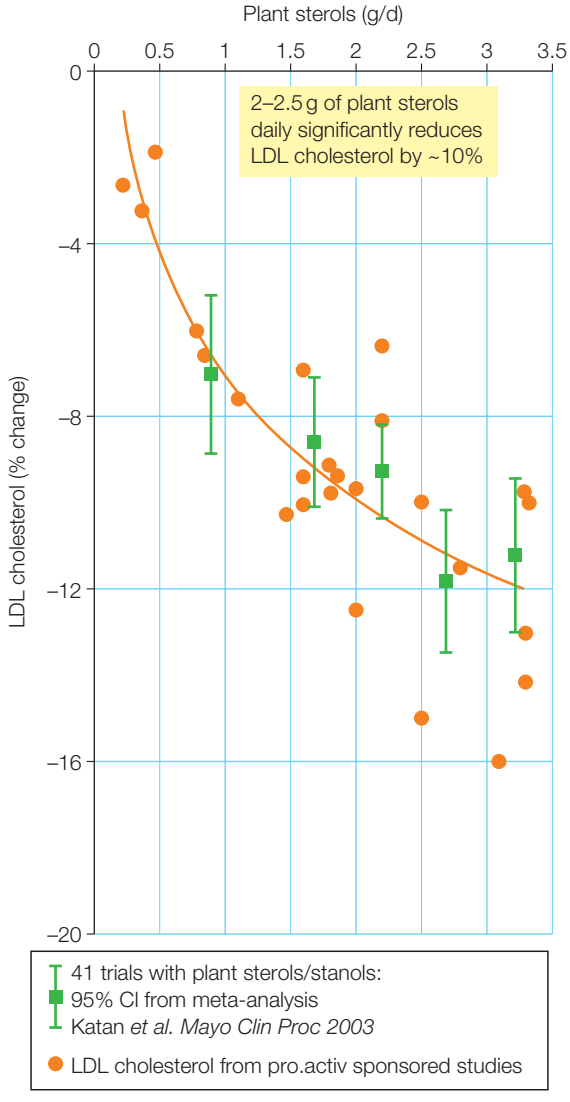
▲ **fig B** These data show the benefits of statins in reducing the risk of CVDs in Asian Indians, who are a particularly high-risk group. Statins had a strong positive benefit to a range of patients.

A UK study showed that men who took a particular statin for five years had a lower risk of death or heart attack, even 10 years after they stopped taking the drug. The study involved 6595 middle-aged men. It showed that for the first five years, the overall risk of heart attack or death from any type of heart disease was 11.8% for the men who took the statin, compared with 15.5% for men who took a **placebo** (an inactive substance that resembles the drug but has no action in the body). The risk was reduced the most while the men were taking the drug, but some level of protection lasted for up to 10 years afterwards.

Most people use statins with little or no ill effect. Side-effects of muscle and joint aches and nausea, constipation and diarrhoea are sometimes reported. However, there are two serious but very rare side-effects. In a tiny number of people, statins trigger a form of muscle inflammation which can be fatal. For example, the US Food and Drug Administration (FDA) reported 3339 cases of these muscle reactions between January 1990 and March 2002, but during this time millions of Americans took statins daily. Statins can also cause liver problems in a small group. As an example, the risk of liver damage in people taking lovastatin is two in a million. Out of 51 741 liver transplant patients in the US between 1990 and 2002, liver failure appeared to be caused by statins in only three cases.

Another risk is more subtle: there is a risk that, if people take statins to lower their blood cholesterol, they will no longer try to eat a healthy diet, and statins give no protection against the other ill effects of a bad diet.

Plant stanols and sterols are now widely sold in spreads and yoghurts. These compounds are very similar in structure to cholesterol. They reduce the amount of cholesterol absorbed from your gut into your blood, which can make it easier for your body to metabolise cholesterol and reduce the levels of LDLs in the blood. Products like these are sold as a food, not as a drug. While there is scientific evidence that they are effective in many people, they have not undergone the levels of testing that drugs such as statins have. Metadata analysis has shown that these products do work if they are eaten regularly in the recommended amounts (2 g per day of plant sterols and stanols). It has been estimated that these products can lower your risk of heart disease by about 25% if they are used correctly (see **fig C**).



▲ **fig C** Scientific evidence from a number of studies shows that plant sterols can reduce harmful LDL cholesterol levels in the blood if used correctly.

ANTICOAGULANTS AND PLATELET INHIBITORY DRUGS

Following heart surgery, or after suffering from a blood clot (thrombosis), drug treatments are used to help prevent the blood clotting too easily. Here are two examples.

Warfarin is an **anticoagulant** that interferes with the manufacture of prothrombin in the body. Low prothrombin levels make the blood clot less easily (see **Section 1B.2**). Warfarin has been used in rat poison – in high doses the blood will not clot at all and the rats bleed to death after the slightest injury. In humans, the dose is carefully monitored to make sure that the clotting of the blood is reduced but not prevented completely.

Platelet inhibitory drugs make the platelets less sticky, and so reduce the clotting ability of the blood. The cheapest and most common of these is aspirin (**fig D**) but clopidogrel is also commonly used.

▲ **fig D** Aspirin is a relatively cheap drug. It has been used traditionally as a painkiller. It is also a very effective way of preventing many cardiovascular problems.

The risks of taking aspirin are well known – it irritates the stomach lining and causes bleeding in the stomach which can become serious. A combination of aspirin and clopidogrel can reduce the risk of developing a range of cardiovascular diseases by 20–25% in some low-risk patients. However, based on data from several studies it appears that, for some patients, the risk of side-effects is much higher when the two drugs are combined. For example, for every 1000 patients at high risk of CVDs treated for 28 months, five cardiovascular events would be avoided – but three major stomach bleeds would be caused. In lower-risk patients, 23 cardiovascular events would be avoided while 10 major bleeds would be caused.

It is difficult to achieve the correct balance between preventing the blood from clotting too easily while allowing it to clot when necessary. For example, when people are treated with anticoagulant drugs such as warfarin, they must be monitored very carefully to make sure that they do not bleed internally, particularly in the brain. The decision whether to give warfarin will depend on many factors, including the patient's age and condition as well as other medication they may be taking.

CHECKPOINT

1. Explain why the side-effects of medication may result in a patient giving up on the treatment. Use the terms *perceived risk* and *actual risk* in your answer.

SKILLS DECISION MAKING

2. The graph in **fig C** comes from the website of a company that makes products containing plant stanols. However, the data appear scientifically acceptable – why? What do they show you about the effect of plant stanols on blood cholesterol levels?

3. (a) Explain why placebos may be used in drug trials.
   (b) The study shown in **fig B** was stopped 2 years early because it was deemed unfair to the patients taking the placebo. Why do you think it was unfair? Is it ever unethical to use a placebo in a trial?

4. Look at **fig B** and answer these questions.
   (a) Explain why statins have a greater effect on reducing the risk of CVDs in people with a lower HDL level.
   (b) Considering that all medical drugs have associated side-effects, what does this graph suggest about which groups should be targeted with statins to reduce CVDs overall in the population?

SUBJECT VOCABULARY

antihypertensive drug which reduces high blood pressure
diuretics drugs which increase the volume of urine produced
beta blockers drugs which block the response of the heart to hormones such as adrenaline
sympathetic nerve inhibitors drugs which inhibit sympathetic nerves, keeping arteries dilated
ACE inhibitors drugs which block the production of angiotensin
side-effect a secondary, usually undesirable effect of a drug or medical treatment
statins drugs that lower the level of cholesterol in the blood
placebo an inactive substance resembling a drug being trialled which is used as an experimental control
plant stanols and sterols similar in structure to cholesterol, these compounds can help reduce blood cholesterol in those consuming them
anticoagulant a substance that interferes with the manufacture of prothrombin in the body
platelet inhibitory drugs drugs used to prevent blood clots forming by preventing platelets clumping together

1C THINKING BIGGER

HEART FAILURE IN THE MIDDLE EAST

SKILLS: CRITICAL THINKING, PROBLEM SOLVING, ANALYSIS, DECISION MAKING, CREATIVITY, INNOVATION, PERSONAL AND SOCIAL RESPONSIBILITY, CONTINUOUS LEARNING, INTELLECTUAL INTEREST AND CURIOSITY, COMMUNICATION, EMPATHY/PERSPECTIVE TAKING

One in four adults in Saudi Arabia are expected to suffer a heart attack within the next 10 years. In the Middle East, the average age for onset of heart failure is 10 years lower than in Western Countries. Heart disease is a multifactorial disease – many factors contribute to the risks of developing heart disease. However, the final failure of the heart can often be attributed to one contributing factor. While 70% of heart failure in the West can be attributed to coronary artery disease, this is not the case in the Middle East.

MEDICAL REVIEW ARTICLE

ABSTRACT

The clinical syndrome of heart failure is the final pathway for a myriad of diseases that affect the heart, and is a leading and growing cause of morbidity and mortality worldwide. Evidence-based guidelines have provided clinicians with valuable data for better applying diagnostic and therapeutic tools, particularly the overwhelming new imaging technology and other, often expensive, therapies and devices, in heart failure patients. In the Middle East, progress has recently been made with the development of regional and multi-centre registries to evaluate the quality of care for patients with heart failure. A new heart function clinic recently began operation and has clearly resulted in a reduced readmission rate for heart failure patients. Many Middle Eastern countries have observed increases in the prevalence of the risk factors for the development of heart failure, including diabetes mellitus, obesity, and hypertension, with heart failure in the Middle Eastern population developing earlier than it is in their Western counterparts by at least 10 years. The earlier onset of disease is the result of the earlier onset of coronary artery disease, highlighting the need for Middle Eastern countries to establish prevention programs across all age groups. The health systems across the Middle East need to be modified in order to provide improved evidence-based medical care. Existing registries also need to be expanded to include long-term survey data, and additional funding for heart failure research is warranted.

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In Middle East and North Africa, health challenges are becoming similar to those in western countries. The World Bank 2013 September http://www.worldbank.org/en/news/press-release/2013/09/04/middle-east-north-Africa-health-challenges-similar-western-countries

From: Mostafa Q Al-Shamiri. Heart failure in the Middle East. *Current Cardiology Reviews* 2013 May; 9(2):174–178 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682400/#R10

SCIENCE COMMUNICATION

SKILLS: ANALYSIS, INTERPRETATION

1 (a) Who do you think the intended audience is?

(b) What is the intended message the author is trying to give?

(c) There are a number of terms used in the article. Select **three** unfamiliar terms from the article and research their meaning. Suggest why those terms have been used.

(d) An abstract is meant to indicate to the reader what is contained in the rest of the document. From the abstract, a researcher might decide whether or not to read the rest of the article. What sort of information would you expect to find in the rest of this article?

INTERPRETATION NOTE

This article is an abstract from a longer article in the journal *Current Cardiology Reviews*. Think about the type of writing used.

BIOLOGY IN DETAIL

SKILLS REASONING

Now you are going to think about the science in the article. You will be surprised how much you know already, but if you choose to do so, you can return to these questions later in your course.

2 (a) What are the main contributing factors to development of heart failure mentioned by the author?

(b) Name **two** more contributing factors.

3 Changes in lifestyle and diet have been blamed for huge increases in the risk factors. For example, diabetes has increased by 87% between 1990 and 2010.

(a) What lifestyle changes are likely to cause such an increase in diabetes?

(b) What changes in diet may contribute to such an increase in diabetes?

4 The author is writing about epidemiology. That is the branch of medicine which deals with the incidence, distribution and possible control of diseases and other factors relating to health. How does understanding the incidence of heart failure and the factors that contribute to it help the medical profession to combat heart failure?

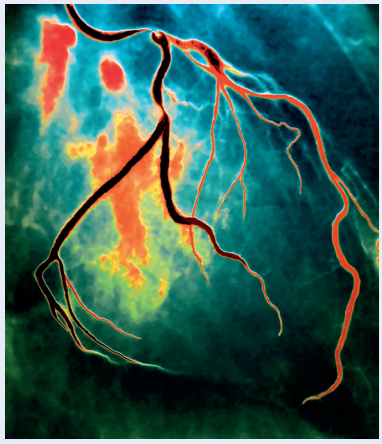
5 Common causes of heart failure are ischaemic heart disease, uncontrolled hypertension and valvular disease. However, in up to 50% of the cases its exact cause remains unknown; this condition is called idiopathic cardiomyopathy. The table shows the results of an epidemiological study.

CAUSE OF HEART FAILURE	% OF CASES IN EACH COUNTRY			
	OMAN	EGYPT	SAUDI ARABIA	YEMEN
ischaemic heart disease	52	66	52	52
valvular disease	8.5	22.5	10.5	7
hypertension	25			25
idiopathic cardiomyopathy	8.3			11

(a) Which cause of heart failure should be the focus of most research?

(b) Suggest why the exact cause of heart failure may be unknown in up to 50% of cases.

ACTIVITY



▲ **fig A** Heart disease, in particular coronary artery disease, is an increasing problem in the Middle East.

Research the risk factors for heart disease. Find out what can be done to reduce these factors.

Prepare a leaflet designed to help people understand how their lifestyle and diet affect their chances of developing heart disease.

Provide advice to someone who has been told that they are at risk of developing heart disease.

THINKING BIGGER TIP

You can refer to the full version of this paper, to the references listed at the end, to online encyclopaedias, to other scientific papers and to books. In each case, judge the reliability of your source before you use it.

1C EXAM PRACTICE

1 (a) What is an atheroma?

A a hardened part of the artery wall
B a swelling in the artery wall
C a fatty deposit in the artery wall
D a narrowing of the artery wall [1]

(b) Justify the use of the term *multifactorial* when used to describe atherosclerosis. [2]

(c) (i) Which of the following is **not** a risk factor for atherosclerosis?

A obesity
B high-salt diet
C high-fibre diet
D lack of exercise [1]

(ii) One weight loss plan suggests eating a diet with no carbohydrate but allows eating as much protein and fat as you like. Discuss the merits of such a diet. [6]

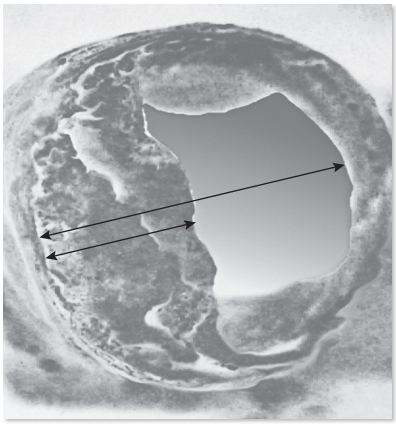
(Total for Question 1 = 10 marks)

2 There are many factors that increase the risk of developing atherosclerosis.

(a) Discuss whether correlation means cause. [4]

(b) Many studies have been conducted to investigate the causes of atherosclerosis and cardiovascular disease. State **three** factors in the design of a study which make the findings more valid. [3]

(c) The photograph below shows a small artery with a large plaque or atheroma. If the internal diameter of the artery is 1 mm, determine the area blocked by the plaque. [2]

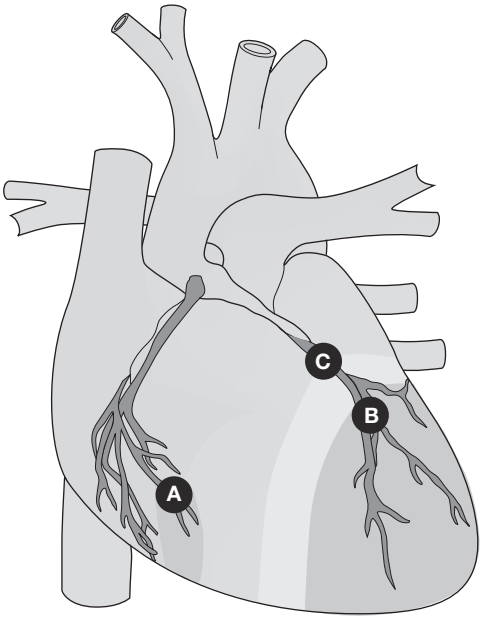


(Total for Question 2 = 9 marks)

3 (a) What is the role of the coronary arteries?

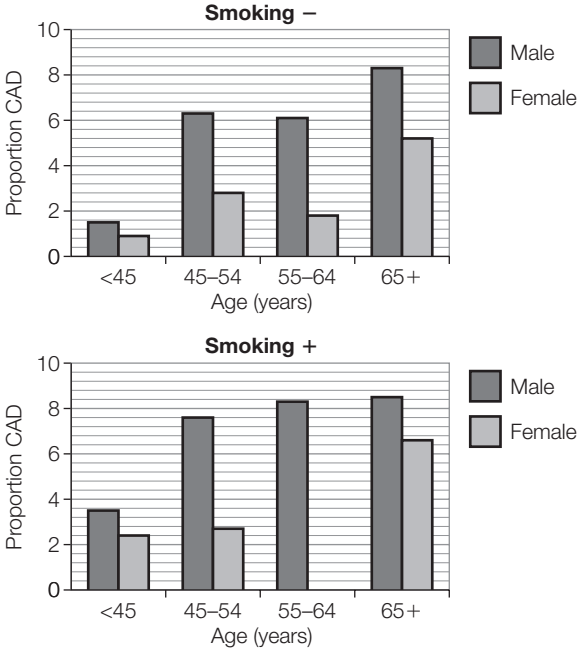
A to deliver oxygenated blood to the atria
B to deliver oxygenated blood to the ventricle walls
C to carry deoxygenated blood into the atria
D to carry oxygen and nutrients to the rest of the body [1]

(b) The illustration below shows the coronary arteries in the heart with the position of three possible blockages labelled A, B and C.



Explain why a blockage at C would have far greater consequences than a blockage at either A or B. [3]

(c) The bar charts below show the proportion of people with coronary artery disease based on a Jordanian study in 2017.



(i) Describe the effect that smoking has on the risk of developing coronary artery disease in men of different ages. [4]

(ii) Suggest why there is no data for women in the 55–64 age bracket. [1]

(iii) What does the lack of data for women in the 55–64 age bracket suggest about the study? That it is:

A not valid

B not reliable

C not precise

D not repeatable. [1]

(iv) Assuming that smoking affects women to the same extent as men, what proportion of women would you expect to have CAD in the 55–64 age bracket of smokers? [3]

(Total for Question 3 = 13 marks)

4 (a) Describe the main stages in the formation of an atheroma. [3]

(b) Explain how atherosclerosis can lead to a heart attack. [3]

(c) The average age for a first heart attack in the UAE is 20 years younger than the global average. A recent survey of 850 heart attack patients in the UAE gave the following results.

Risk factor	Diabetes	High blood pressure	High blood cholesterol
Number of patients with risk factor		380	212
% of patients with risk factor	38	44.7	

Calculate the number of patients in the survey who had diabetes. [2]

Calculate the % of heart attack patients in the survey who had high blood cholesterol. [2]

(d) State **two** other risk factors that increase the chance of a heart attack. [2]

(Total for Question 4 = 12 marks)

5 (a) Explain why perceived risk is often not the same as actual risk. [2]

(b) One risk factor for cardiovascular disease is obesity. The table below shows the BMI scale.

BMI	Category
18.5–24.9	normal
25–29.9	overweight
30–34.9	obese
35–39.9	dangerously obese

(i) What is the BMI for a man who is 1.8 metres tall and weighs 115 kg?

A 0.03

B 30.6

C 35.5

D 63.9 [1]

(ii) Suggest three changes in lifestyle that a health professional might advise for this man. [3]

(iii) Name another quick and easy measure that people could use to indicate if they are obese. [1]

(c) Despite increasing evidence of the risks caused by obesity, approximately one-third of the population in the Middle East are obese. Discuss why so many people are obese. [3]

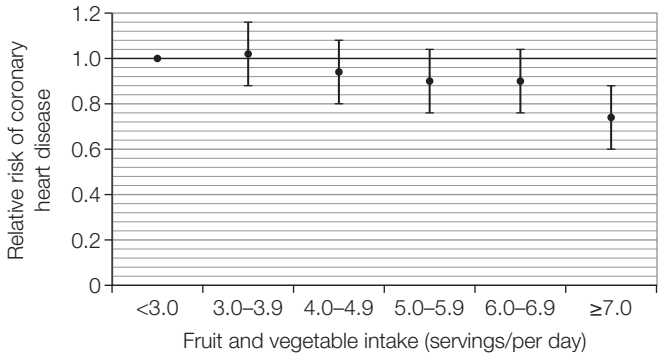
(Total for Question 5 = 10 marks)

6 A person at risk of cardiovascular disease may be given medication to reduce their risk.

(a) How might anticoagulants or platelet inhibitors reduce the risk of a heart attack or stroke? [2]

(b) Factors such as high blood pressure and type 2 diabetes are a direct result of obesity. Evaluate the use of medication such as antihypertensives and statins to treat people who are at risk of cardiovascular disease. [4]

(c) The graph below shows the relative risk of coronary heart disease plotted against the number of servings of fruit and vegetables eaten per day.



(i) People are advised to eat at least five servings of fruit and vegetables per day. Justify this advice using the information in the graph. [3]

(ii) Suggest what evidence there is in the graph to modify the advice. [2]

(Total for Question 6 = 11 marks)

MATHS SKILLS

In order to be able to develop your skills, knowledge and understanding in Biology, you will need to have developed your mathematical skills in a number of key areas. 10% of the marks in your exams will be for level 2 or higher maths. This is maths where you will need to make some kind of decision such as what equation to use or select what data to use from a graph or some other source. The maths will be tested in a biological context. Marks will be awarded for the correct answer, but you may also gain marks for showing your working – so always remember to set out your maths calculations clearly. This section gives more explanation and examples of some key mathematical concepts you need to understand. Further examples relevant to your International AS/A level Biology studies are given throughout the book.

ARITHMETIC AND NUMERICAL COMPUTATION

USING STANDARD FORM

Dealing with very large or small numbers can be difficult. To make them easier to handle, you can write them in the format $a \times 10^b$. This is called standard form.

To change a number from decimal form to standard form:

- Count the number of positions you need to move the decimal point by until it is directly to the right of the first number which is not zero.
- This number is the index number that tells you how many multiples of 10 you need. If the original number was a decimal, your index number must be negative.

Here are some examples:

DECIMAL NOTATION	STANDARD FORM NOTATION
0.000 000 012	1.2×10^{-8}
15	1.5×10^{1}
1000	1×10^{3}
3 700 000	3.7×10^{6}

USING RATIOS, FRACTIONS AND PERCENTAGES

Ratios, fractions and percentages help you to express one quantity in relation to another with precision. Ratios compare like quantities using the same units. Fractions and percentages are important mathematical tools for calculating proportions.

RATIOS

A ratio is used to compare quantities. You can simplify ratios by dividing each side by a common factor. For example 12 : 4 can be simplified to 3 : 1 by dividing each side by 4.

WORKED EXAMPLE

Divide 180 into the ratio 3 : 2

Our strategy is first to work out the total number of parts. Then divide 180 by the number of parts to find the value of one part.

Total number of parts = 3 + 2 = 5

Value of one part = 180 ÷ 5 = 36

Answer = 3 × 36 : 2 × 36 = 108 : 72

Check your answer by making sure the parts add up to 180:

72 + 108 = 180

EXAM HINT

You may be asked to work out the ratio of offspring from a genetic cross. This is level 2 maths because you need to calculate the ratio from a genetic diagram.

FRACTIONS

When using fractions, make sure you know the key strategies for the four operators.

Remember:

- the denominator is the number under the line in a fraction
- the numerator is the number over the line in a fraction
- the operator is what the fraction is doing (adding, subtracting, multiplying or dividing).

To add or subtract fractions, find the lowest common multiple (LCM) and then use the golden rule of fractions. The golden rule states that a fraction remains unchanged if the numerator and denominator are multiplied or divided by the same number.

WORKED EXAMPLE

$\frac{1}{2} + \frac{1}{5} = \frac{5}{10} + \frac{2}{10} = \frac{7}{10}$

To multiply fractions together, simply multiply the numerators together and multiply the denominators together.

WORKED EXAMPLE

$\frac{2}{7} \times \frac{4}{9} = \frac{8}{63}$

To divide fractions, simply invert or flip the second fraction and multiply.

WORKED EXAMPLE

$\frac{2}{3} \div \frac{7}{9} = \frac{2}{3} \times \frac{9}{7} = \frac{18}{21} = \frac{6}{7}$

PERCENTAGES

When using percentages, it is useful to recall the different types of percentage questions.

To increase a value by a given percentage, use a percentage multiplier.

WORKED EXAMPLE

Increase 30 mg by 23%

If we increase by 23%, our new value will be 123% of the original value. We therefore multiply by 1.23.

Answer = 30 × 1.23 = 36.9 mg

EXAM HINT

In the exam, this may be asked as: 'An enzyme-controlled reaction produced 30 mg of product at 20 °C. At 30 °C the product increased by 23%. Calculate the mass of product at 30 °C.' This is level 2 maths because you need to decide how to carry out the calculation.

To decrease a value by a given percentage, you need to focus on the part that is left over after the decrease.

WORKED EXAMPLE

Decrease 30 mg by 23%

If we decrease by 23%, our new value will be 100 – 23 = 77% of the original value. We therefore multiply by 0.77.

Answer = 30 × 0.77 = 23.1 mg

To calculate a percentage increase, use the following equation:

$$\text{Percentage change} = \frac{\text{difference between values}}{\text{original value}} \times 100$$

To calculate percentage decrease, use the same equation but remember that your answer should be negative. Also remember that a percentage increase or decrease requires two steps: calculate the change, then calculate the percentage.

WORKED EXAMPLE

The volume of a solution increased from 40 ml to 50 ml. Calculate the percentage increase.

Change in volume = 10 ml

$$\text{Percentage increase} = \frac{10}{40} \times 100 = 25\%$$

EXAM HINT

This could be asked in the context of conservation: 'A population of gorillas increased from 40 to 50. Calculate the percentage increase in population size.' This is level 2 maths because there are two steps in the calculation. You need to calculate the change, then you need to calculate the percentage.

ALGEBRA

USING ALGEBRAIC EQUATIONS

Using algebraic equations is a very important skill for finding the value of an unknown quantity. In the real world, letters are used to symbolise important variables such as the blood sugar level of a diabetic or the irregular heartbeat of a patient.

The key rule to remember when using equations is that any operation that you apply to one side of the equation must also be applied to the other side.

WORKED EXAMPLE

Find the value of x in the following equation: $7x - 6 = 36$

Adding 6 to each side gives $7x = 42$

Dividing each side by 7 gives $x = 6$

CHANGING THE SUBJECT OF AN EQUATION

It can be helpful to rearrange an equation to express or isolate the variable you are interested in. Always remember that any operation that you apply to one side of the equation must also be applied to the other side.

WORKED EXAMPLE

The diameter of a cell measured under the light microscope at magnification ×100 is 2 mm. Calculate the actual size.

You may remember the equation

image size = actual size × magnification

but note the question is asking us to find the actual size given the image size and magnification. We can rearrange the equation to suit our needs:

$$\frac{\text{image size}}{\text{magnification}} = \text{actual size}$$

$$\text{So actual size} = \frac{2}{100} = 0.02 \text{ mm}$$

HANDLING DATA

USING SIGNIFICANT FIGURES

Often when you do a calculation, your answer will have many more figures than you need. Using an appropriate number of significant figures will help you to interpret results in a meaningful way.

Remember the 'rules' for significant figures:

- the first significant figure is the first figure which is not zero
- digits 1–9 are always significant
- zeros which come after the first significant figure are significant unless the number has already been rounded.

Here are some examples.

EXACT NUMBER	TO ONE S.F.	TO TWO S.F.	TO THREE S.F.
45 678	50 000	46 000	45 700
45 000	50 000	45 000	45 000
0.002 755	0.003	0.002 8	0.002 76

UNDERSTANDING THE TERMS MEAN, MEDIAN AND MODE

There are three different measures of average that you should know how to calculate.

- The **mean** is calculated by adding up all of the values in the data set and dividing them by the number of values. It is sometimes called the arithmetical average. The mean takes into account each number of the data set equally and can be used for further statistical analysis such as calculating a standard deviation. However, a disadvantage of the mean is that it may be affected by extreme values.
- The **median** is the middle value when the values are arranged in order. The median of a data set is found by putting the values in order from lowest to highest and then finding the middle value. If there is an even number of values, the median is found by calculating the mean of the two middle values.
- The **mode** is the value that occurs most often. The mode of a data set is found by identifying the most frequent value. It may not be possible to calculate the mode if there are two or more values with the same highest frequency.

WORKED EXAMPLE

Find the mean, median and mode of the following data set:
7, 12, 18, 6, 2, 12

To find the mean, we add up all of the values in the data set and divide them by the number of values.

$$\text{mean} = \Sigma\frac{x}{n}$$
$$= \frac{(7 + 12 + 18 + 6 + 2 + 12)}{6}$$
$$= \frac{57}{6}$$
$$= 9.5$$

To find the median, we need to arrange the values in increasing order: 2, 6, 7, 12, 12, 18.

Since there is an even number of values, we need to look at the two middle values and find the mean. The third value is 7 and the fourth value is 12.

$$\text{median} = \frac{(7 + 12)}{2} = 9.5$$

To find the mode, we need to identify the value that occurs most frequently. The only number that occurs more than once is 12.

$$\text{mode} = 12$$

EXAM HINT

You will need to recall the equation to use and probably select the data to use from a table of results or some other source.

CALCULATING THE MEAN FROM FREQUENCY DATA

The mean can be calculated from frequency data by finding the sum of the individual values multiplied by their respective frequencies and then dividing by the total frequency.

WORKED EXAMPLE

The table below shows the results of a survey looking into the number of units of alcohol consumed in a week by a sample of patients. Find the mean number of units of alcohol consumed per week.

UNITS OF ALCOHOL CONSUMED IN A WEEK	NUMBER OF PATIENTS
0	4
2	7
4	12
6	9
8	15
10	23

$$\text{mean} = \frac{(0 \times 4) + (2 \times 7) + (4 \times 12) + (6 \times 9) + (8 \times 15) + (10 \times 23)}{70}$$
$$= \frac{0 + 14 + 48 + 54 + 120 + 230}{70}$$
$$= \frac{466}{70}$$
$$= 6.6571$$
$$= 6.7 \text{ to } 1 \text{ d.p.}$$

EXAM HINT

You are given the data but this is level 2 maths because there are three steps in the calculation. You need to multiply units per week by the number of patients and then add up those values before dividing by the number of patients.

UNDERSTANDING MEASURES OF DISPERSION INCLUDING STANDARD DEVIATION AND RANGE

Two different sets of data may have similar averages but statisticians are interested in looking deeper into the data for meaningful differences in dispersion. For example, if one data set refers to patients who are given a new cancer drug and a second data set refers to patients who are given a placebo drug, it is very important to look for key differences in the dispersion of data, such as standard deviation and range, and not just at measures of average.

RANGE

The range of a set of data is the difference between the highest and lowest values in the set. To find the range, subtract the smallest value in the set from the largest value in the set.

STANDARD DEVIATION

Standard deviation is a measure of the dispersion or 'spread' of data around the mean.

- A low standard deviation indicates that the data have a narrow range and the points are closely grouped to the mean. This could indicate greater reliability.
- A high standard deviation indicates that the data points have a larger range and are less well grouped. This might indicate lower reliability.

To calculate the standard deviation, use the formula:

$$s = \sqrt{\frac{\Sigma(x - \bar{x})^2}{n}}$$

where s = standard deviation, x is an individual value, $\bar{x}$ = the mean value, n = the number of values.

TECHNIQUE

1 Calculate the mean of the data set by finding the sum of the values and then dividing by the number of values. This is $\bar{x}$.
2 For each data value, calculate the difference between the data value and the mean. Record these figures in a table.
3 Find the square of each of these differences. Record these figures in a new column in your table.
4 Find the sum of these squares. This is $\Sigma(x - \bar{x})^2$.
5 Divide this figure by the number of items in the data set.

This is $\frac{\Sigma(x - \bar{x})^2}{n}$

6 Find the square root of your answer. This is the standard deviation.

WORKED EXAMPLE

A pupil investigates the effect that two newly developed fertilisers (A and B) have on the growth of potato crops. Fourteen 10 m² areas of a field were sectioned off and treated with either fertiliser A or B. The table below shows the yields of potatoes from the test areas following harvest.

(a) Calculate the mean and standard deviation for the test plot yields for fertilisers A and B.

(b) Interpret the results of your answers to (a).

	TEST PLOT YIELD/Kg						
FERTILISER	PLOT 1	PLOT 2	PLOT 3	PLOT 4	PLOT 5	PLOT 6	PLOT
A	25	27	34	18	21	26	28
B	17	35	42	19	35	22	44

(a) To calculate the mean yield for A:

25 + 27 + 34 + 18 + 21 + 26 + 28 = 179

179/7 = 25.6 kg to 1 d.p.

To calculate the standard deviation for A:

$(25 - 25.6)^2 = 0.36$ $(27 - 25.6)^2 = 1.96$

$(34 - 25.6)^2 = 70.56$ $(18 - 25.6)^2 = 57.76$

$(21 - 25.6)^2 = 21.16$ $(26 - 25.6)^2 = 0.16$

$(28 - 25.6)^2 = 5.76$

Sum of squares = 157.72

EXAM HINT

You will not be expected to recall the equation for standard deviation. It is important that you set out any part of the calculation clearly. If your final answer is incorrect, you may still gain marks for using the correct technique.

Divide by the number of plots:

157.72/7 = 22.5314

Now calculate the square root of this value:

$\sqrt{22.5314}$ = 4.8 to 1 d.p.

To calculate the mean yield for B:

17 + 35 + 42 + 19 + 35 + 22 + 44 = 214

214/7= 30.6 kg to 1 d.p.

To calculate the standard deviation for B:

$(17 - 30.6)^2 = 184.96$ $(35 - 30.6)^2 = 19.36$

$(42 - 30.6)^2 = 129.96$ $(19 - 30.6)^2 = 134.56$

$(35 - 30.6)^2 = 19.36$ $(22 - 30.6)^2 = 73.96$

$(44 - 30.6)^2 = 179.56$

Sum of squares = 741.72

$\sqrt{741.72/7}$ = 10.3 kg to 1 d.p.

(b) Fertiliser B produces a greater yield of potato crop (19% increase from fertiliser A), however the variation in crop yield (as shown by the standard deviation) of plots treated with fertiliser B is much greater and so fertiliser A produces a more consistent crop yield.

UNDERSTANDING SIMPLE PROBABILITY

The term *probability* is used to talk about the likelihood of an event happening on a scale of 0 to 1. A probability of 0 means that it is impossible that an event will occur. A probability of 1 means that it is certain that an event will occur. You should be comfortable interpreting probabilities in a scientific context, such as the probability of developing a disease or inheriting a specific gene.

INTERPRETING A SCATTERGRAM

A scattergram is a useful way of representing the relationship between two variables. To draw a scattergram, first choose appropriate scales and label both axes. Then, use a pencil to draw a small point (a cross or sharp dot) for each pair of variables.

A scattergram can be used to interpret whether there is correlation between two variables. We say that there is correlation between two variables if when one variable changes, there is also a change in the other variable.

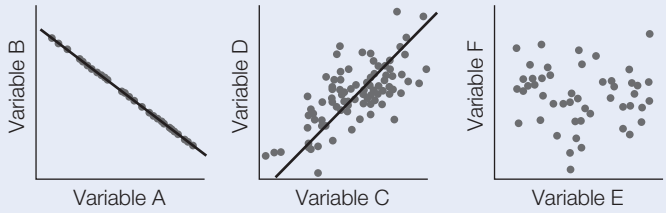
- If the points are distributed tightly around a line, the variables are strongly correlated.
- If the points are loosely distributed around a line, the variables are weakly correlated.
- If there is no pattern in the distribution of points, there is no correlation.

Correlation can be positive (as one variable increases, the other also increases) or negative (as one variable increases, the other decreases).

A scattergram may include one or more points that lie outside of the main spread of values. Such a point is called an outlier or anomaly and it can be ignored.

To draw a line of best fit, use a ruler to draw a straight line that passes as close as possible to all of the points. You can use a line of best fit to make estimations. This is called interpolation. The more closely correlated the variables, the more accurate your estimate is likely to be.

WORKED EXAMPLE



There is a strong negative correlation between variables A and B.

There is a weak positive correlation between variables C and D.

There is no correlation between variables E and F.

EXAM HINT

It is important to use the information given in the scattergram. Refer to the axis titles, e.g. As variable A increases variable B decreases. There is a strong negative correlation.

CONSTRUCTING HISTOGRAMS

Constructing frequency tables and histograms is often the first step to looking carefully at a set of raw continuous data and helps us to begin to look for patterns and behaviours in a data set. Histograms are very similar to bar charts but there are two differences.

- In a bar chart, each column represents a discrete category. The columns are of equal widths and always separated.
- In a histogram, the columns represent continuous data. The width of the columns is usually the same for each category. However, for more advanced work the widths may vary. The columns are always adjacent.

TECHNIQUE

1. Find the range of your values.
2. Choose the categories that you will use. Make sure that they are continuous (i.e. there are no gaps and there is no overlap between categories).
3. Create a frequency table.
4. Plot your data, ensuring that frequency is represented on the *y*-axis and that the categories are represented on the *x*-axis.

WORKED EXAMPLE

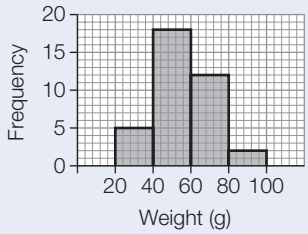
The weights of field mice found in a specified area of farmland to the nearest gram are shown below. Draw a histogram to represent the weights of field mice.

Weights of field mice (g): 42, 66, 75, 44, 52, 56, 60, 81, 64, 54, 37, 59, 47, 79, 66, 76, 53, 35, 40, 63, 56, 28, 43, 78, 83, 50, 38, 67, 68, 47, 52, 49, 32, 46, 72, 58, 58

To choose our categories, we first identify the range of the data. The highest value is 83 g and the lowest value is 28 g. The categories we choose need to at least cover this range. One sensible way of splitting this range is to use four categories each covering an interval of 20 g:

WEIGHT/g	FREQUENCY
20–39	5
40–59	18
60–79	12
80–99	2

We can now use this frequency data to draw a histogram.



PRINCIPLES OF SAMPLING

When a scientist studies a population, it is not possible to study each organism in detail. Scientists therefore use sampling to estimate characteristics of the whole population by looking at a subset of individuals in the population. It is important that the sample chosen is representative of the habitat.

Once a suitable sample has been selected, it can be analysed. A measure of biodiversity that takes into account both the species richness and the species abundance of an area can be calculated using the following formula.

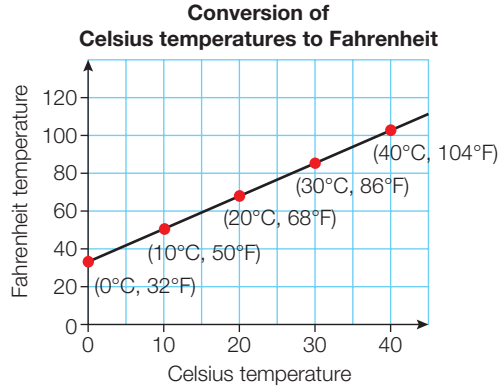
$$D = \frac{N(N-1)}{\sum n(n-1)}$$

where n is the number of individuals of a particular species (or the percentage cover for plants), and N is the total number of all individuals of all species (or the total percentage cover for plants).

GRAPHS

UNDERSTAND THAT $y = mx + c$ REPRESENTS A LINEAR RELATIONSHIP

Two variables are in a linear relationship if they increase at a constant rate in relation to one another. If you plotted a graph with one variable on the x-axis and the other variable on the y-axis, you would get a straight line. Any linear relationship can be represented by the equation $y = mx + c$ where the gradient of the line is m and the value at which the line crosses the y-axis is c. An example of a linear relationship is the relationship between degrees Celsius and degrees Fahrenheit, which can be represented by the equation $F = \frac{9}{5}C + 32$ where C is temperature in degrees Celsius and F is temperature in degrees Fahrenheit.



CALCULATE A RATE OF CHANGE FROM A GRAPH SHOWING A LINEAR RELATIONSHIP

The rate of change from a graph showing a linear relationship is the gradient, or steepness, of the line. It is a measure of the rate of change of one variable (represented on the x-axis) in relation to the other variable (represented on the y-axis).

TECHNIQUE

1 Draw a right-angled triangle anywhere on the line.

2 Use the following equation to calculate the rate of change:

$$\text{gradient} = \frac{\text{difference on } y\text{-axis}}{\text{difference on } x\text{-axis}}$$

3 State the unit for your answer.

DRAW AND USE THE SLOPE OF A TANGENT TO A CURVE AS A MEASURE OF A RATE OF CHANGE

A tangent is a straight line that just touches the curve at one point. The gradient of a curve at a given point is equal to the gradient of the tangent to the curve at that point.

TECHNIQUE

1 Use a ruler to draw a tangent to the curve.

2 Calculate the gradient of the tangent using the technique given for a linear relationship. This is equal to the gradient of the curve at the point of the tangent.

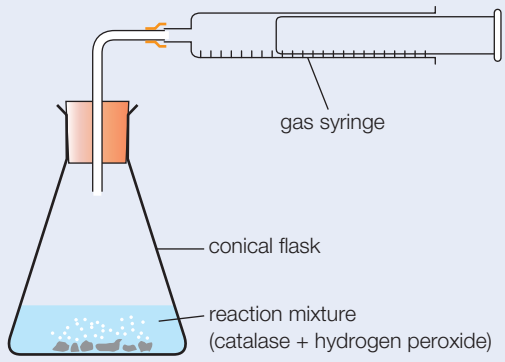
3 State the unit for your answer.

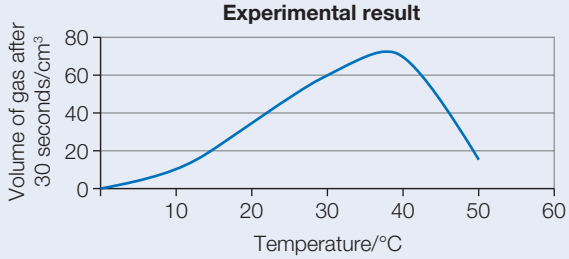
APPLYING YOUR SKILLS

You will often find that you need to use more than one maths technique to answer a question. In this section, we will look at two example questions and consider which maths skills are required and how to apply them.

WORKED EXAMPLE

Hydrogen peroxide is a toxic by-product of metabolism and is made in all living cells. Cells make the enzyme catalase in order to convert the toxin into water and oxygen. In order to study the effect of temperature on catalase activity, an experiment was set up using the equipment shown in the figure below. The volume of oxygen released in 30 seconds was measured at various temperatures using the gas syringe. The results of the experiment are shown in the graph below.





(a) *Calculate the percentage increase in volume of oxygen produced in 30 seconds at 40 °C compared to that produced at 10 °C.* (3 marks)

(b) *Calculate the rate of gas production at 20, 40 and 50 °C and interpret the results.* (5 marks)

(c) *A further experiment is carried out where the volume of oxygen is recorded over the entire time of the reaction at 10 °C and 40 °C. The results are shown below:*

	TOTAL VOLUME OF OXYGEN RELEASED/cm³									
TEMPERATURE / °C	**0 s**	**10 s**	**20 s**	**30 s**	**40 s**	**50 s**	**60 s**	**70 s**	**80 s**	**90 s**
10	0	2	5	9	16	22	28	33	35	35
40	0	7	15	27	33	35	35	35	35	35

Display both sets of results on a graph with an appropriate scale. (4 marks)

(d) *Calculate the difference in rate between the reactions at 30 seconds.* (4 marks)

(a) The volume of gas at 10 °C = 10 cm^3 (1 mark)

The volume of gas at 40 °C = 70 cm^3 (1 mark)

The percentage increase = $\frac{(70 - 10)}{10} \times 100 = 600\%$ increase (1 mark)

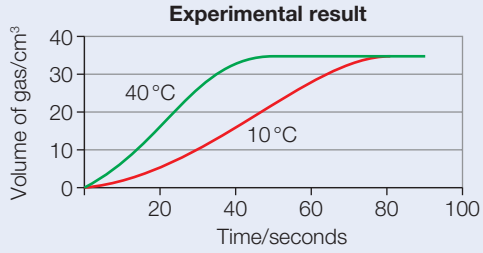
(b) 20 °C = $\frac{35}{30}$ = 1.17 $cm^3\ s^{-1}$ (1 mark)

40 °C = $\frac{70}{30}$ = 2.33 $cm^3\ s^{-1}$ (1 mark)

50 °C = $\frac{15}{30}$ = 0.5 $cm^3\ s^{-1}$ (1 mark)

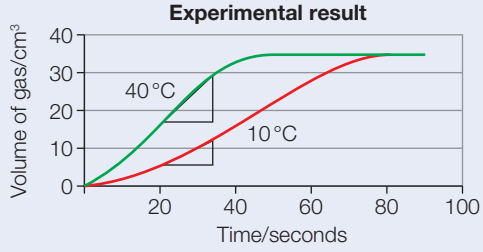
The rate has doubled between 20 °C and 40 °C, but at 50 °C, the rate has decreased. (2 marks)

(c)



(marks awarded for: axes correct way round, axes labelled with units, points plotted correctly, suitable line drawn)

(d) We draw a tangent to each curve at 15 seconds so that we can use the gradient of the curve to calculate the rate.



(1 mark for two correct tangents
1 mark for calculating the gradients
1 mark for calculating the rates of reactions
1 mark for calculating the difference)

We can then use the following equation to calculate gradient:

$$\text{gradient} = \frac{\text{difference on } y\text{-axis}}{\text{difference on } x\text{-axis}}$$

Rate of reaction at 10 °C at 30 seconds = $\frac{5}{13}$ = 0.38 $cm^3\ s^{-1}$

Rate of reaction at 40 °C at 30 seconds = $\frac{8}{10}$ = 0.8 $cm^3\ s^{-1}$

Difference in rate between reactions at 15 seconds
= 0.8 − 0.38 = 0.42 $cm^3\ s^{-1}$

WORKED EXAMPLE

A photomicrograph of a T helper cell was taken using an electron microscope set at a magnification of ×50 000. In the image, several organelles were clearly identified and measured.

(a) *Calculate the actual object length of each organelle.* (4 marks)

ORGANELLE	IMAGE LENGTH/mm	OBJECT LENGTH/μm
nucleus	240	
endoplasmic reticulum	360	
lysosome	10	
mitochondrion	120	

(b) *A lysosome is a spherical organelle. Calculate the surface area and volume of a lysosome.* (3 marks)

(c) *Calculate the surface area to volume ratio of a lysosome.* (2 marks)

(a) The question tells us that the magnification is ×50 000.

We know that image size = actual size × magnification

To make it easier to use, we can rearrange this equation as actual size = $\frac{\text{image size}}{\text{magnification}}$

Actual length of nucleus = $\frac{240}{50\,000}$ = 0.0048 mm

Actual length of ER = $\frac{360}{50\,000}$ = 0.0072 mm

Actual length of lysosome = $\frac{10}{50\,000}$ = 0.0002 mm

Actual length of mitochondrion = $\frac{120}{50\,000}$ = 0.0024 mm

Before we can put these figures in the table, we need to convert to μm. 1 mm = 1000 μm so we need to multiply each figure by 1000.

ORGANELLE	IMAGE LENGTH/mm	OBJECT LENGTH/μm
nucleus	240	4.8
endoplasmic reticulum	360	7.2
lysosome	10	0.2
mitochondrion	120	2.4

(1 mark each)

(b) Recall the following formulae, where r is radius:

Surface area of sphere = $4\pi r^2$

Volume of sphere = $\frac{4}{3}\pi r^3$

From (a) you know that the diameter of the lysosome is 0.2 μm. This means that the radius must be 0.1 μm. (1 mark)

Surface area of lysosome = $4\pi(0.1)^2 = 4\pi \times 0.01 = 0.1257\ \mu m^2$ to 4 d.p. (1 mark)

Volume of lysosome = $\frac{4}{3}\pi(0.1)^3 = \frac{4}{3}\pi \times 0.001 = 0.0042\ \mu m^3$ to 4 d.p. (1 mark)

(c) It is simplest and most accurate to use the exact expressions from (b) involving π, rather than the final answers which have been rounded.

Surface area to volume ratio = $4\pi \times 0.01 : \frac{4}{3}\pi \times 0.001$

We can simplify by multiplying each side by 1000 and dividing each side by π:

Surface area to volume ratio = $40 : \frac{4}{3}$ (1 mark)

Now we can divide each side by 4 and multiply by 3 to get:

Surface area to volume ratio = 120 : 4 = 30 : 1 (1 mark)

PREPARING FOR YOUR EXAMS

IAS AND IAL OVERVIEW

The Pearson Edexcel International Advanced Subsidiary (IAS) in Biology and the Pearson Edexcel International Advanced Level (IAL) in Biology are modular qualifications. The IAS can be claimed on completion of the International Advanced Subsidiary (IAS) units. The International Advanced Level can be claimed on completion of all the units (IAS and IA2 units).

- International AS students will sit three exam papers. The IAS qualification can either be standalone or contribute 50% of the marks for the International Advanced Level.
- International A level students will sit six exam papers, the three IAS papers and three IAL papers.

The tables below give details of the exam papers for each qualification.

IAS Papers	**Paper 1: Unit 1** **Molecules, Diet, Transport and Health**	**Paper 2: Unit 2** **Cells, Development, Biodiversity and Conservation***	**Paper 3: Unit 3** **Practical Skills in Biology 1**
Topics covered	Topics 1–2	Topics 3–4	Topics 1–4
% of the IAS level qualification	40%	40%	20%
% of the IA level qualification	20%	20%	10%
Length of exam	1 hour 30 minutes	1 hour 30 minutes	1 hour 20 minutes
Marks available	80 marks	80 marks	50 marks
Question types	multiple choice short open open response calculation extended writing	multiple choice short open open response calculation extended writing	short open open response calculation
Mathematics	A minimum of 10% of the marks across all three both papers will be awarded for mathematics at Level 2 or above		

* This paper will contain some synoptic questions which require knowledge and understanding from Unit 1.

IAL Papers	**Paper 1: Unit 4** **Energy, the Environment, Microbiology and Immunity****	**Paper 2: Unit 5** **Respiration, the Internal Environment†**	**Paper 3: Unit 6** **Co-ordination and Gene Technology**
Topics covered	Topics 5–6	Topics 7–8	Topics 5–8
% of the IAL qualification	20%	20%	10%
Length of exam	1 hour 45 minutes	1 hour 45 minutes	1 hour 20 minutes
Marks available	90 marks	90 marks	50 marks
Question types	multiple choice short open open response calculation extended writing	multiple choice short open open response calculation extended writing	drawing short open open response calculation
Mathematics	A minimum of 10% of the marks across all three papers will be awarded for mathematics at Level 2 or above		

** This paper will contain some synoptic questions which require knowledge and understanding from Units 1 and 2.
† This paper will contain some synoptic questions which require knowledge and understanding from Units 1, 2 and 4.

EXAM STRATEGY

ARRIVE EQUIPPED

Make sure you have all of the correct equipment needed for your exam. As a minimum you should take:

- pen (a black ballpoint pen is best)
- pencil (HB)
- ruler (ideally 30 cm)
- rubber (make sure it's clean and doesn't smudge the pencil marks or rip the paper)
- calculator (scientific).

ENSURE YOUR ANSWERS CAN BE READ

Your handwriting does not have to be perfect but the examiner must be able to read it! When you're in a hurry it's easy to write key words that are difficult to decipher.

PLAN YOUR TIME

Note how many marks are available on the paper and how many minutes you have to complete it. This will give you an idea of how long to spend on each question. Be sure to leave some time at the end of the exam for checking answers. A rough guide of a minute a mark is a good start, but short answers and multiple choice questions may be quicker. Longer answers might require more time.

UNDERSTAND THE QUESTION

Always read the question carefully and spend a few moments working out what you are being asked to do. The command word used will give you an indication of what is required in your answer. It can be useful to highlight key words in the question.

Be scientific and accurate, even when writing longer answers. Use the technical terms you've been taught.

Always show your working for any calculations. Marks may be available for individual steps, not just for the final answer. Also, even if you make a calculation error, you may be awarded marks for applying the correct technique.

PLAN YOUR ANSWER

In questions marked with an *, marks will be awarded for your ability to structure your answer logically showing how the points that you make are related or follow on from each other where appropriate. Read the question fully and carefully (at least twice!) before beginning your answer.

MAKE THE MOST OF GRAPHS AND DIAGRAMS

Diagrams and sketch graphs can earn marks – often more easily and quickly than written explanations – but they will only earn marks if they are carefully drawn.

- If you are asked to read a graph, pay attention to the labels and numbers on the x- and y-axes. Remember that each axis is a number line.
- If asked to draw or sketch a graph, always ensure you use a sensible scale and label both axes with quantities and units. If plotting a graph, use a pencil and draw small crosses or dots for the points.
- Diagrams must always be neat, clear and fully labelled.

CHECK YOUR ANSWERS

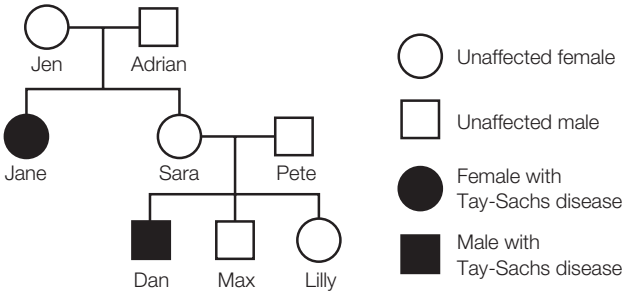
For open-response and extended writing questions, check the number of marks that are available. If three marks are available, have you made three distinct points?

For calculations, read through each stage of your working. Substituting your final answer into the original question can be a simple way of checking that the final answer is correct. Another simple strategy is to consider whether the answer seems sensible. Pay particular attention to using the correct units.

SAMPLE EXAM ANSWERS

QUESTION TYPE: MULTIPLE CHOICE

The genetic pedigree diagram below shows the inheritance of Tay–Sachs disease in one family.



Put a cross (☒) in the box that correctly completes the statement.

The female whose genotype cannot be identified from the diagram is…

A Jane ☐
B Jen ☐
C Lilly ☐
D Sara ☐ (1)

You are allowed to write on the exam paper, and it will help to do so. Start by writing the genotypes of the females with Tay–Sachs disease because they must be homozygous recessive. This means that their mums must have one recessive allele. Now put just one dominant allele on those females who are unaffected. Which female has only one allele? Make sure you do not confuse the two names which are similar (Jane and Jen)!

Multiple choice questions always have one mark and the answer is given! For this reason students often make the mistake of thinking that they are the easiest questions on the paper. Unfortunately, this is not the case. These questions often require several answers to be worked out and an error in one of them will lead to the wrong answer being selected. The three incorrect answers supplied (distractors) will feature the answers that students arrive at if they make typical or common errors. The trick is to answer the question before you look at any of the answers.

Question analysis

- Multiple choice questions look easy until you try to answer them. Very often they require some working out and thinking.
- In multiple choice questions you are given the correct answer along with three incorrect answers (called distractors). You need to select the correct answer and put a cross in the box of the letter next to it.
- If you change your mind, put a line through the box (☒) and then mark your new answer with a cross (☒).

Average student answer

B Jen ☒

Jen cannot be the right answer since we know that she is unaffected (and therefore must have one dominant allele). She has given birth to Jane who has Tay–Sachs, and therefore Jen (the mother) must have a recessive allele as well. We know Jane must have two recessive alleles since she has Tay–Sachs disease. Sara is unaffected but has given birth to Dan who has Tay–Sachs disease, and therefore she, Sara, must be the same genotype as her mum Jen.

All this just leaves Lilly: We know she is unaffected, so must have at least one dominant 'normal' allele. However we have no idea whether she is homozygous or heterozygous. Thus Lilly is the correct answer.

COMMENTARY

This is an incorrect answer because:

- The student did not do the necessary working to find the correct answer. For a question like this, you should write the genotype of each person on the diagram.

If you have any time left at the end of the paper go back and check your answer to each part of a multiple choice question so that a slip like this does not cost you a mark.

QUESTION TYPE: SHORT OPEN

Cystic fibrosis and albinism are examples of recessive genetic disorders. Tay-Sachs disease is another example of a recessive genetic disorder.

Explain the meaning of the term recessive genetic disorder. (2)

The command word in this question is explain. This indicates that you will need to use 'therefore', 'so' or 'because' in your answer. Answer the question bit by bit: explain what makes an allele recessive, and then use a 'therefore' to explain how someone might suffer from this disorder.

Question analysis

- Generally one piece of information is required for each mark given in the question. There are two marks available for this question so make sure you make two distinct points.
- Clarity and brevity are the keys to success on short open questions. For one mark, it is not always necessary to write complete sentences.

Average student answer

The only way you are able to get the disease is if both your parents had the disease or both your parents are carriers. You have to be homozygous, two alleles the same. The recessive allele codes for the disease.

Misreading the question can lose you marks, as can answering in insufficient detail. One recessive allele does not code for the disease, but simply codes for a faulty protein.

COMMENTARY

This is an average answer because:

- The student will get one mark for remembering that people only suffer from a recessive genetic disorder if they inherit two copies of the recessive allele from their parents.
- The student has not explained what made the allele potentially cause a disorder: the version of the gene is faulty and does not code for a protein properly.

QUESTION TYPE: OPEN RESPONSE

Molecules are transported across the cell membrane in a number of different ways.

Describe the structure of a cell membrane. (3)

The command word in this question is describe. This means that you need to give an account of something. You do not need to include a justification or reason. Three marks are available so three distinct points need to be made. Remember that you can use bullet points or diagrams in your answer.

Question analysis

- With any question worth three or more marks, think about your answer and the points that you need to make before you write anything down. Keep your answer concise, and the information you write relevant to the question. You will not gain marks for writing down biology that is not relevant to the question (even if correct) but it will cost you time.

Average student answer

A cell membrane is made up of a phospholipid bilayer. Within this bilayer there are some proteins that span the membrane and others that are free to move within the membrane. Other features of the membrane include cholesterol, which sits within the bilayer, glycoproteins and glycolipids which are on the outer layers of the membrane and attached to either a protein or a lipid.

At this level, your answers need technical terms and clarity in expression otherwise you will find yourself losing marks.

COMMENTARY

This is an average answer because:

- The student has made five points, three of which meet the criteria needed to get full marks.
- The last sentence is poorly phrased: glycoproteins are molecules including a short carbohydrate group which is already attached to a protein.

QUESTION TYPE: EXTENDED WRITING

An investigation was carried out to study the effect of caffeine on the heart rate of a chicken embryo. The heart from a chicken embryo was removed and placed in a glucose solution. The heart rate was determined and recorded as a base heart rate. The experiment was repeated using glucose solutions containing five different concentrations of caffeine. The heart rate was determined and recorded as a percentage of the base heart rate for each solution.

Describe how this investigation could be carried out using Daphnia *instead of chicken embryos.* (4)

Four marks are available so four points need to be made. If you have carried out the practical and written it up carefully (or corrected your write up using your teacher's feedback) then you should be well-prepared for this question.

Question analysis

- There will be questions in your exams which assess your understanding of practical skills and draw on your experience of the core practicals. For these questions, think about:
  - how apparatus is set up
  - the method of how the apparatus is to be used
  - how readings are to be taken
  - how to make the readings reliable
  - how to control any variables.
- It helps with extended writing questions to think about the number of marks available and how they might be distributed. For example, if the question asked you to give the arguments for and against a particular case, then assume that there would be equal numbers of marks available for each side of the argument and balance the viewpoints you give accordingly. However, you should also remember that marks will also be available for giving an overall conclusion so you should be careful not to omit that.
- It is vital to plan out your answer before you write it down. There is always space given on an exam paper to do this so just jot down the points that you want to make before you answer the question in the space provided. This will help to ensure that your answer is coherent and logical and that you don't end up contradicting yourself. However, once you have written your answer go back and cross these notes out so that it is clear they do not form part of the answer.

Average student answer

By placing a Daphnia under a microscope, you will be able to determine the bpm by counting the heart beats in one minute. This will give you a control to compare against. Then by adding caffeine to the slide that the Daphnia is placed on, in regular increasing concentrations of caffeine, you should be able to calculate the heart rate of the Daphnia at different caffeine concentrations. By comparing against the control, this will allow you to note the differences in heart rate in relation to the concentration of caffeine.

Notice that the question says 'describe how this experiment could be carried out using *Daphnia*'. You need to adapt what you know already and apply it to this new situation.

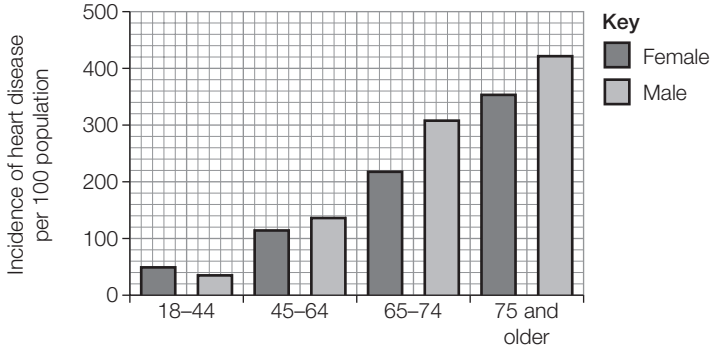
COMMENTARY

This is an average answer because:

- Some important details have been missed. The student does not mention repeating the experiment to check for anomalies or controlling variables to ensure the results are valid.
- The student has not detailed how the heart rate is to be counted. The heart will beat between 100–200 times a minute so a sensible method would be by using a felt pen to place a dot on a piece of paper every time the heart beats.

QUESTION TYPE: CALCULATION

Age and gender are two factors that may influence the development of heart disease in an individual. The graph below shows the results of a survey in America on the incidence of heart disease in adults aged 18 and older.



Calculate the increased risk that a man who is 75 or older has of developing heart disease, compared to a man aged between 18 and 44 years old. (2)

The command word here is calculate. This means that you need to obtain a numerical answer to the question, showing relevant working. If the answer has a unit, this must be included.

Finding the numbers requires you to read the graph really carefully, paying close attention to the increments on the *y*-axis, as well as choosing the correct set of bars.

Question analysis

- The important thing with calculations is that you must show your working clearly and fully. The correct answer on the line will gain all the available marks. However, an incorrect answer can gain all but one of the available marks if the correct working is shown.
- Show the calculation that you are performing at each stage and not just the result. When you have finished, look at your result and see if it is sensible.
- At some point during your answer, you will need to do some kind of sum, and the skills are to decide
  - which numbers you need
  - which operation you need.

Average student answer

410 – 15 = 395. $\frac{395}{15}$ = 26.3, so 26.3 times.

The student has not read the graph correctly. Five of the small sections on the *y*-axis equal 100, so each small section of the *y*-axis corresponds to 20. Therefore, the calculation of difference is actually 420 – 35, which is 385.

To work out the increased risk, you divide the difference by the risk for 18–44-year-old men.

It's a good idea when you finish the question to check whether you need to put in the units. In this question, there are none as it's simply a case of 'multiples of risk'.

COMMENTARY

This is an average answer because:

- The student has misread the graph so has used incorrect figures in the calculation.
- However, the correct technique has been used to work out the increased risk, so a mark would be awarded for using the correct method.