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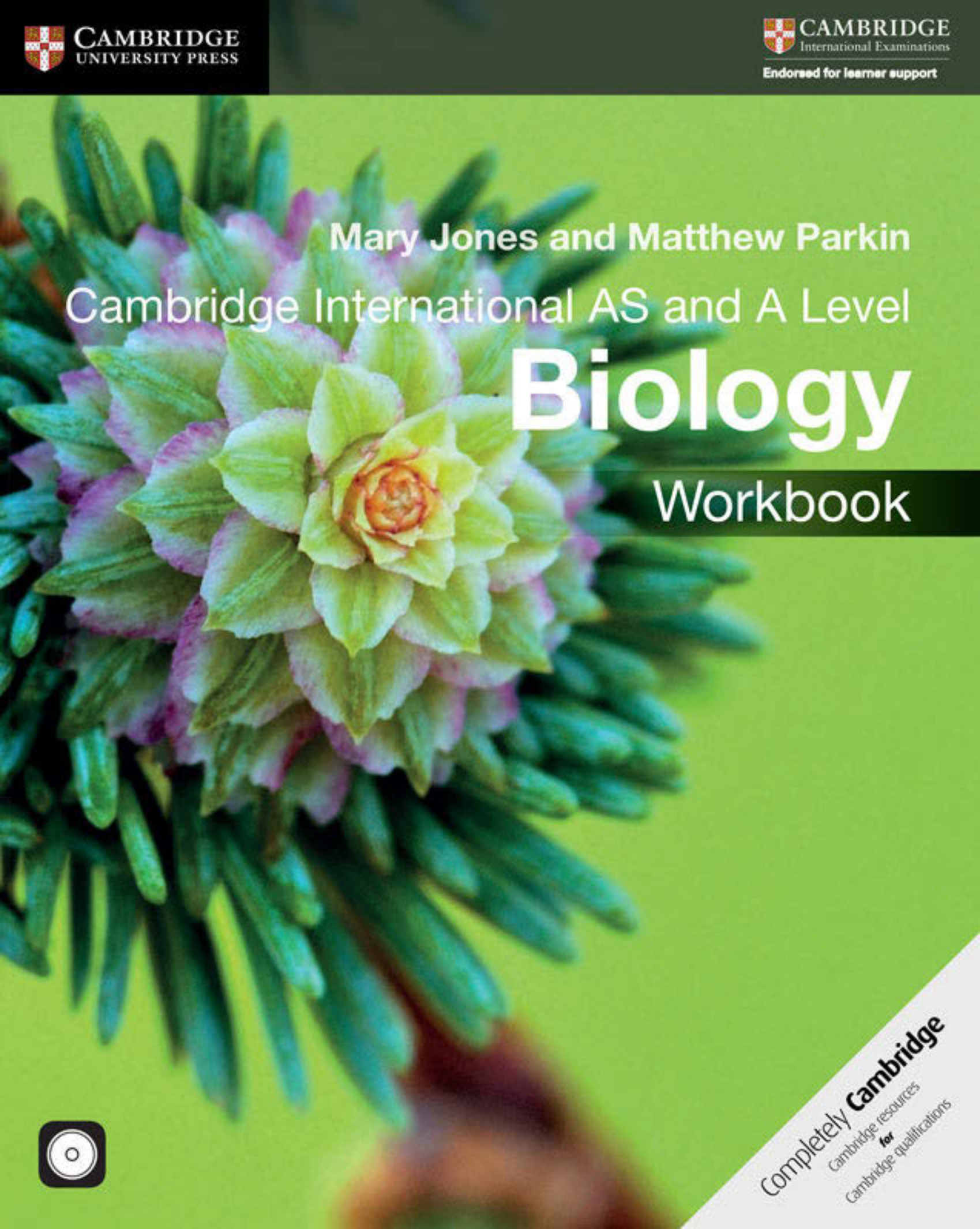
Mary Jones and Matthew Parkin

Cambridge International AS and A Level Biology Workbook



Mary Jones and Matthew Parkin

Cambridge International AS and A Level

Biology

Workbook

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How to use this book

A **Chapter outline** appears at the start of every chapter to set the scene and to help with navigation through the book.

Chapter outline

The questions in this chapter cover the following topics:

- the structure of animal, plant and bacterial cells, and of viruses
- the use of light microscopes and electron microscopes to study cells
- drawing and measuring cell structures
- the variety of cell structures and their functions
- the organisation of cells into tissues and organs

Each **Exercise** in every chapter helps students to practise the necessary skills for studying Biology at AS and A Level.

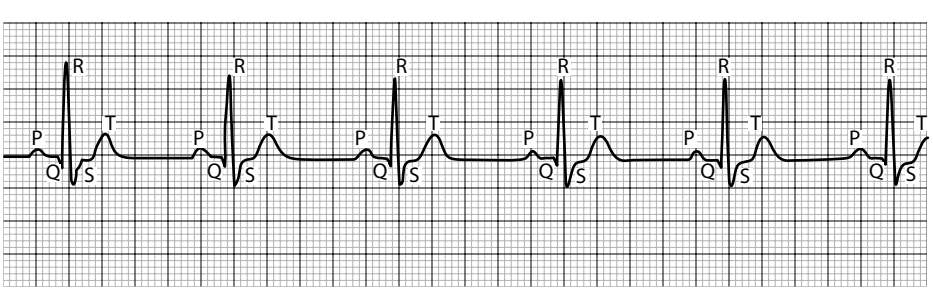
Exercise 8.3 Interpreting graphs of heart rate and blood pressure

Understanding how graphs relate to the topic under investigation and using them to extract numerical data are important skills. The topic of mammalian transport uses numerous graphical representations.

1 Figure 8.6 shows a typical electrocardiogram (ECG) from a healthy human. We can use ECG traces to calculate the heart rate.

a First, calculate the time that one **small** square represents.

b Now determine how many small squares one heart cycle takes (good places to use are the tops of the R waves).



1 large square = 0.2 s

Detailed **Learning support** is provided throughout to help students to tackle the different exercises and build confidence to answer questions independently.

TIP

Be careful converting from seconds to minutes. Remember that 0.5 of a minute is 30 s.

Exam-style questions allow students to thoroughly prepare for examinations and check answers which are provided on the CD-ROM at the back of the book.

Exam-style questions

1 Figure 9.5 shows two magnifications of a section through part of an airway.

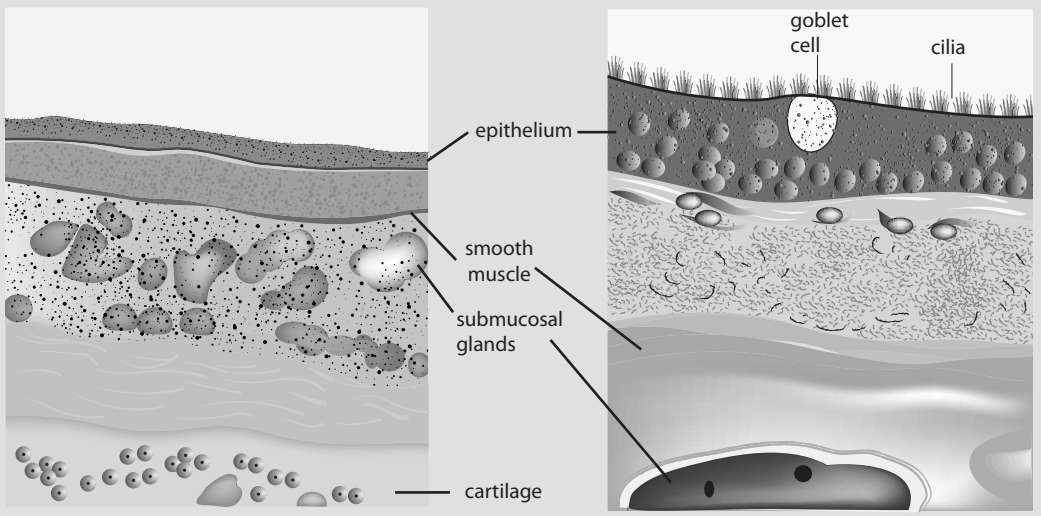


Figure 9.5 Tissue maps showing the wall of a region of the airways.

a The part of airway that the section was taken from was the:

A bronchus

B terminal bronchiole

C respiratory bronchiole

D alveolar duct. [1]

Contents

Chapter 1
Cell structure

Chapter outline

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- the variety of cell structures and their functions
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Exercise 1.1 Units for measuring small objects

Cells are small, and the organelles that they contain are sometimes very, very small. In this exercise, you will practise converting between the different units that we use for measuring very small objects. You will also make sure that you are able to write numbers in standard form.

1 The units that we use when measuring cells are millimetres (mm), micrometres (μm) and nanometres (nm).

Copy and complete:

a 1 μm = 1000 nm = $10^{\cdots\cdots}$ nm

b 1 nm = ... μm = $10^{\cdots\cdots}$ μm

c 1 nm = ... mm = $10^{\cdots\cdots}$ mm

TIP
1 mm = 1000 μm
= 10^3 μm
So 1 μm = 1/1000 mm
= 10^{-3} mm

Standard form is a way of writing down large or small numbers simply. The rules are:

- Write down the digits as a number between 1 and 10.
- Then write $\times 10^{\text{power of the number}}$.

To work out the correct power, imagine moving the decimal point to the right or left, until you get a number between 1 and 10. Count how many moves you have to make, and that is the power of ten you should write.

For example, if your number is 4297, you would move the decimal point like this:

So we write this number as 4.297×10^3.

Here are some examples of writing large numbers in standard form:
$6000 = 6 \times 10^3$
$6248 = 6.248 \times 10^3$
$82\,910 = 8.291 \times 10^4$
$547.5 = 5.475 \times 10^2$

2 Write these numbers in standard form:
- **a** 5000
- **b** 63
- **c** 63 000
- **d** 63 497
- **e** 8521.89

Here are some examples of writing small numbers in standard form:
$0.678 = 6.78 \times 10^{-1}$
$0.012 = 1.2 \times 10^{-2}$
$0.0057 = 5.7 \times 10^{-3}$

3 Write these numbers in standard form:
- **a** 0.1257
- **b** 0.0006
- **c** 0.0104

4 A cell measures 0.094 mm in diameter.
- **a** Convert this to micrometres.
- **b** Express this value in standard form.

5 A cell organelle is 12 nm long.
Express this value in μm, in standard form.

6 A mitochondrion is 1.28×10^2 μm long.
Express this value in nm.

7 A chloroplast is 2.7×10^3 nm in diameter.
Express this value in μm.

Exercise 1.2 Magnification calculations

This exercise will help you to gain confidence in doing magnification calculations, as well as providing further practice in using different units and converting numbers to standard form. You will also need to think about selecting a suitable number of significant figures to give in your answers. In general, you should use the same number of significant figures as there are in the value with the smallest number of significant figures that you used in your calculations.

$$\text{magnification} = \frac{\text{image size}}{\text{actual size}}$$

TIP
Remember – magnification has no units.

1 A light micrograph of a plant cell shows the cell to be 5.63 cm long. The real size of the cell is 73 μm. Follow the steps to find the magnification of the micrograph.

Step 1 Convert 5.63 cm to μm.

Step 2 Substitute into the magnification equation:

$$\text{magnification} = \frac{\qquad}{\qquad}$$

Step 3 Calculate the magnification. Write the answer as ×.....

2 An electron micrograph of a nucleus shows it to be 44 mm in diameter. The actual diameter of the nucleus is 6 μm. Calculate the magnification of the electron micrograph.

3 An electron micrograph of a **mitochondrion** shows its diameter as 28 mm. The magnification of the image is given as ×22 700. Follow the steps to find the actual diameter of the mitochondrion.

Step 1 Convert 28 mm to µm.

Step 2 Rearrange the magnification equation, and then substitute into it:

$$\text{actual size} = \frac{\text{image size}}{\text{magnification}}$$

$$= \frac{\qquad}{\qquad}$$

Step 3 Calculate the actual diameter of the mitochondrion. Remember to give your answer to the same number of significant figures as the value with the smallest number of significant figures that you used in your calculation.

4 An image of a **chloroplast** in an electron micrograph is 36 mm long. The magnification of the micrograph is ×1285. Calculate the actual length of the chloroplast.

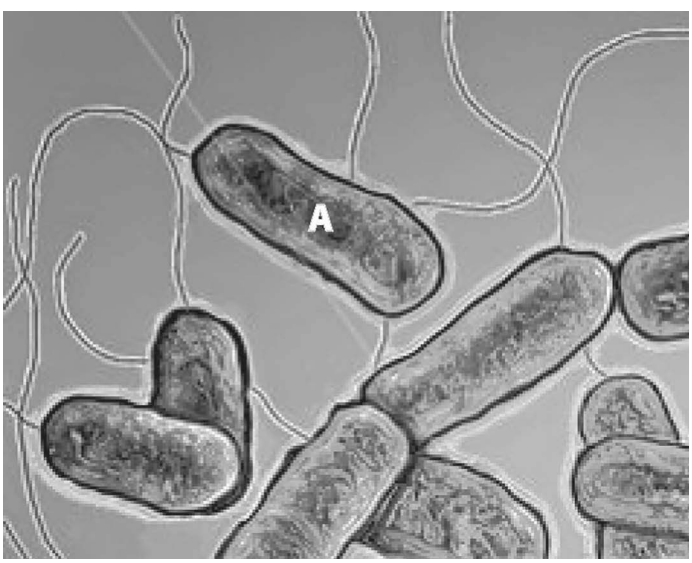


Figure 1.1 Micrograph of *Legionella* bacteria.

5 The micrograph shows a group of *Legionella* bacteria. The image has been magnified ×980.

a Measure the maximum length of bacterium **A**.

b Calculate the actual length of this bacterium. Show all the steps in your working.

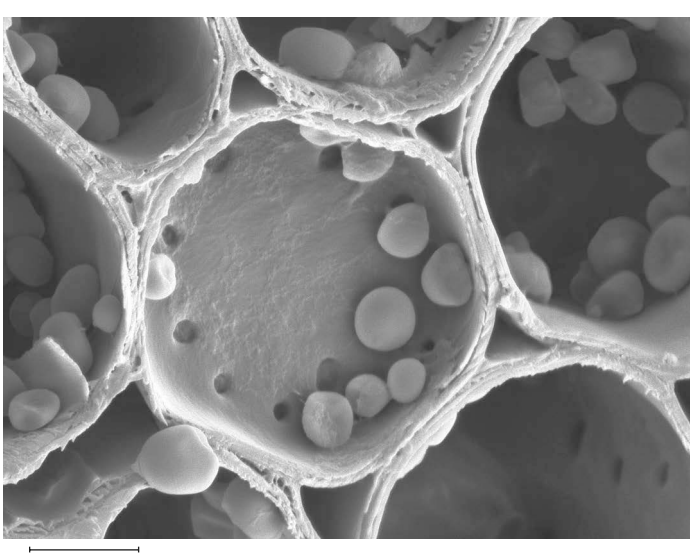


Figure 1.2 Micrograph of plant cells with starch grains.

6 The micrograph shows some plant cells containing starch grains. There is a scale bar beneath the image.

a Measure the length of the scale bar in mm.

b Convert this measurement to µm.

c Use this image size of the scale bar, and the actual size that we are told it represents, to calculate the magnification of the image.

d Measure the maximum diameter of the central cell in the micrograph.

e Use the value of the magnification you have calculated to find the actual diameter of this cell.

7 The micrograph shows a cell from the **pancreas** of a mammal. Several mitochondria are visible.

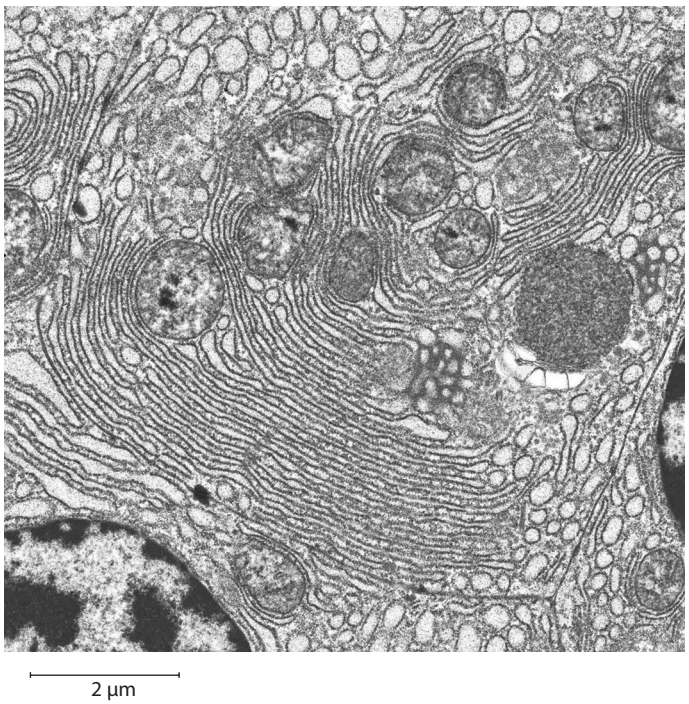


Figure 1.3 Micrograph of a cell from the pancreas.

Use the scale bar to calculate the actual diameter of the largest mitochondrion.

Exercise 1.3 Drawing from light micrographs

Being able to draw good diagrams from micrographs, or from what you can see when using a microscope, is nothing to do with being good at art. Your task as a biologist is to make a clear, simple representation of what you can see. Use a sharp, medium hard (e.g. HB) pencil and have a good eraser to hand. Each line should be clean and not have breaks in it – unless there really are breaks that you want to represent.

1 This drawing was made by a student from the electron micrograph of the plant cells shown in the micrograph Figure 1.2 in Exercise 1.2.6.

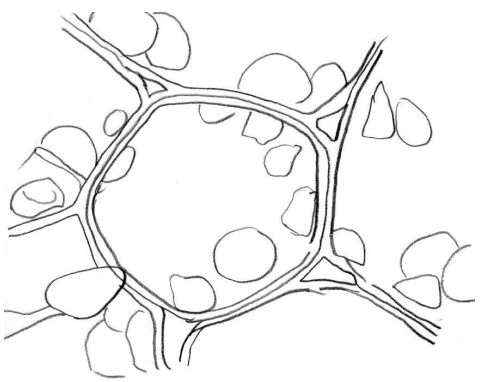


Figure 1.4 Student's drawing of plant cells.

a Use these criteria to assess the quality of the student's drawing. Copy the table, and put a tick in one box in each row. You could also add a brief comment explaining why you made each decision.

Feature	Done very well	Done fairly well	Poorly done
suitably large diagram – makes good use of space available but does not extend over any text			
clean, clear, continuous lines			
overall shape and proportions look approximately correct			
correct number of starch grains shown, each carefully drawn the right shape and size			
relative sizes of starch grains and cell size correctly shown			
no shading has been used			
good and correct detail of cell walls shown			

b Now make your own drawing of the cells shown in the same electron micrograph, Figure 1.2, taking care to meet all of the criteria fully.

2 The micrograph in Figure 1.5 shows a **lymphocyte**, a type of white blood cell found in mammals.

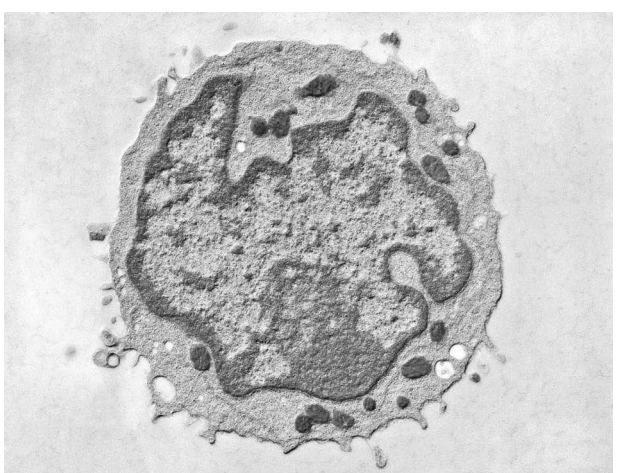


Figure 1.5 Micrograph of lymphocyte.

a Make a drawing of the lymphocyte.

b Construct a list of criteria for your drawing, using the criteria from 1.3.1a as a guide.

c Assess the standard of your drawing against your criteria. Alternatively, or as well, you could exchange your drawing with a partner, and assess each other's drawings.

d The magnification of the micrograph of the lymphocyte is ×4750.

Calculate the actual diameter of the lymphocyte. Give your answer in μm, using standard form.

e Use your answer to **d** to calculate the magnification of your drawing.

Exercise 1.4 Electron microscopes and optical (light) microscopes

The micrographs in this chapter have been made using different kinds of microscopes. In this exercise, you will practise identifying features that distinguish images taken with different types of microscope, and then summarise the differences between what we can see using optical (light) microscopes and electron microscopes.

1 Copy and complete this table. In the 'type of microscope' column, choose from optical microscope, transmission electron microscope or scanning electron microscope.

Micrograph	Type of microscope used to produce the micrograph	Reason for your decision
Figure 1.2		
Figure 1.3		
Figure 1.5		

2 Copy and complete this table, to compare what can be seen in typical animal cells and plant cells using optical microscopes and electron microscopes. Put a tick or a cross in each box.

Organelle	Visible in plant cells		Visible in animal cells	
	Visible using optical microscope	Visible using electron microscope	Visible using optical microscope	Visible using electron microscope
nucleus				
mitochondrion				
membranes within mitochondrion				
Golgi body				
ribosomes				
endoplasmic reticulum				
chloroplast				
internal structure of chloroplast				
centriole				

Exercise 1.5 Using an eyepiece graticule and stage micrometer

An eyepiece graticule, calibrated using a stage micrometer, enables you to work out the actual size of objects you can see using a microscope. This exercise provides practice in this technique, and also involves decisions about how many significant figures to give in your answers.

An eyepiece graticule is a tiny piece of glass or plastic that you can put into the eyepiece of a microscope.

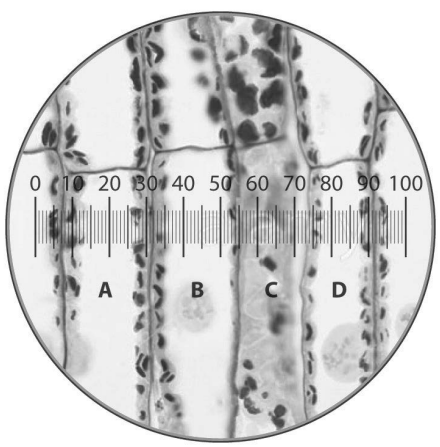


Figure 1.6 Micrograph of palisade cells seen using an eyepiece graticule.

Figure 1.6 shows a group of palisade cells, as they look through a light microscope with an eyepiece graticule. The highest power objective lens of the microscope is being used.

The small divisions on the graticule scale can be referred to as 'graticule units'. Measure the total width of the four palisade cells **A**, **B**, **C** and **D** in graticule units.

TIP
When you are doing this using your own microscope, you will need to swivel the eyepiece and/or move the slide, so that your eyepiece graticule scale lies neatly over the thing you want to measure.

In order to find out the true size represented by one eyepiece graticule unit we now need to calibrate the eyepiece graticule using a stage micrometer. This is a slide that is accurately marked off in small divisions of 0.01 mm.

Figure 1.7 shows what is seen when the slide with the palisade cells is replaced on the microscope stage by a stage micrometer.

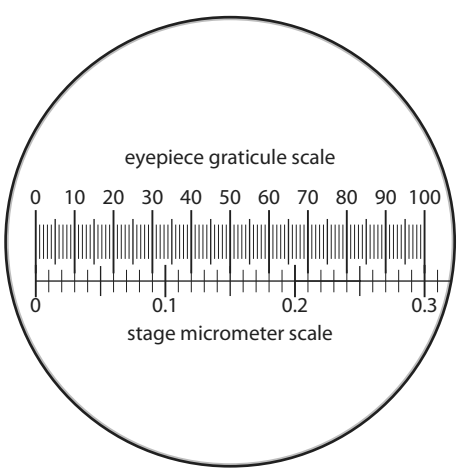


Figure 1.7 Stage micrometer seen using an eyepiece graticule.

TIP
It's essential to use the same objective lens – the one that you used when you measured the palisade cells in eyepiece graticule units. Again, you may need to swivel the eyepiece, and move the slide on the stage, to get them lined up against one another.

1 a Look for a good alignment of marks on the two scales, as far apart as possible. The 0s of both scales match up, and there is another good match at 80 small divisions on the eyepiece graticule.

How many small divisions on the micrometer equal 80 small divisions on the eyepiece graticule?

b Remember that one small division on the micrometer is 0.01 mm. Use your answer to **a** to calculate how many micrometres (μm) are represented by one small division on the eyepiece graticule.

c Use your answer to **b** to find the total width of the four palisade cells in the micrograph.

d Now calculate the mean width of a palisade cell.

2 Explain why it is not possible to see both the palisade cells and the stage micrometer scale at the same time.

3 Figure 1.8 shows a light micrograph of some villi in the small intestine, seen using an eyepiece graticule.

Figure 1.9 shows the same eyepiece graticule, using the same objective lens, but this time with a stage micrometer on the microscope stage.

Use the two images to calculate the length of the villus that can be seen beneath the eyepiece graticule. Show each step in your working.

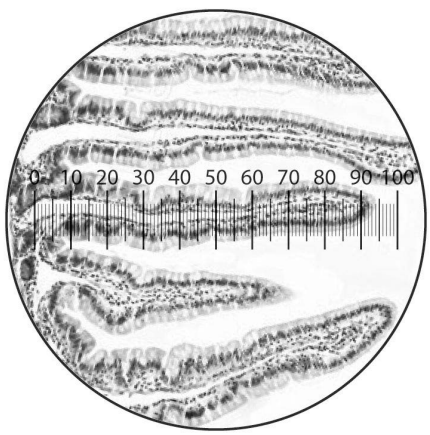


Figure 1.8 Light micrograph of villi seen using an eyepiece graticule.

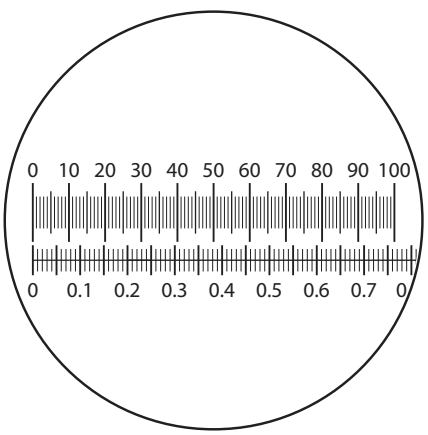


Figure 1.9 Stage micrometer seen using the eyepiece graticule.

Exercise 1.6 Membranes in different types of cells

Most cells in multicellular organisms become specialised for a particular set of functions. In this exercise, you will consider data relating to the membranes in two different types of cell, and use your biological knowledge to suggest explanations for patterns that you can pick out in these data.

All cells are surrounded by a **cell surface membrane**, and also contain many other membranes within them. Researchers estimated the total quantity of membranes in 20 liver cells and 20 exocrine pancreas cells, and then calculated the percentage of these membranes in all the different membrane-containing structures in the cells. Their results are shown in the table.

Source of membrane	Mean percentage of all membranes	
	Liver cells	Exocrine pancreas cells
cell surface membrane	1.8	4.7
mitochondrial membranes	39.4	22.3
nuclear membrane	0.5	0.7
rough endoplasmic reticulum	33.4	61.9
smooth endoplasmic reticulum	16.3	0.1
Golgi apparatus	7.9	10.3
lysosomes	0.4	0
other small vesicles	0.3	0

1 Explain why we *cannot* use these results to draw the conclusion that the mean quantity of cell surface membrane in liver cells is less than that in exocrine pancreas cells.

2 Which of the sources of membranes listed in the table are made up of two membranes (an envelope)?

3 Using the data in the table, state the organelle that contains the greatest mean percentage of membrane in:

a liver cells

b pancreas cells.

4 Liver cells have a wide variety of functions in metabolism, including synthesising proteins, breaking down toxins, synthesising cholesterol and producing bile. Exocrine pancreas cells have a single main role, which is the production and secretion of digestive enzymes.

Use this information to suggest explanations for the differences between the percentages for mitochondria and rough endoplasmic reticulum in the liver cells and the pancreas cells.

Exercise 1.7 Command words

In examinations, you will only rarely see a question that ends with a question mark. Almost all questions start with a word that tells you what to do. These are called command words. It is extremely important that you identify the command word in each question part, and understand what it means. If you don't do what the command word asks, you are likely to get few, or perhaps no, marks for your answer.

1 Some of the command words used in examination questions are listed below:

describe	**explain**	**discuss**	**list**	**suggest**
outline	**name**	**state**	**deduce**	**define**

Match each description with the correct command word:

a Give a concise answer, with no supporting argument.

b Give a formal statement, possibly one that you have learnt by heart.

c Write an account to help someone else to 'see' something you are looking at, e.g. a graph; or give a step-by-step account of a structure or process.

d Work out an answer from information you have been given.

e Give the technical term, e.g. for a structure or a process.

f Give a brief account, picking out the most important points and omitting detail.

g Give reasons; use your knowledge of biology to say why or how something happens.

h State points on both sides of an argument, e.g. reasons for and against a particular viewpoint, or how a set of results could be interpreted to support or reject a hypothesis.

i Use information provided, and your biological knowledge, to put forward possible answers; there is often more than one possible correct answer.

j State, very briefly, a number of answers to the question; if a particular number is asked for, you should give exactly that number of answers.

Exam-style questions

This is a straightforward question that relies on your recall of facts and concepts. You could answer part **b** either in words, or by using a labelled diagram. Note that the command word for **b** is 'outline'.

1 The table below lists some features of prokaryotic and eukaryotic cells.

Feature	Prokaryotic cell	Eukaryotic cell
cell surface membrane		
nucleus		
ribosomes		
mitochondria		
chloroplasts		

a Copy and complete the table. If a feature can be present in the cell, write a tick in the box. If it cannot be present, write a cross. You should write either a tick or a cross in each box. [5]

b Viruses are not usually considered to be living organisms and are not made of cells.

Outline the key features of the structure of a virus. [2]

[Total: 7 marks]

This question asks you to identify structures within an animal cell. You should find this relatively straightforward, although you may have to think carefully about part **b**.

2 The diagram is a drawing of a cell from the body of a mammal.

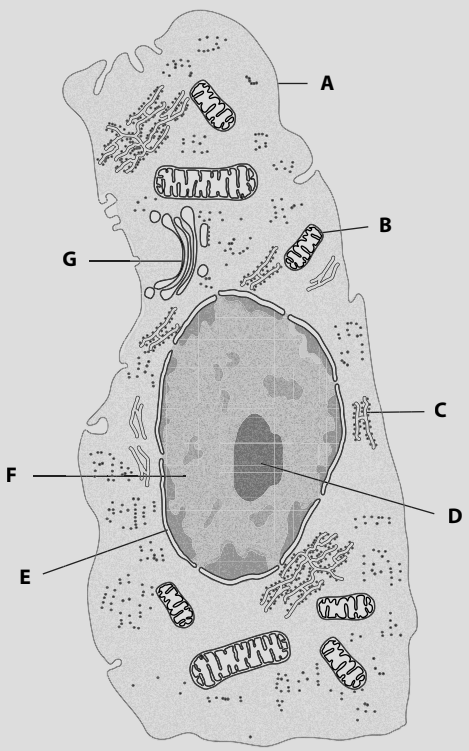


Figure 1.10 Diagram of a micrograph of a mammalian body cell.

a State the type of microscope that would be used to allow this amount of detail to be seen in the cell. [1]

b List the letters of the structures in the drawing which are made up of, or are surrounded by, phospholipid membranes. [3]

c Describe the functions of :

i structure **B** [2]

ii structure **E** [2]

iii structure **G**. [2]

[Total: 10 marks]

3 The diagram shows a method for separating the different components of cells. This technique is called ultracentrifugation.

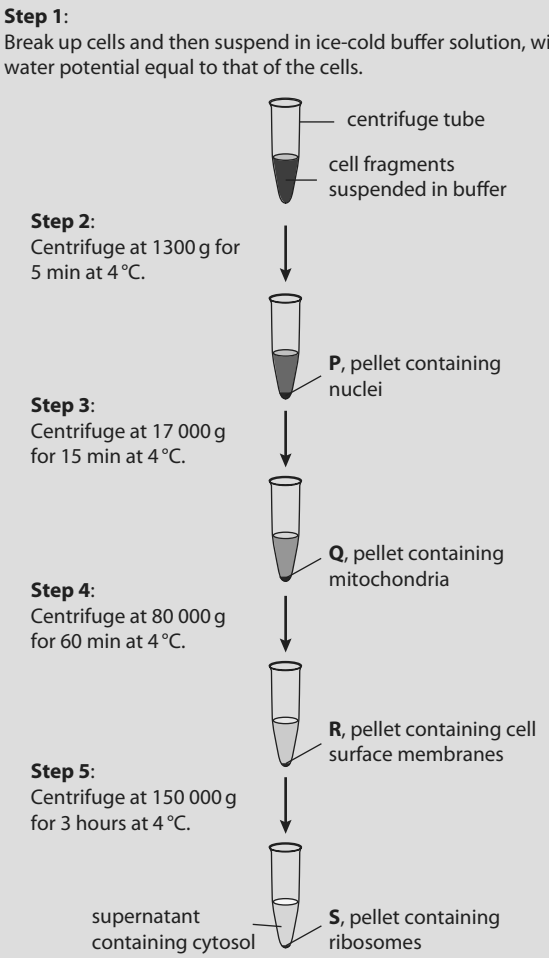


Figure 1.11 Ultracentrifugation.

a Suggest why the solution in which the broken-up cells were suspended:

i was ice-cold [1]

ii contained a buffer [2]

iii had the same water potential as the cells. [2]

b Suggest why ribosomes do not collect in the pellet until the final stage of the ultracentrifugation. [1]

c Give the letter of the component or components in which you would expect to find:

i DNA [1]

ii phospholipids. [1]

d If this process were carried out using plant cells, which other cell organelles might you expect to find in the pellet containing mitochondria? Explain your answer. [2]

[Total: 10 marks]

Examination questions often contain something new, such as an unfamiliar micrograph. But a combination of your own knowledge and the information in the question should help you work out suitable answers. Look carefully at the mark allocations, which guide you in how detailed an answer you need to give.

4 The photograph shows a micrograph of parts of two cells from the small intestine of a mammal. The structures along the surfaces of the two cells are microvilli.

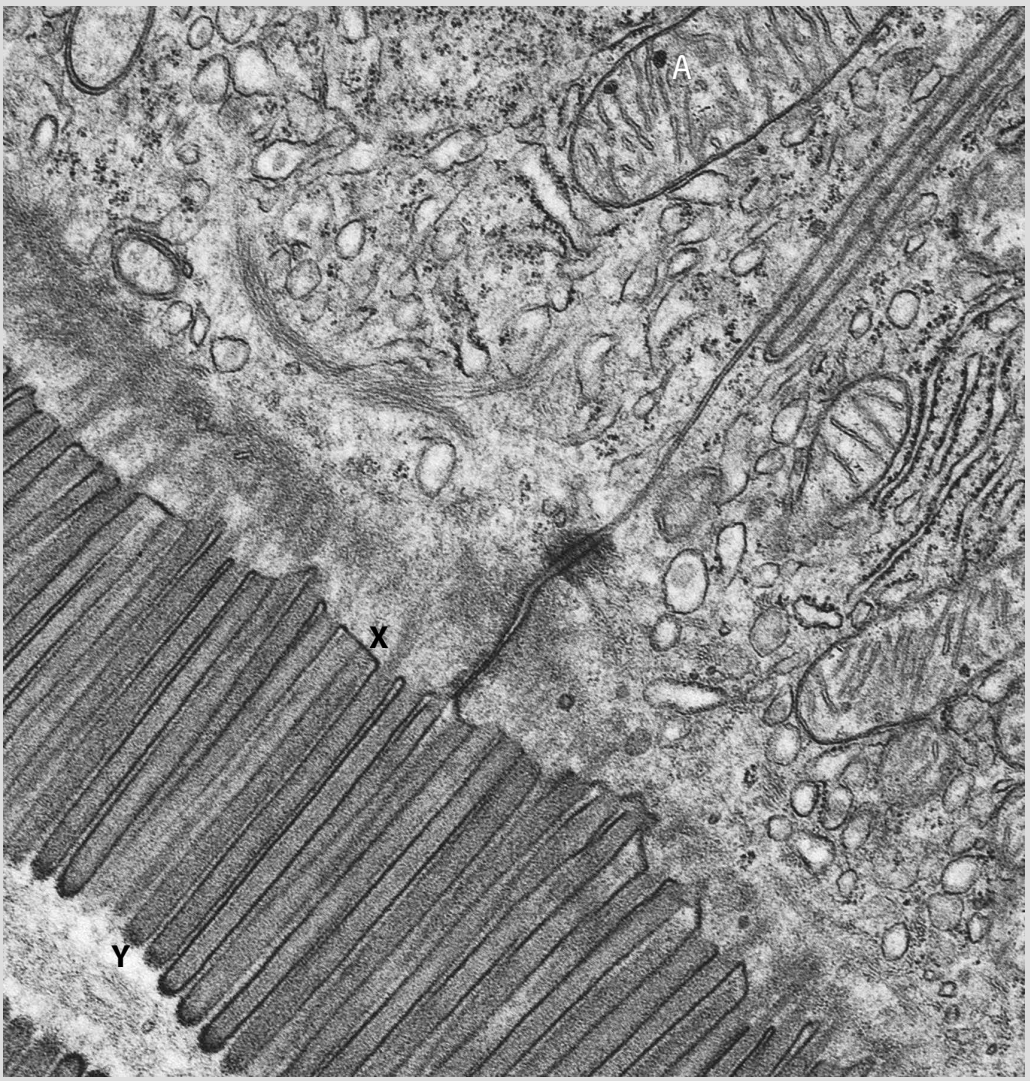


Figure 1.12 Micrograph of cells from the small intestine.

a State the type of microscope that was used to obtain this micrograph.
Give a reason for your answer. [2]

b Identify organelle **A**. [1]

c **i** The magnification of the micrograph is × 12 500. Calculate the length of the microvillus between points **X** and **Y**. Show your working. [3]

ii Microvilli greatly increase the surface areas of the cells. Suggest why the cells lining the small intestine have microvilli. [2]

[Total: 8 marks]

Chapter 2
Biological molecules

Chapter outline

The questions in this chapter cover the following topics:

- how large biological molecules are made from smaller molecules
- the structure and function of carbohydrates, lipids and proteins
- biochemical tests to identify carbohydrates, lipids and proteins
- some key properties of water that make life possible

Exercise 2.1 Taking notes

Note taking is an important skill, and your own notes should be able to extract the relevant information from complex writing. There is little value in writing down the whole passage of information.

1 Read the passage below about carbohydrates carefully and then copy and complete the table below to make a summary of the structures and functions of the different **polysaccharides**.

Polysaccharides are **polymers** of **monosaccharides** and are made by joining the monosaccharides with **glycosidic bonds**. Glucose is the **monomer** for many polysaccharides. It is a highly soluble and reactive molecule and would affect the osmotic potential of cells and interfere with biochemical reactions. In plants, glucose is stored as starch, which is a mixture of two substances – amylose and amylopectin. In animals, glucose is stored as glycogen. **Amylose** is made of α-glucose molecules joined by α (1 → 4) glycosidic bonds, resulting in a very compact, helical molecule. **Amylopectin**, also made of α-glucose molecules, has many α (1 → 4) glycosidic bonds and has side branches joined by α (1 → 6) glycosidic bonds. **Glycogen** is made of α-glucose joined with both α (1 → 4) glycosidic and α (1 → 6) glycosidic bonds to make an even more branched molecule. Large numbers of branches enable rapid hydrolysis into glucose molecules. **Cellulose** is a polymer of β-glucose. In β-glucose, the –OH group on carbon number 1 points upwards, so that in cellulose molecules every other glucose molecule is inverted 180°. Cellulose molecules do not have branches and are long straight chains. About 60–70 cellulose molecules bind to each other using **hydrogen bonds** to form microfibrils. Several microfibrils bind together to form fibres, and these fibres make up the cell wall. Cellulose fibres have very high tensile strength, preventing cells from bursting, but allow free passage of water and water-soluble molecules.

Polysaccharide	Name of monomer	Bonds joining monomers	Description	Function
amylose	α-glucose	α (1 → 4)	long helical compact	cellular storage of glucose (energy) does not affect osmotic potential found in plants
amylopectin				
glycogen				
cellulose				

Exercise 2.2 Calculating the concentration of solutions and making dilutions

It is essential to be able to accurately produce different concentrations of solutions. You can be asked to make up concentrations as either percentages (%) or as the number of moles per unit volume (mol dm^{-3}).

GETTING THE UNITS RIGHT

It is important to understand the units of volume and mass when making up solutions of different concentrations, and you may have to do some conversions.

The SI unit of mass is the kilogram (kg). In biology, you will often come across mass measured in kilograms (kg), grams (g), milligrams (mg), micrograms (µg) and sometimes even nanograms (ng).

- 1 kg is equivalent to 1000 g.
- 1 g is equivalent to 1000 mg.
- 1 mg is equivalent to 1000 µg.
- 1 µg is equivalent to 1000 ng.

In order to convert your value to smaller units you need to multiply by 1000, and to convert to larger units you need to divide by 1000.

For example, 0.005 kg is equivalent to:

$$0.005 \times 1000 = 5 \text{ g}$$

and is also equivalent to:

$$0.005 \times 10^6 = 5000 \text{ mg}.$$

The SI unit of volume is the cubic metre (m^3). In biology, you will usually come across volumes as cubic decimetres (dm^3), cubic centimetres (cm^3) and cubic millimetres (mm^3).

- 1 cubic decimetre (dm^3) is equivalent to 1000 cubic centimetres (cm^3).
- 1 cubic centimetre (cm^3) is equivalent to 1000 cubic millimetres (mm^3).

In order to convert values given in cubic decimetres to cubic centimetres, you need to multiply by 1000 and to convert cubic centimetres into cubic decimetres you need to divide by 1000.

1 Carry out the following unit conversions:

a 150 mg into g

b 225 mg into kg

c 0.005 kg into mg

d 100 ng into g

e 100 cm^3 into dm^3

f 0.005 cm^3 into mm^3

g 150 mm^3 into dm^3

h 0.000005 dm^3 into mm^3.

CALCULATING CONCENTRATIONS AS PERCENTAGES OF TOTAL VOLUME

When the concentration of a solution is given as a percentage, e.g. 1.0% sucrose solution, it means that 1 g of sucrose was dissolved in distilled water and made up to a total volume of 100 cm^3.

Percentage concentration may be calculated using the formula:

$$\text{percentage concentration} = \frac{\text{mass of solute in grams}}{\text{volume of solution in cm}^3} \times 100\%$$

2 Place the following statements about making up 100 cm^3 of a 5% sucrose solution in the correct order:

- **A** Make up to 100 cm^3 by adding distilled water.
- **B** Dissolve in a small amount of distilled water.
- **C** Place dissolved sucrose into a 100 cm^3 volumetric flask.
- **D** Use a top pan balance to measure out 5 g of sucrose.

3 Calculate the sucrose concentrations in percentages of the following solutions:

- **a** 5 g of sucrose made up to a volume of 100 cm^3
- **b** 10 g of sucrose made up to a volume of 500 cm^3
- **c** 0.5 g sucrose made up to a volume of 500 cm^3
- **d** 37.5 g sucrose made up to a volume of 150 cm^3
- **e** 450 g sucrose made up to a volume of 1 dm^3
- **f** 0.005 g sucrose made up to a volume of 100 mm^3.

4 Calculate the mass of sucrose required to make the following solutions:

- **a** 100 cm^3 of 0.5% sucrose solution
- **b** 250 cm^3 of 12% sucrose solution
- **c** 500 cm^3 of 25% sucrose solution
- **d** 750 cm^3 of 50% sucrose solution
- **e** 500 mm^3 of 10% sucrose solution
- **f** 1 dm^3 of 45% sucrose solution.

CALCULATING CONCENTRATIONS AS MOLARITIES

Concentrations of solutions are often given as molarities. This tells you how many moles of solute are dissolved in one cubic decimetre of water. A **mole** is the relative molecular mass of a substance in grams.

The molarity of a solution can be calculated using the following equation:

$$\text{molarity (mol dm}^{-3}) = \frac{\text{number of moles of solute}}{\text{total volume of solution in dm}^3}$$

To make a 1 mol dm^{-3} solution of a substance, you need to weigh out **1 mole** of the substance, place it into a 1 dm^3 volumetric flask and add distilled water up to a total volume of 1 dm^3.

For example, if you wish to make a 1 mol dm^{-3} glucose solution:

Step 1 Find out the molecular formula of glucose ($C_6H_{12}O_6$).

Step 2 Determine the relative molecular mass of glucose.

The relative atomic masses of the elements are: carbon 12, hydrogen 1, and oxygen 16, so the relative mass of glucose is:

$(12 \times 6) + (1 \times 12) + (16 \times 6) = 72 + 12 + 96 = 180$.

Step 3 Weigh out 180 g of glucose.

Step 4 Dissolve the glucose in a small amount of distilled water.

Step 5 Place the glucose solution into a 1 dm^3 volumetric flask and add distilled water to make a final volume of 1 dm^3.

5 Calculate the masses of solutes required to make up the following solutions:

a 1 dm^3 of 1 mol dm^{-3} glucose solution

b 1 dm^3 of 1 mol dm^{-3} maltose solution

c 1 dm^3 of 1 mol dm^{-3} glycine ($C_2H_5O_2N$) solution

d 100 cm^3 of 2 mol dm^{-3} glucose solution

e 100 cm^3 of 2 mol dm^{-3} sucrose solution.

You should also be able work out what molarity of solution is made when you are given a mass of solution and the volume that it is made up to with distilled water.

$$\text{molarity (mol dm}^{-3}) = \frac{\text{number of moles of solute}}{\text{total volume of solution in dm}^3}$$

For example, 171 g of sucrose was dissolved by addition of distilled water and made up to 0.5 dm^3. To calculate the molarity of the solution, you must follow the steps below:

Step 1 Calculate the mass of 1 mole of sucrose ($C_{12}H_{22}O_{11}$):

$(12 \times 12) + (22 \times 1) + (11 \times 16) = 144 + 22 + 176 = 342$ g

Step 2 Calculate how many moles are present in 171 g of sucrose:

$(171 \div 342) = 0.5$ moles

Step 3 Calculate the molarity by dividing the number of moles by the volume of water in dm^3:

$(0.5 \div 0.5) =$ **1 mol dm^{-3}**

TIP

Be careful to make sure that you convert units! Often dilute solutions are given as mmol dm^{-3} where 1000 mmoles is equivalent to 1 mole.

6 Now try to work out the molar concentrations of the following solutions:

a 171 g sucrose dissolved in 1 dm^3 distilled water

b 150 g glycine ($C_2H_5O_2N$) dissolved in 1 dm^3 distilled water

c 4.5 g glucose dissolved in 100 cm^3 distilled water

d 1.8 g glucose dissolved in 1 dm^3 distilled water

e 342 mg sucrose dissolved in 1 cm^3 distilled water.

Exercise 2.3 Graph plotting and using calibration curves

Benedict's test is a test for reducing sugars. Benedict's reagent is initially blue due to the presence of copper (II) sulphate. When heated in the presence of a reducing sugar, the copper (II) sulphate is reduced into insoluble red copper (I) oxide. Higher concentrations of reducing sugar will cause the solution to have less blue colour. The degree of blue colour can be quantified by using a colorimeter.

MAKING DILUTIONS

To decide what concentration of reducing sugar is in a particular solution, we must produce a calibration curve graph using a range of known concentrations. These are created by diluting stocks of reducing sugar solutions of known concentrations.

1 Copy and complete the table below to show how to make a range of concentrations when given a 1% standard solution of sucrose. The first two are done for you.

Concentration of sucrose / %	Volume of 1% glucose solution / cm^3	Volume of added water / cm^3
0.9	9	1
0.8	8	2
0.7		
0.6		
0.5		
0.4		
0.3		
0.2		
0.1		

To make wider ranges of dilutions you will need to be able to perform serial dilutions. An example of this is shown in the lower diagram below.

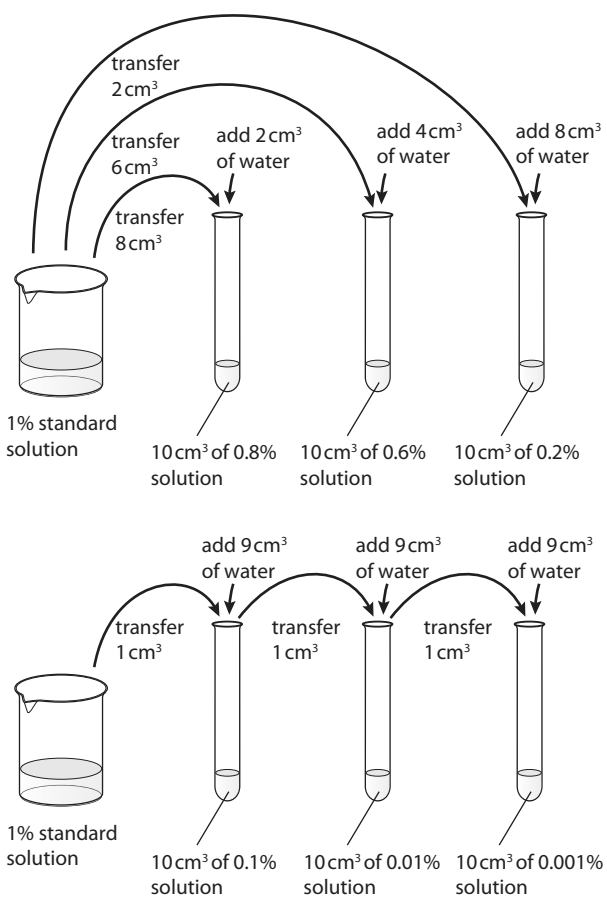


Figure 2.1 Producing a range of concentrations from standard solutions.

2 Describe how you could make up the following glucose concentrations when given a 1% standard solution (there may be several different ways for each!):

a 0.02%

b 0.003%

c 0.0005%.

PLOTTING A CALIBRATION CURVE

A calibration curve is a graph with the known concentrations plotted against their percentage absorbance.

The table below shows the percentage of red light absorbed using a colorimeter from Benedict's tests performed on a variety of glucose concentrations.

Concentration of glucose / %	Absorption of light / %
1.0	5
0.8	35
0.6	45
0.4	64
0.2	85
0.1	92
0	96

3 Plot a calibration curve of concentration of glucose against absorption of light.
Follow the steps below to plot your graph:

Step 1 Label the *x*-axis with the independent variable, in this case, concentration of glucose / %.

Step 2 Label the *y*-axis with the dependent variable, in this case, absorption of light / %.

Step 3 Select appropriate linear scales on both axes. Make sure that you can fit all the plots along each axis, but try to use at least half of each axis. You do not need to start the axes at 0 if it is not appropriate.

Step 4 Plot the points carefully with a sharp pencil.

Step 5 Draw a smooth line or curve of best fit through the points. It is appropriate to use a line or curve of best fit when we can safely assume the intermediate points would lie along the line. If we cannot be sure of this we should join the points with straight lines.

4 A mystery sample of glucose was analysed using a Benedict's test. The colorimeter gave an absorption reading of 74%.

a Using a ruler, draw a straight line across from 74% to meet the curve then drop the line down to the *x*-axis. Record the concentration of glucose that would give an absorption of 74%.

b Repeat this for an absorption of 53%.

5 When comparing different solutions of glucose using this method, it is important to control many factors in order to make a valid comparison.

List **three** factors that need to be kept constant.

Exercise 2.4 Processing and analysing data

You will need to be able to apply your factual knowledge in order to interpret unfamiliar data. Do not be put off by the fact that you have not seen the information in that context before – look carefully at the information and use your knowledge.

1 Look carefully at the fatty acids in Figure 2.2 and answer the questions.

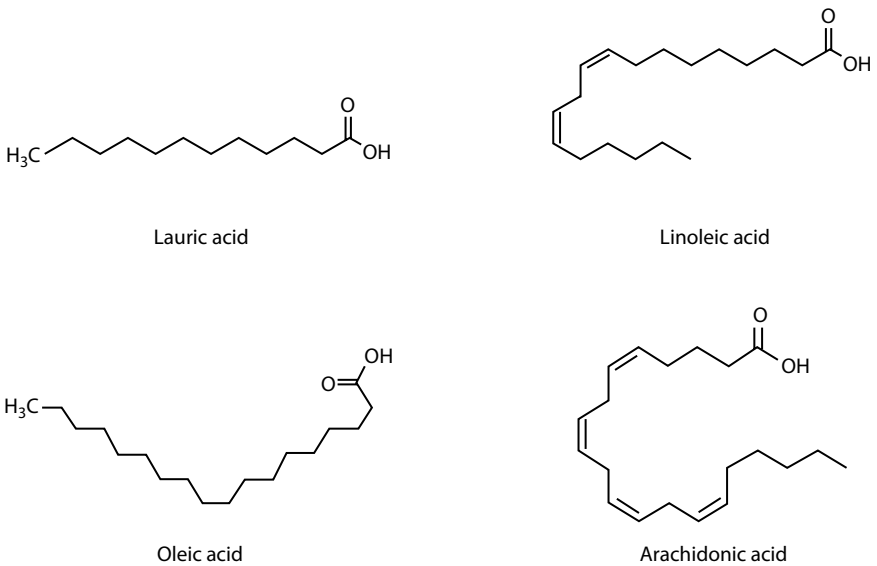


Figure 2.2 The structure of four different fatty acids.

a Copy out and complete the table below identifying which fatty acids are saturated, monounsaturated and polyunsaturated.

Fatty acid	Type of fatty acid	Melting point / °C
lauric acid		
oleic acid		
linoleic acid		
arachidonic acid		

b The melting points of these fatty acids are: 45 °C, 13 °C, –49 °C, –11 °C. The presence of C=C bonds causes the melting point of fatty acids to be lowered. Match each fatty each with its corresponding melting point and enter the data in the table.

c Suggest why the melting points of the different fatty acids are different.

Now look at the table below which shows the proportions of saturated, monounsaturated and polyunsaturated fatty acids found in lipids extracted from different organisms.

Organism	Total mass of lipid material tested / g	Saturated fatty acids / g	Monounsaturated fatty acids / g	Polyunsaturated fatty acids / g
sheep (animal)	100	40.8	43.8	9.6
cow (butter) (animal)	100	54.0	19.8	2.6
duck (animal)	50	16.7	24.5	6.8
mackerel (animal)	10	2.4	3.2	2.3
olive oil (plant)	200	28.0	139.4	22.4
corn oil (plant)	100	12.7	24.7	57.8
sunflower oil (plant)	100	11.9	20.2	63.0
hemp oil (plant)	75	7.5	10.0	50.0
coconut oil (plant)	150	127.8	9.9	2.5

When you compare data you need to make sure that it is a fair comparison. The masses of fatty acids for the different species in the table were taken from different starting masses of total lipid. You will need to make each class of fatty acid proportional to the total mass of lipid, in other words grams (g) per 100 g of total lipid.

To convert the mass of each type of fat into mass per 100 grams, carry out the following steps:

Step 1 Calculate the mass of each type of fat per gram of total lipid:

$$\text{mass per gram} = \frac{\text{mass of fat}}{\text{total lipid mass}}$$

Step 2 Calculate the amount of each type of fat per 100 g:

$$\text{mass per 100 g of lipid} = \text{mass per gram} \times 100 \text{ g}$$

For example, in duck fat there are 16.7 g of saturated fat in 50 g of total lipid.

- In 1 g of total lipid there will be (16.7 ÷ 50) = 0.334 g saturated fat per gram of total lipid.
- If there is 0.334 g of saturated fat in 1 g of fatty material, there will be 0.334 g × 100 = 33.4 g of saturated fat in 100 g of total lipid.

2 a Copy out and complete the table below.

Organism	Saturated fatty acids / g per 100 g	Monounsaturated fatty acids / g per 100 g	Polyunsaturated fatty acids / g per 100g
sheep (animal)	40.8	43.8	9.6
cow (butter) (animal)	54.0	19.8	2.6
duck (animal)			
mackerel (animal)			
olive oil (plant)			
corn oil (plant)	12.7	24.7	57.8
sunflower oil (plant)	11.9	20.2	63.0
hemp oil (plant)			
coconut oil (plant)			

TIP

Think about the following points:

- The higher the level of saturation of a fatty acid, the higher the energy content.
- The more unsaturated the fatty acid, the lower the melting point.
- **Homeothermic** animals maintain a constant internal body temperature.

Now that you have all the masses in the form of grams per 100 g of total lipid, you can start to evaluate the data.

b Identify any patterns that you can see in the data.

c Are there any results that do not seem to fit in with the patterns you have identified?

d Can you now suggest any explanations for any of the patterns? You will now need to use some of your knowledge about fatty acids here.

Exercise 2.5 Drawing molecular structures

Most biochemical reactions are best represented by drawing them out. Accuracy when drawing molecular structures is important, and it is easy to make mistakes that can cost marks in exams.

1 You need to be able to understand the formation of glycosidic bonds in **disaccharides** and **polysaccharides** and be able to draw chemical structures.

a Copy the diagram of two glucose molecules shown in Figure 2.3.

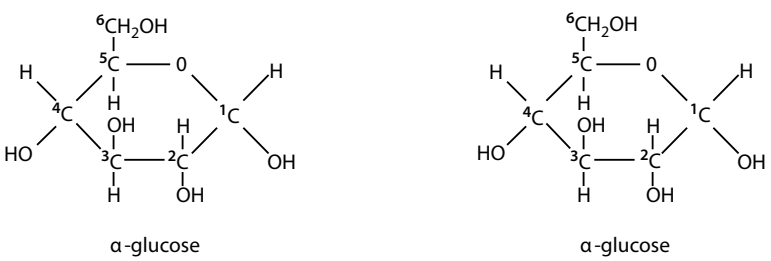


Figure 2.3 Two α-glucose molecules.

Step 1	Draw a ring around the hydrogen in the –OH group on carbon number 1 of the α-glucose on the left.
Step 2	Now draw a ring around the –OH group on carbon number 4 of the α-glucose on the right.
Step 3	Draw the reversible arrows as shown in the diagram.
Step 4	Draw out the disaccharide maltose and label it underneath the arrows. Also label the glycosidic bond.
Step 5	Show on the arrows where water (H_2O) is added or taken away.
Step 6	Next to the arrows, write the names of the reactions that would have taken place in each direction (**hydrolysis** and **condensation**).

b Now use your knowledge of dipeptide formation to repeat this procedure in order to show the formation of a **peptide bond** between the two amino acids shown in Figure 2.4.

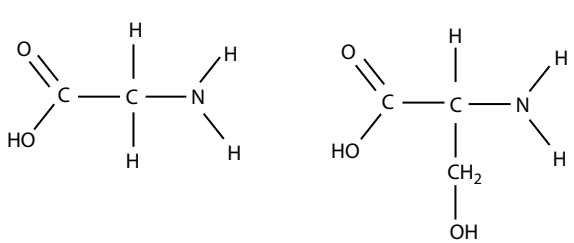


Figure 2.4 Molecular structure of the amino acids glycine (left) and serine (right).

2 Below is an example of an exam question and the answer given by a student. Use the attached mark scheme to identify what is correct and what is incorrect. When you have marked the student's answer, write your own, corrected answer.

i Complete the diagram below showing the formation of a **triglyceride**. [2]

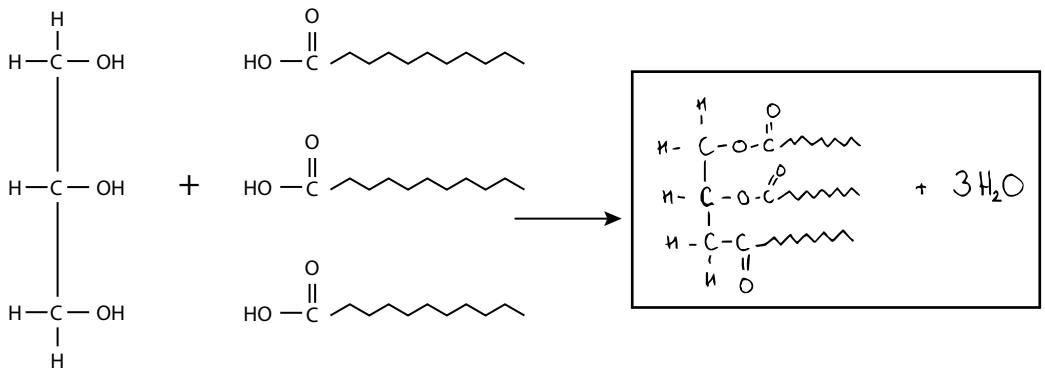


Figure 2.5 The formation of a triglyceride.

ii Name the type of reaction that would have taken place.

condensation / hydrolysis ..... [1]

Mark scheme

i	3 water molecules on right of arrow	1 mark
	correct bonds drawn on the triglyceride	1 mark
ii	condensation	1 mark

Exercise 2.6 Planning experiments that generate reliable results

You need to be able to plan experiments that will enable you to generate valid conclusions. This means that your experiment will need:

- repeats – to improve reliability and make it easier to spot anomalous values
- to have one variable changed at a time. All other variables must be controlled.

1 Read this experimental plan written by a student and then answer the questions.

An experiment to determine the temperature at which egg white protein (albumin) denatures.

Apparatus:

4 test tubes
test tube rack
measuring cylinder
4 eggs
thermometer
glass marker pen

Bunsen burner
stop clock.
thermometer

Method:

The test tubes will be placed into the test-tube rack. Into each test-tube I will pour the clear liquid egg white from one egg. I will place a thermometer into the egg white of each tube. I will heat the tubes to different temperatures using the Bunsen burner for 5 minutes and see in which ones the albumin goes white. I will carry out the experiment at 20 °C, 25 °C, 50 °C and 55 °C. The lowest temperature at which the albumin goes white is the temperature at which it denatures.

a State the **independent variable** the student was testing.

b State the **dependent variable** the student was measuring.

c Will this experiment generate valid data? Explain your answer.

d Write an improved method that would produce more reliable, valid data. In your method you should think about:

i how you will change the independent variable, what range you will use and how you will monitor it

ii how you will measure the dependent variable more accurately and reliably

iii what variables you will control and how you will control each one

iv how you will make the results more reliable.

Exercise 2.7 Extended writing skills

Any higher level study of biology requires you to be able to write well organised, factual essays. A good essay has factual detail in keeping with A level standard and is planned so that it flows and does not jump around from topic to topic. The number of words is a guide, although a shorter essay with more scientific detail and relevance to the question is better than a longer one with less relevance.

1 a Write an essay on the biological importance of water (maximum 500 words).

Start by planning it to include the following:

- water as a solvent
- water as a transport medium
- high specific heat capacity
- high latent heat of vaporisation
- density and freezing properties
- high surface tension and cohesion
- water as a reagent.

For each of these properties you need to:

- explain how water achieves it
- give biological examples.

Try to give examples of both plants and animals.

b When you have written it use the mark scheme in the Answers to decide how many marks you would gain – be critical of yourself!

Exam-style questions

1 **a** Chemical bonds are found in all biological molecules. Complete the table below to match up different bonds with some biological molecules.

	Hydrogen bond	Disulfide bond	Ionic bond	α (1 → 4) glycosidic bond
found in the tertiary structure of a protein				
found in amylose				
found in cellulose				
found in the secondary structure of a protein				

[4]

b Figure 2.6 shows two amino acids.

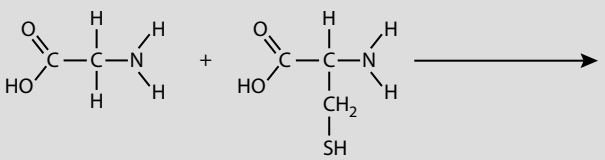


Figure 2.6 Diagram to show the joining of two amino acids.

i Complete the diagram to show the dipeptide formed by joining these two amino acids. [2]

ii Name the type of reaction that occurs to join the two amino acids. [1]

[Total: 7 marks]

2 Figure 2.7 shows a diagram of the enzyme RNase.

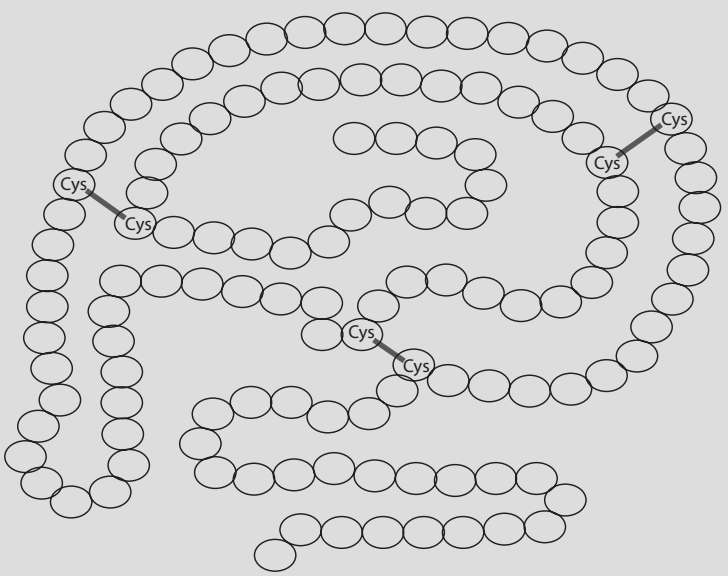


Figure 2.7 Diagram to represent the structure of RNase.

a State the level of protein structure shown in Figure 2.7. [1]

b Addition of a substance called b-mercaptoethanol causes the reduction of disulfide bonds. Explain the effect this would have on RNase activity. [4]

[Total: 5 marks]

3 A student set up a series of reactions to test the activity of the enzymes amylase and sucrase. Biochemical tests were carried out on each of the reaction mixtures after incubating at 37 °C for three hours.

The table below shows the reactions and tests carried out.

Tube	Contents	Iodine test	Benedict's test	Biuret test
A	starch and amylase			
B	starch and sucrase			
C	sucrose and sucrase			
D	sucrose and amylase			

a Complete the table by indicating which tests would give positive (+) and negative (–) results. [3]

b Explain how you could carry out a biochemical test to show that a solution contained a mixture of both glucose and sucrose. [4]

[Total: 7 marks]

4 Figure 2.8 shows the structure of the disaccharide sucrose.

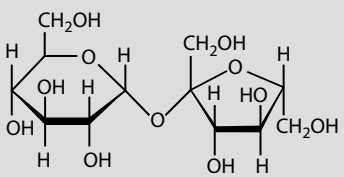


Figure 2.8 Diagram to show the structure of sucrose.

a **i** Name the two monosaccharides produced by the breakdown of sucrose. [1]

ii Draw the structure of the two monosaccharides produced by the breakdown of sucrose. [2]

iii Name the type of reaction that is shown by the breakdown of sucrose. [1]

b Figure 2.9 shows a light micrograph of potato tuber cells.

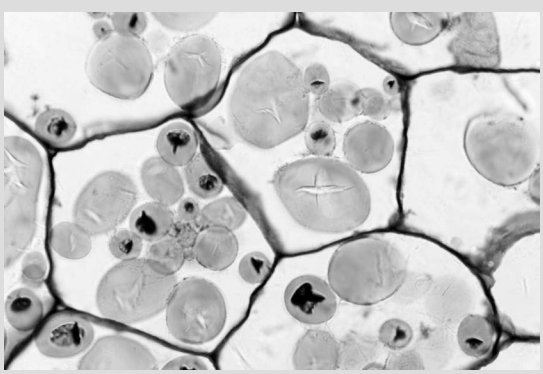


Figure 2.9 Light micrograph of potato tuber cells.

i Add labels on the diagram to show the locations of cellulose and starch. [2]

ii Explain how the structure of cellulose enables it to carry out its function. [4]

iii Explain the advantages of storing starch rather than glucose in plant cells [3]

[Total: 13 marks]

5 **a** Describe how you could test a sample of sesame seeds for the presence of lipids. [3]

b Figure 2.10 shows the general structure of a triglyceride.

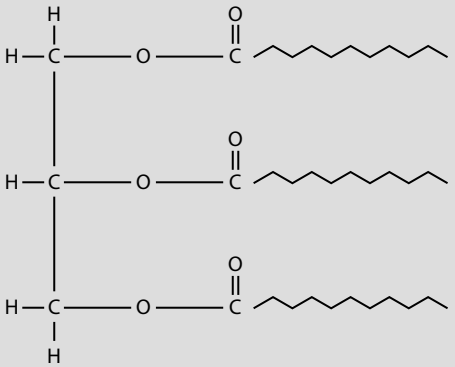


Figure 2.10 Diagram of a triglyceride.

Complete the diagram to show the products of hydrolysis of this triglyceride. [2]

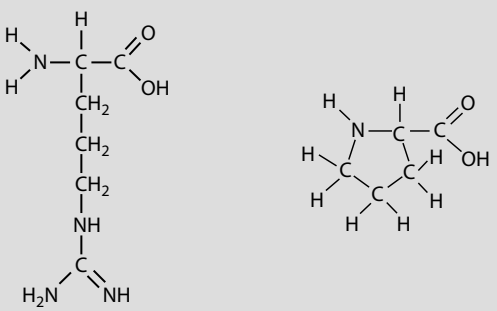
c The table below shows the molecular formulae and melting points of three fatty acids.

Fatty acid	Molecular formula	Melting point / °C
linoleic acid	$C_{18}H_{32}O_2$	–5
oleic acid	$C_{18}H_{34}O_2$	13
stearic acid	$C_{18}H_{36}O_2$	69

Using the information in the table, suggest reasons for the different melting points of the fatty acids. [4]

[Total: 9 marks]

6 **a** The p53 gene is a tumour suppressor gene. It codes for the p53 protein which binds to other cellular proteins to regulate cell division. Tumour cells often contain mutated p53 protein where an amino acid called arginine is replaced by a different amino acid called proline. Figure 2.11 shows the structures of arginine and proline.



Arginine Proline

Figure 2.11 The structures of the amino acids arginine and proline.

Arginine is a hydrophilic amino acid that has a net positive charge.
Proline is a hydrophobic uncharged amino acid.

i Draw the R-group of arginine. [1]

ii Using the example above, explain how changing the primary sequence of a **polypeptide** could affect its function. [3]

b Collagen is a fibrous protein found in many animal tissues including bones and cartilage. Explain how the structure of fibrous proteins such as collagen gives them high tensile strength. [3]

[Total: 7 marks]

Chapter 3
Enzymes

Chapter outline

The questions in this chapter cover the following topics:

- how enzymes work
- the factors that affect enzyme activity, including inhibitors
- finding and using V_{max} and K_m
- how to carry out experiments with enzymes
- the advantages of using immobilised enzymes

Exercise 3.1 Answering questions about graphs

Exam questions often provide a graph, and then ask various questions relating to it. In this exercise, you practise answering questions involving three different command words, all about the same graph. You then calculate a rate by drawing a tangent to one of the curves.

When you are asked to **describe** a graph, your task is to change the information shown by the line into words. You don't use your biological knowledge for this. Concentrate on the overall trend, then any obvious changes in gradient. Quote figures, referring to both the *x*- and *y*-axes, and remember to give units.

Explaining a graph, however, requires to you to say *why* the graph is the shape that it is.

When asked to **compare** two graphs, try to make statements that include words such as 'but', 'however', and comparative terms such as 'faster', 'higher', 'greater'. Quote comparative figures for particular values that look significant to you; you could subtract one from the other, or calculate how many times greater one is than the other.

A student extracted catalase from 100 g of carrot and 100 g of apple. He added the two extracts to two tubes of hydrogen peroxide solution and measured the oxygen given off over a period of 10 minutes.

The graph shows the results he obtained.

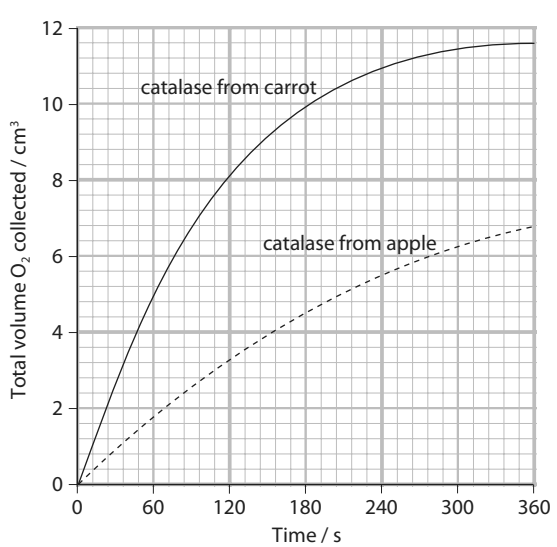


Figure 3.1 Graph showing the time course of the reaction for two sources of catalase.

1 **a** Describe the curve for the catalase from carrot.

b Explain the shape of this curve.

2 Compare the curves for catalase from carrot and catalase from apple.

We can calculate the rate at which oxygen is given off at a particular time. Here's how to do this for the apple catalase curve:

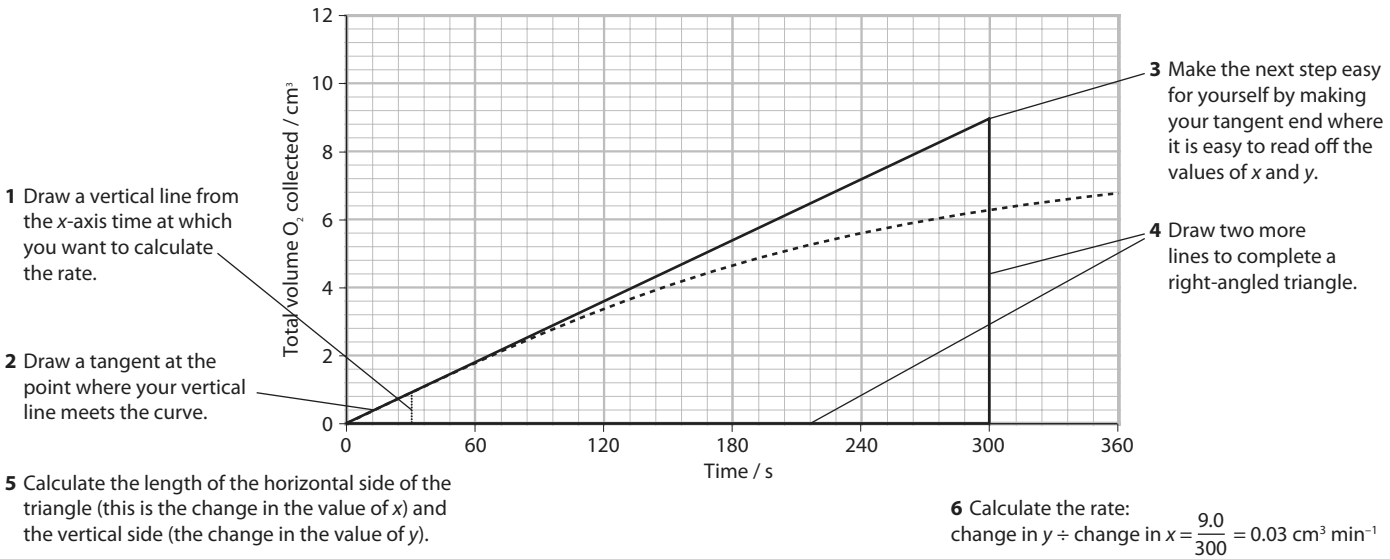


Figure 3.2 Calculating a gradient by drawing a tangent.

3 Calculate the rate at which oxygen is given off at 30 s for the carrot catalase curve.

Exercise 3.2 Effects of temperature and pH on enzyme activity

Like Exercise 3.1, this exercise involves interpreting graphs. Here, however, some of the data are rather unexpected, and you are asked to think about what might be causing these unexpected results.

Spondias is a South American tree whose fruit is used for making juices and ice cream. Like the cells of many fruits, the cells of *Spondias* contain an enzyme called polyphenol oxidase. The substrate for this enzyme is a group of colourless compounds, which the enzyme converts to brown quinones. Normally, the enzyme and its substrate are kept in separate cellular compartments, but when the fruit is damaged they meet and the damaged tissue turns brown.

Producers of fruit juice and other products from *Spondias* need to understand how this enzyme works, so that they can prevent browning in their products. A team of researchers added an extract from *Spondias* fruits to a solution of pyrocatechol, which is a substrate for polyphenol oxidase. They measured the degree of browning using a colorimeter.

The graphs in Figures 3.3 and 3.4 show how temperature and pH affected the rate of activity of polyphenol oxidase from *Spondias* fruits.

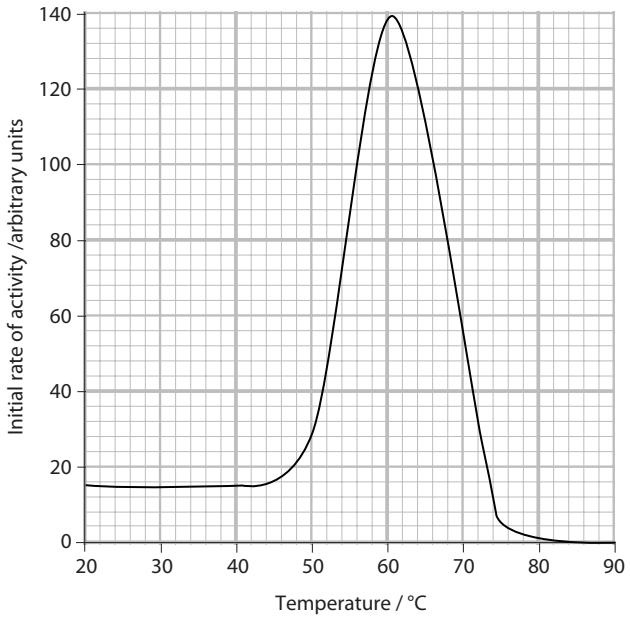


Figure 3.3 The effect of temperature on the rate of activity of polyphenol oxidase.

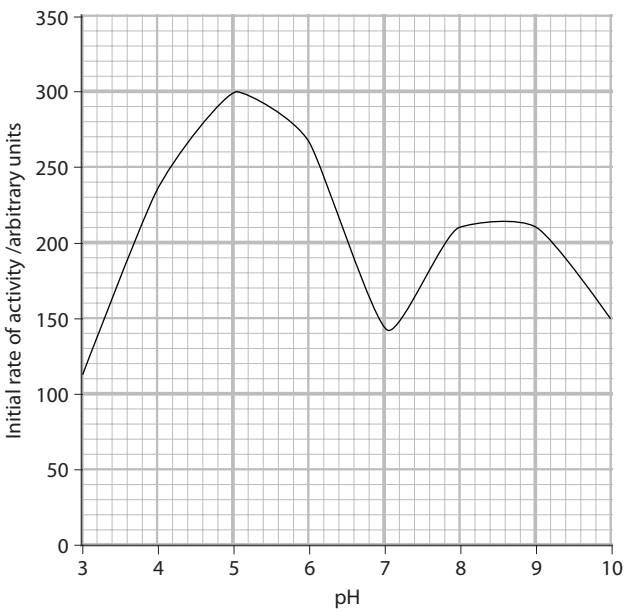


Figure 3.4 The effect of pH on the rate of activity of polyphenol oxidase.

1 **a** Describe the effect of temperature on the rate of activity of polyphenol oxidase from *Spondias* fruits.

b Explain the effects you have described in your answer to **a**.

2 **a** Describe how the effect of pH on the rate of activity of polyphenol oxidase from *Spondias* fruits differs from the usual effect of pH on the activity of an enzyme.

b The researchers concluded that the extract they had made from the *Spondias* fruits probably contained more than one type of polyphenol oxidase. What is the evidence for this conclusion?

3 The researchers recommended that the food manufacturers could reduce the browning of products made from *Spondias* fruits by adding lemon juice during their processing. Use the data in the graphs to explain how this might work.

Exercise 3.3 Finding V_{max} and K_m

In this exercise, you first plot a graph, and then use it to find V_{max} and the Michaelis–Menten constant, K_m.

Lipase is an enzyme that hydrolyses lipids to fatty acids and glycerol.

A researcher extracted lipase from *Burkholderia cepacia*, a species of bacterium. The lipase was added to an emulsion of olive oil. The rate of activity of the enzyme was measured by finding how much fatty acid was released from the olive oil in one minute.

The researcher investigated the effect of substrate concentration on the initial rate of reaction, *V*, of the lipase. The results are shown in the table.

Concentration of substrate / %	Initial rate of activity of lipase / μmol of fatty acid produced per minute
0	0
5	8
10	16
15	22
20	26
25	29
30	31
35	32
40	33
45	33
50	33

1 Which **two** of these variables would the researcher keep constant in the experiments:

- the concentration of the lipase
- the concentration of the olive oil
- the temperature?

2 On a sheet of graph paper, construct a line graph to display these data. Draw a best fit line.

3 V_{max} is the initial rate of reaction at which substrate concentration is no longer limiting the reaction rate. Use your graph to find V_{max}.

4 The Michaelis–Menten constant for the enzyme, K_m, is the substrate concentration at which the rate of activity of the enzyme is ½ V_{max}.

Step 1 On the *y*-axis of your graph, find the value that is exactly half the value of V_{max}.

Step 2 Draw a horizontal line from this point on the *y*-axis, until it hits the curve.

Step 3 Draw a vertical line from this point on the curve, down to the *x*-axis.

Step 4 Read off the value of *x* at this point. This is K_m.

5 The researcher repeated this experiment using lipase extracted from a different species of bacterium. He found that K_m for this species was lower than that for *B. cepacia*.

What can you conclude about the relative affinity for their substrates of the lipases from the two species of bacteria?

Exercise 3.4 Planning an investigation into the effect of inhibitor concentration on urease activity

Many experiments involve finding the effect of one variable (the independent variable) on another (the dependent variable). Any other variables that might affect your results should be kept the same – these are often known as controlled variables. It's often necessary to do some preliminary trials, to try to decide on the values of the independent and controlled variables that might work best. In this exercise, you will think about how you could do such an experiment.

Here is some information about urease, its substrate and an inhibitor that slows down its action.

- Urease is an enzyme that converts urea to ammonia:

$$CO(NH_2)_2 + H_2O \rightarrow 2NH_3 + CO_2$$

- Farmers often add fertilisers containing urea to the soil, which is a way of providing slow-release nitrogen compounds for their crops. These fertilisers sometimes also contain a urease inhibitor. This reduces the production of ammonia.
- You can obtain an extract containing urease by soaking soya beans in water overnight, then liquidising the mixture in a blender (or use a pestle and mortar). Filter the mixture, and keep the filtrate to use as your enzyme extract.
- Urea can be bought as a powder, which dissolves in water.
- The inhibitor can also be bought as a powder, which dissolves in water.
- Ammonia dissolves in water to form a solution with a pH above 7.

The rate of production of ammonia can be followed by measuring the pH of the enzyme–substrate mixture, using an indicator solution or a pH meter.

Answer the questions below, to explain how you would plan an experiment to investigate how the concentration of the inhibitor affects the rate of activity of the enzyme.

1 **a** What is your independent variable?

b What is your dependent variable?

c List the important variables that you must keep the same.

2 What risks can you identify? What can you do to keep yourself and others safe?

3 You will need to do some preliminary work to find out a suitable concentration of substrate to use, so that you can obtain results in a reasonable length of time.

a Imagine that you have been provided with a bottle of urea powder. Describe how you could make up a 10% solution of urea in water.

b Imagine that you have made a solution containing urease from soya beans (as described above). You try adding 5 cm^3 of this urease solution to 5 cm^3 of the 10% urea solution, and measure the pH change. You find that the change in pH is very slow.

Complete the sentence to suggest how you could make the reaction happen more quickly:

You could use a ..... concentrated solution of urease.

4 Imagine you have been provided with a 10% solution of the inhibitor.

a Describe how you could use this solution to make up a range of solutions with different concentrations.

b Suggest a suitable range and interval for the concentration of the inhibitor. Remember that the range is the spread between your lowest and highest value, and the interval is the difference between each value. You should have at least five values.

5 Describe how you will carry out your experiment.

6 Draw a results chart, with full headings, that you would be able to fill in as you collect your results.

Remember:

- The results chart should be drawn using a ruler. Each row and column should be separated from the next by a ruled line.
- The independent variable should be in the first column of your table.
- The repeat readings for the dependent variable should be in the next columns.
- The mean values of the dependent variable should be in the last column of the table.

7 Sketch the curve that you would expect to obtain if the inhibitor is a non-competitive inhibitor.

Exercise 3.5 Calculating actual and percentage error

We can never be absolutely certain that a value that we measure is a true value. It is possible to estimate the actual error in a reading quantitatively. We can then use this to estimate the percentage error in a reading.

Whenever you make a measurement with an instrument – such as a measuring cylinder, pipette, thermometer – you cannot be certain that the reading is exactly correct. There is an **uncertainty** or error in your measurement.

In general, we say that the size of the error is equivalent to half the size of the smallest division on the scale you are reading from.

For example, imagine you have a thermometer marked off in °C. When you read the thermometer, you can read the scale to the nearest 0.5 °C. However, we must accept that there is an uncertainty in this reading of 0.5 °C. So, if you read a temperature of 17.5 °C, you can show this by writing it as 17.5 ± 0.5 °C. This is the **error** in our measurement.

1 A 1000 cm^3 measuring cylinder is marked off in intervals of 10 cm^3. What is the actual error in each reading of volume that you make using this measuring cylinder?

If you are measuring a ***change*** in a quantity, then you must take into account that there are uncertainties in the readings for both the starting value and the final value. For example, if you measure a temperature at the start of an experiment as 22.0 °C, and at the end as 27.5 °C, then you must add together the 0.5 °C uncertainties for each reading. The change in temperature is therefore given as an increase of 5.5 ± 1 °C.

2 A 100 cm^3 measuring cylinder is marked off in intervals of 2 cm^3. What is the size of the actual error if you measure a change in volume using this measuring cylinder?

Once we have worked out the size of the error in the measurements, we can use this to calculate the **percentage error**:

$$\text{percentage error} = \frac{\text{size of the error in the reading}}{\text{the reading}} \times 100$$

So, if we measure a volume of 28 cm^3 using a 50 cm^3 measuring cylinder marked off in intervals of 1 cm^3, the error in that measurement is ± 0.5 cm^3, and the percentage error is:

$$\frac{0.5}{28} \times 100 = 1.8\%$$