Sixth Form Handbook

Biology

Contents

About the course

Biology involves the study of a wide range of topics, ranging from molecular biology to the study of ecosystems and microorganisms to mammoths. Many areas of biology are at the cutting edge of science with vital innovations occurring every year.

Biology is also a well-recognised and respected course and is identified as a key facilitating subject by the Russell Group of Elite Universities. It can lead students on to study many different types of science course at university. Students from Poole High School have gone on to study pure Biology, Biochemistry, Environmental Sciences, Forensics as well as medical related courses such as physiotherapy, medicine, dentistry and nursing.

Topics include:

1 Biological molecules
2 Cells
3 Organisms exchange substances with their environment
4 Genetic information, variation and relationships between organisms
5 Energy transfers in and between organisms (A-level only)
6 Organisms respond to changes in their internal and external environments (A-level only)
7 Genetics, populations, evolution and ecosystems (A-level only)
8 The control of gene expression (A-level only)

How you will be assessed

A Level

Paper 1	Paper 2	Paper 3
What's assessed • Any content from topics 1–4, including relevant practical skills	**What's assessed** • Any content from topics 5–8, including relevant practical skills	**What's assessed** • Any content from topics 1–8, including relevant practical skills
Assessed • written exam: 2 hours • 91 marks • 35% of A-level	**Assessed** • written exam: 2 hours • 91 marks • 35% of A-level	**Assessed** • written exam: 2 hours • 78 marks • 30% of A-level
Questions • 76 marks: a mixture of short and long answer questions • 15 marks: extended response questions	**Questions** • 76 marks: a mixture of short and long answer questions • 15 marks: comprehension question	**Questions** • 38 marks: structured questions, including practical techniques • 15 marks: critical analysis of given experimental data • 25 marks: one essay from a choice of two titles

Practical Work

The new Biology specification places an emphasis on practical work and you will find your skills improving throughout the year. Assessment of these skills will be through written questions in the exams and a practical endorsement that you work towards over the two years and is assessed by your teacher. Universities will be looking to see that you have passed this practical endorsement although it does not contribute towards your grade.

There are twelve required practical's. Questions in the papers have been written in the expectation that students have carried out at least the twelve required practical activities.15% of the marks in the papers will relate to practical work.

A-level grades will be based only on marks from written exams.
A separate endorsement of practical skills will be taken alongside the A-level. This will be assessed by teachers and will be based on direct observation of students' competency in a range of skills that are not assessable in written exams.

Lab books

We expect all students to maintain a clear lab book providing evidence for the practical endorsement.

- Each page should be numbered and dated.
- Write in ink. Pencil should not be used for anything other than graphs and diagrams.
- Cross out mistakes (single line through) and re-write i.e. do not overwrite, erase, or use Tippex.
- Printed information, graphs, photographs and flat "data" such as chromatograms or TLC plates should be stuck in flat and not folded. No work should be covered.
- Complete a table of contents for additional practicals. You will provided a list of required practicals.

Lab books may contain:

- title and date of experiment
- objectives
- risk assessments
- apparatus, with sketches/photos of set up
- method, including all measurements
- data and observations input to tables (or similar) while carrying out the experiment
- calculations, including uncertainty – annotated to show thinking
- graphs
- analysis and conclusions
- cross-references to earlier data and references to external information

Plagiarism

For some practicals you will need to carryout research. You must cite sources of information using the Harvard referencing system

- To reference a quotation in the body of your work you put quotation marks "..." around the section that you have taken from someone else's work. After the last quotation mark you put the reference in brackets. For books it should include the surname of the writer, the year they wrote it and the page number you took the quote from.
- You then have to include the full reference at the end of your report in a 'References' section e.g. Kennedy, D. (1987) *'Islands of White: Settler society and culture in Kenya and Southern Rhodesia, 1890-1939'* (2nd Edition) Durham: Duke University Press.

- Websites also require referencing in a similiar way e.g. Mooney, A. and Blackburn, T. (2003) *Children's views on childcare* [online] Available from: www.childlink.co.uk Accessed [6th June 2007]. If the website has no known author, simply skip to "The title of the website" and carry on from there.

Lab Health & Safety

You are more likely to suffer a minor injury - a cut, burn or scald - in a kitchen than in a laboratory. We know there are hazards involved in working in a laboratory so Risk Assessments are made for every experiment and protective measures are taken to control those risks. In biology lessons most risks arise from the use of chemicals, but some other practical activities have associated hazards e.g. heating, cutting. Laboratory safety is about minimising exposure to risk, as well as protecting yourself from the results of mishaps.

You will be healthy, safe and successful in your laboratory work provided you plan your work taking note of the health and safety information provided, you wear eye protection and whatever else is recommended and you carry out all instructions thoughtfully and correctly.

All the experiments in this course have been checked for health and safety implications, but you will be expected to carry out a Risk Assessment (and have it checked before starting any practical work) for some.

A risk assessment is nothing more than a careful examination of what, in your experiment or investigation, could cause harm to people, so that you can weigh up whether you have taken enough precautions or should do more to prevent harm. The important things you need to decide are whether a hazard is significant, and whether you have it covered by satisfactory precautions so that the risk is small.

Hazard means anything that can cause harm. **Risk** is the chance, high or low, that somebody will be harmed by the hazard.

Good laboratory practice

As well as the specific protective measures to be taken when hazardous chemicals are being used, there are also general procedures to be observed in all laboratories at all times.

- **Long hair** should be tied back and you should not wear 'wet look' hair preparations, which can make hair unusually flammable.
- A **long sleeves** should be worn to avoid damage to arms.
- **Closed shoes** should be worn to avoid damage to feet.
- **Eating, drinking and chewing** are not permitted in laboratories.
- **Eye protection** should be worn whenever a Risk Assessment requires it, or whenever there is any risk to your eyes. This includes, for example, washing up at the end of the lesson and even when you have finished practical work, as long as other students are still working.
- Chemicals that you use will be **clearly labelled** with the name of the chemical, any hazards, and the date of acquisition or preparation. When taking liquids from a bottle, remove the stopper with one hand and keep the stopper in your hand whilst pouring from the bottle. This way, the stopper is likely to be replaced at once and to remain uncontaminated. Pour liquids from the opposite side to the label, so that it does not become damaged by corrosive chemicals.
- Study carefully the best techniques for **safely heating** chemicals. Small quantities of solid can be heated in test tubes; liquids present greater problems, because of the risk of 'bumping' and 'spitting'. Boiling tubes are safer than test tubes (because of their greater volume), but should be **less than one-fifth full**. You are likely to point test tubes away from your own face, but do

remember the need to do the same for your neighbours. **Use a water bath to heat flammable liquids**; **NEVER use a naked flame**.

- You must always **clear up chemical spillages straight away**. Whilst a few spills may need chemical neutralisation or similar treatment, most minor spills can be wiped up using damp green paper towels.
- In the event of getting a chemical in your eye, or on your skin, **flood the area with large quantities of water at once**. Keep the water running for at least 10 minutes (20 minutes for alkalis in the eye). Even if the chemical reacts exothermically with water, provided a large quantity of water is used, the heating effect will be negligible. We have eye wash stations in each laboratory.
- A heat burn from apparatus, scalding liquids or steam is treated by **immersing the area in cool water** for at least 10 minutes. Preferably use running water from rubber tubing, fixed to a tap.
- **Report all accidents at once.**

Our Expectations of You

At the beginning of the course you will be asked to sign a form to confirm that you have fully read and understood the course expectations.

Course requirements

A level Biology builds on the knowledge, understanding and skills that you obtained in your GCSEs (including Maths and English). If you are feeling a little rusty you need to dust off your revision guide.

The A-level requires a **considerably** more independent approach than you experienced at GCSE. You will need to make sure you consolidate knowledge outside of lessons and ask whenever help is required. You will not attain a good grade by simply cramming at the end. You will need to actively participate and concentrate fully in lessons from day one. You can expect to receive flipped learning tasks before each lesson that you must complete before arriving in class.

Your Notes

We expect all students to maintain a well-organised folder. These will be spot checked at times during the course.

Your folder should include a minimum of:

- Notes of theory – there is a section towards the end of this handbook to help you with this.
- Flipped learning tasks.
- Topic overview sheets.
- Completed independent study tasks and questions – with corrections.
- End of topic tests – with corrections and next steps.

Independent Study

To achieve a good grade it is imperative that you work outside of lessons to prepare, consolidate and develop the ideas covered during lessons. **It is our expectation that from the start of the course, for each lesson at least 1 hour of independent study is completed.**

At the beginning of a topic you can expect a topic overview sheet. This details the lessons, success criteria and resources. You will also receive flipped learning tasks, essentially, **preparation work that must be carried out before the lesson.** If you do not prepare for the lesson you will often be unable to participate as fully and gain the most from the lesson. Continued lack of preparation will result in disciplinary action.

The independent work you may carry out (but are in no way limited to):

- preparation work from the topic overview and flipped tasks.
- reading/watching videos around the subject.
- extra notes as necessary to ensure full understanding, taken after the lesson.
- writing up experiments.
- completing past paper questions.
- acting on feedback from independent assessments and in class assessments.
- answering questions from the book.
- completing the workbook.
- attending drop in sessions on offer by the department to get 1:1 help.

Past Paper Questions

You will regularly be set past paper questions to allow you to consolidate your knowledge and practice exam technique. Either your teacher will mark these, or they will be self/peer assessed in class. It is the expectation that you will use your corrected past paper questions to revise.

Any poor performance in past paper questions that is down to a lack of effort will result in disciplinary action. Any past paper questions handed in late will result in disciplinary action, and will not normally be marked. If you know that you will be away on any deadline date, for a school trip or otherwise, then it is your responsibility to get the work in before you leave. It is your responsibility to collect a copy of the past paper questions if you are absent. Past paper questions are not to be carried out on the evening before the deadline. Start your past paper questions as soon as possible and if you have difficulties there will then be time for you to seek help. Progress will be tracked against your target grade. Underachievement will be identified and you will be required to attend additional drop in sessions and retake the past paper questions.

Teachers may choose to spend lesson time giving feedback on the past paper questions if they feel this is appropriate. Otherwise answers to the past paper questions will be placed on the A level Biology google classroom after all classes have completed it.

Assessment Grade Boundaries

These grade boundaries are indicative only; they may change in either direction depending on the content included in the assignment.

A	80 –100%
B	70 – 79%
C	60 – 69%
D	50 – 59%
E	40 – 49%
U	0 – 39%

End of topic tests

Further assessment of your progress will be made at the end of each topic, through the use of class tests. The format of these is past exam questions. Poor performance in these indicates a lack of effort and independent study by the student concerned or a difficulty with

the content or exam technique. This will be addressed with compulsory attendance to drop in sessions and retaking the assessment paper. An average of these results will be used for reports and when predicted UCAS grades are set.

Course Reading List & Materials

Books

You will be expected to borrow Oxford University Press 'AQA BIOLOGY' from the library. This book covers everything (almost!) in the specification. Like all textbooks they contain a contents page and index, with a glossary towards the back. Most chapters also contain 'How science works' or 'Maths' features, Synoptic links, Study tips and Hints. Summary questions throughout the book (answers at back) will help you think about what you are studying. At the end of each topic you will find exam-style practice questions to help you check your progress. There are additional sections towards the end of the book dedicated to mathematical and practical skills. The books are a guide through the course however you will need to supplement these with additional reading and independent study.

You will also be given the opportunity to purchase A level Biology workbooks. These contain past paper style questions on each topic and the answers are in the back of the book.

Similarly there will an opportunity to purchase a CGP revision guide at a reduced price, these have proved helpful for students as an alternative source of revision notes.

Biology classrooms will contain several copies of 'Essential Maths Skills for A level Biology' published by Hodder Education. These will be available for you to use during drop in sessions.

Useful websites

Physics and Maths Tutor
http://www.physicsandmathstutor.com/biology-revision/a-level-aqa/
Website contains additional notes and questions.

Tasks before September

The summer task below is part of the first topic that is to be covered in September. The content contains a great deal of new vocabulary that I would like you to learn so we can maximize class time for working on exam technique and addressing problems. Following the tasks are pages that can be used for reference. You may also, of course, use any other sources of information you wish, however, it is important to check that your sources are the same level as the attached pages.

You are expected to complete the tasks below. If you have a problem with this please see Mrs Home. Your work will be checked during the first lesson of the year. **During the second week of the year you will be given an appropriate assessment on the content of the summer**

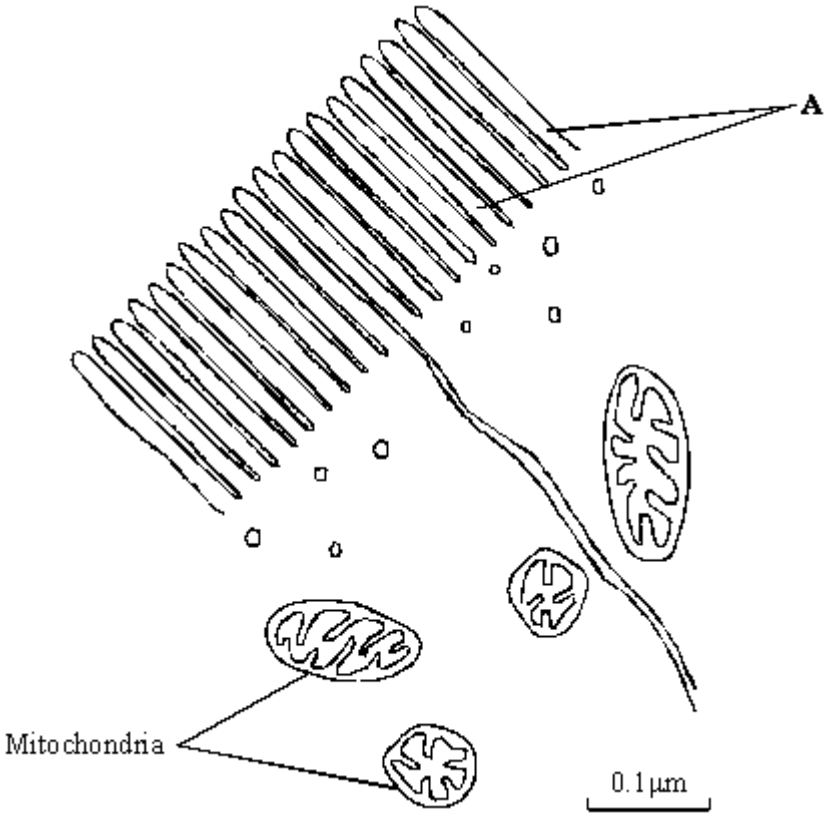
task. Poor performance in this assessment will result in discussion and a second assessment after a further week. Continued poor performance will put your suitability for a place on the course in question.

Cells

SECTION A: Methods of studying cells

a) Describe a light microscope and how it works.
b) Draw a table detailing the units of measurement of length, their symbol and their standard form equivalence in metres.
c) Define magnification.
d) Write the equation for calculating the magnification of an image. Also, draw this in the triangle form.
e)

The drawing shows an electron micrograph of parts of epithelial cells from the small intestine.



The scale bar on this drawing represents a length of 0.1µm. Calculate the magnification of the drawing. Show your working. (2)

f) Define resolution.
g) Explain how cell fractionation and ultracentrifugation can be used to separate cell components. You may wish to include diagrams for clarity.

SECTION B: The electron microscope

a) Explain why electron microscopes were developed (refer to magnification and resolution)
b) Describe the two types of electron microscope.
c) Draw and complete a table to show the features and limitations of an SEM and a TEM.

SECTION C: Eukaryotic cell structure

a) Label a diagram of an animal cell including the following organelles:

- cell-surface membrane
- nucleus (containing chromosomes, consisting of protein-bound, linear DNA, and one or more nucleoli)
- mitochondria
- Golgi apparatus and Golgi vesicles
- lysosomes (a type of Golgi vesicle that releases lysozymes)
- ribosomes
- rough endoplasmic reticulum and smooth endoplasmic reticulum

b) Label a diagram of a plant cell including the above plus the following organelles:

- chloroplasts (in plants and algae)
- cell wall (in plants, algae and fungi)
- cell vacuole (in plants).

c) Draw a table of the organelles in plant and animal cells with a **brief** description of the function of each organelle

You must now learn this content. Use the strategies that you used for revision for GCSE to help you. REMEMBER: you need to force yourself to recall the information at least 3 times at different intervals in order to remember it.

I look forward to teaching you in September. Enjoy ☺

3 Cell structure
3.1 Methods of studying cells

Learning objectives

- Explain the principles of magnification and resolution.
- Describe what cell fractionation is.
- Explain how ultracentrifugation works.

Specification reference: 3.2.1.3

Study tip

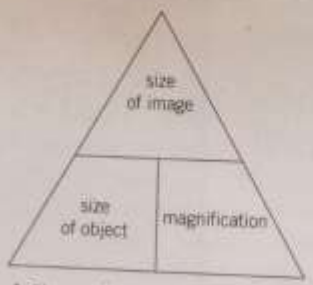
Make sure that you use scientific terms correctly. For example, light has a longer wavelength than a beam of electrons. It's not correct to say that optical microscopes have a longer wavelength than electron microscopes though.

Maths link

MS 1.8, 0.1, 0.2 and 2.2, see Chapter 11.

▼ **Table 1** *Units of length*

Unit	Symbol	Equivalent in metres
kilometre	km	10^{3}
metre	m	1
millimetre	mm	10^{-3}
micrometre	µm	10^{-6}
nanometre	nm	10^{-9}



▲ **Figure 1** *The equation triangle for calculating the size of image, magnification and size of object*

The cell is the basic unit of life. However, with a few exceptions, cells are not visible to the naked eye and their structure is only apparent when seen under a microscope.

Microscopy

Microscopes are instruments that produce a magnified image of an object. A simple convex glass lens can act as a magnifying glass but such lenses work more effectively if they are used in pairs in a compound light microscope. The relatively long wavelength of light rays means that a light microscope can only distinguish between two objects if they are 0.2 µm, or further, apart. This limitation can be overcome by using beams of **electrons** rather than beams of light. With their shorter wavelengths, the beam of electrons in the electron microscope can distinguish between two objects only 0.1 nm apart.

Magnification

The material that is put under a microscope is referred to as the **object**. The appearance of this material when viewed under the microscope is referred to as the **image**.

The magnification of an object is how many times bigger the image is when compared to the object.

$$\text{magnification} = \frac{\text{size of image}}{\text{size of real object}}$$

In practice, it is more likely that you will need to calculate the size of an object when you know the size of the image and the magnification. In this case:

$$\text{size of real object} = \frac{\text{size of image}}{\text{magnification}}$$

The important thing to remember when calculating the magnification is to ensure that the units of length (Table 1) are the same for both the object and the image.

Worked example

An object that measures 100 nm in length appears 10 mm long in a photograph. What is the magnification of the object?

$$\frac{\text{size of image}}{\text{size of real object}} = \frac{10\,\text{mm}}{100\,\text{nm}}$$

Now convert the measurements to the same units – normally the smallest – which in this case is nanometres. There are 10 000 000 nanometres in 10 millimetres and therefore the magnification is:

$$\frac{\text{size of image}}{\text{size of real object}} = \frac{10\,000\,000\,\text{nm}}{100\,\text{nm}} = \frac{100\,000}{1} = \times 100\,000 \text{ times}$$

These figures can also be expressed in standard form as follows:

$$\frac{\text{size of image}}{\text{size of real object}} = \frac{10^{7}}{10^{2}} = \frac{10^{5}}{1} = \times 10^{5}$$

Resolution

The resolution, or resolving power, of a microscope is the minimum distance apart that two objects can be in order for them to appear as separate items. Whatever the type of microscope, the resolving power depends on the wavelength or form of radiation used. In a light microscope it is about 0.2 µm. This means that any two objects which are 0.2 µm or more apart will be seen separately, but any objects closer than 0.2 µm will appear as a single item. In other words, greater resolution means greater clarity, that is the image produced is clearer and more precise.

Increasing the magnification increases the size of an image, but does not always increase the resolution. Every microscope has a limit of resolution. Up to this point increasing the magnification will reveal more detail but beyond this point increasing the magnification will not do this. The object, while appearing larger, will just be more blurred.

Cell fractionation

In order to study the structure and function of the various organelles that make up cells, it is necessary to obtain large numbers of isolated organelles.

Cell fractionation is the process where cells are broken up and the different organelles they contain are separated out.

Before cell fractionation can begin, the tissue is placed in a cold, buffered solution of the same water potential as the tissue. The solution is:

- cold – to reduce enzyme activity that might break down the organelles
- is of the same water potential as the tissue – to prevent organelles bursting or shrinking as a result of osmotic gain or loss of water
- buffered – so that the pH does not fluctuate. Any change in pH could alter the structure of the organelles or affect the functioning of enzymes.

There are two stages to cell fractionation:

Homogenation

Cells are broken up by a homogeniser (blender).This releases the organelles from the cell. The resultant fluid, known as homogenate, is then filtered to remove any complete cells and large pieces of debris.

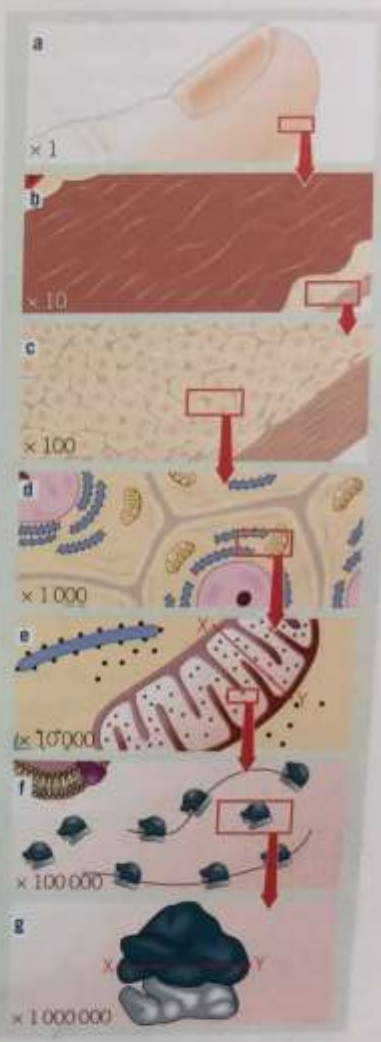
Ultracentrifugation

Ultracentrifugation is the process by which the fragments in the filtered homogenate are separated in a machine called a centrifuge. This spins tubes of homogenate at very high speed in order to create a centrifugal force. For animal cells, the process is as follows:

- The tube of filtrate is placed in the centrifuge and spun at a slow speed.
- The heaviest organelles, the nuclei, are forced to the bottom of the tube, where they form a thin sediment or pellet.
- The fluid at the top of the tube (supernatant) is removed, leaving just the sediment of nuclei.
- The supernatant is transferred to another tube and spun in the centrifuge at a faster speed than before.

Hint

Practise working out actual sizes from diagrams and photographs with a given scale. Practice makes it easy.



▲ **Figure 2** *The effect of progressive magnification of a portion of human skin*

Study tip

Remember that the solution used during cell fractionation prevents *organelles* bursting or shrinking as a result of osmotic gain or loss of water. Don't refer to *cells* bursting or shrinking. This is a common error!

Summary questions

1 Distinguish between magnification and resolution.

2 An organelle that is 5 µm in diameter appears under a microscope to have a diameter of 1 mm. Calculate how many times the organelle has been magnified.

3 A cell organelle called a ribosome is typically 25 nm in diameter. Calculate its diameter when viewed under an electron microscope that magnifies it 400 000 times.

4 At a magnification of ×12 000 a structure appears to be 6 mm long. Determine its actual length.

5 Chloroplasts have a greater mass than mitochondria but a smaller mass than nuclei. Starting with a sample of plant cells, describe briefly how you would obtain a sample rich in chloroplasts. Use Figure 3 to help you.

6 Using the magnifications given in Figure 2, calculate the actual size of the following organelles as measured along the line labelled X–Y. In your answer, use the most appropriate units from Table 1.

a The organelle in box e

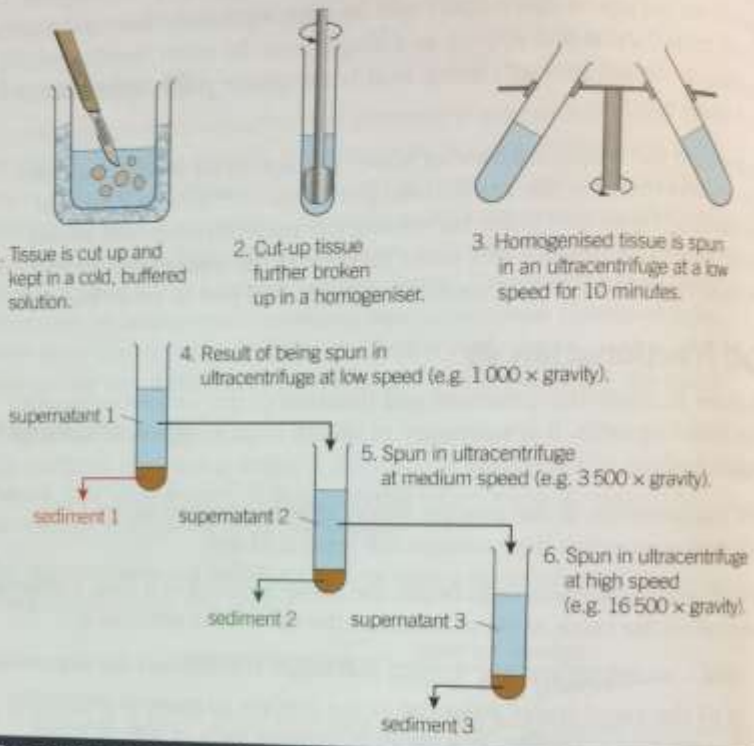
b The organelle in box g

Maths link

MS 1.8 and 2.2, see Chapter 11.

- The next heaviest organelles, the mitochondria, are forced to the bottom of the tube.
- The process is continued in this way so that, at each increase in speed, the next heaviest organelle is sedimented and separated out.

A summary of cell fractionation is given in Figure 3.



Organelles to be separated out	Speed of centrifugation /revolutions min^{-1}
nuclei	1 000
mitochondria	3 500
lysosomes	16 500

▲ **Figure 3** *Summary of cell fractionation*

The techniques of cell fractionation and ultracentrifugation enabled considerable advances in biological knowledge. They allowed a detailed study of the structure and function of organelles, by showing what isolated components do.

◀ **Figure 4** *An ultracentrifuge used to separate the various components of cell homogenate*

3.2 The electron microscope

Light microscopes have poor resolution as a result of the relatively long wavelength of light. In the 1930s, however, a microscope was developed that used a beam of electrons instead of light. This is called an electron microscope and it has two main advantages:

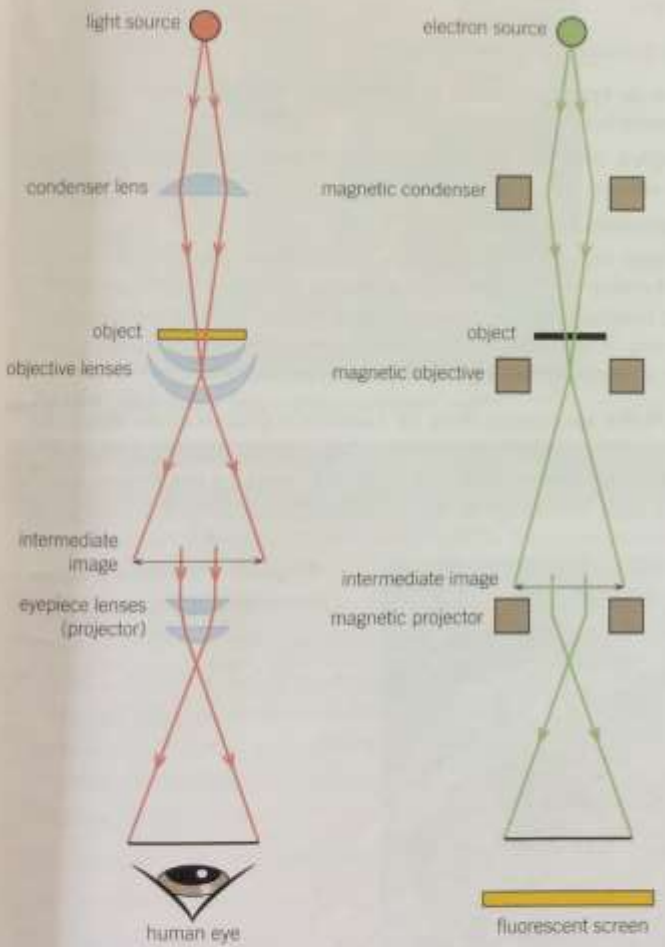
- The electron beam has a very short wavelength and the microscope can therefore resolve objects well – it has a high resolving power.
- As electrons are negatively charged the beam can be focused using electromagnets (Figure 2).

The best modern electron microscopes can resolve objects that are just 0.1 nm apart – 2000 times better than a light microscope. Because electrons are absorbed or deflected by the molecules in air, a near-vacuum has to be created within the chamber of an electron microscope in order for it to work effectively.

Learning objectives

- → Explain how electron microscopes work.
- → Explain the differences between a transmission electron microscope and a scanning electron microscope.
- → Describe the limitations of the transmission and the scanning electron microscopes.

Specification reference: 3.2.1.3



▲ **Figure 2** *Comparison of radiation pathways in light and electron microscopes*

▲ **Figure 1** *Scientist looking at a sample using a transmission electron microscope (TEM)*

Study tip

Remember that the greater resolving power of an electron microscope compared to a light microscope is due to the electron beam having a shorter wavelength than light.

There are two types of electron microscope:

- the transmission electron microscope (TEM)
- the scanning electron microscope (SEM).

The transmission electron microscope

The TEM consists of an electron gun that produces a beam of electrons that is focused onto the specimen by a condenser electromagnet. In a TEM, the beam passes through a thin section of the specimen. Parts of this specimen absorb electrons and therefore appear dark. Other parts of the specimen allow the electrons to pass through and so appear bright. An image is produced on a screen and this can be photographed to give a **photomicrograph**. The resolving power of the TEM is 0.1 nm although this cannot always be achieved in practice because:

- difficulties preparing the specimen limit the resolution that can be achieved
- a higher energy electron beam is required and this may destroy the specimen.

The main limitations of the TEM are:

- The whole system must be in a vacuum and therefore living specimens cannot be observed.
- A complex 'staining' process is required and even then the image is not in colour.
- The specimen must be extremely thin.
- The image may contain artefacts. Artefacts are things that result from the way the specimen is prepared. Artefacts may appear on the finished photomicrograph but are not part of the natural specimen. It is therefore not always easy to be sure that what we see on a photomicrograph really exists in that form.

Study tip

Look at photographs taken with an SEM and a TEM and make sure you can identify cell organelles. Don't just rely on diagrams.

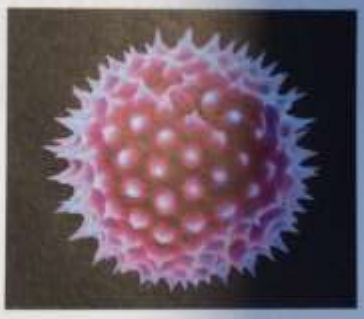
In the TEM the specimens must be extremely thin to allow electrons to penetrate. The result is therefore a flat, 2-D image. We can partly get over this by taking a series of sections through a specimen. We can then build up a 3-D image of the specimen by looking at the series of

◀ **Figure 3** *Part of an animal cell seen under a TEM*

photomicrographs produced. However, this is a slow and complicated process. One way in which this problem has been overcome is the development of the SEM.

The scanning electron microscope

All the limitations of the TEM also apply to the SEM, except that specimens need not be extremely thin as electrons do not penetrate. Basically similar to a TEM, the SEM directs a beam of electrons on to the surface of the specimen from above, rather than penetrating it from below. The beam is then passed back and forth across a portion of the specimen in a regular pattern. The electrons are scattered by the specimen and the pattern of this scattering depends on the contours of the specimen surface. We can build up a 3-D image by computer analysis of the pattern of scattered electrons and secondary electrons produced. The basic SEM has a lower resolving power than a TEM, around 20 nm, but is still ten times better than a light microscope.



▲ **Figure 4** *False-colour [SEM] of a pollen grain from a marigold plant*

▲ **Figure 5** *False-colour SEM of human red blood cells*

Summary questions

1 Explain how the electron microscope is able to resolve objects better than the light microscope.

2 Explain why specimens have to be kept in a near-vacuum in order to be viewed effectively using an electron microscope.

3 State which of the biological structures in the following list can be resolved using each of the microscopes below:

plant cell (100 µm) DNA molecule (2 nm) virus (100 nm)
actin molecule (3.5 nm) a bacterium (1 µm)

a a light microscope

b a transmission electron microscope

c a scanning electron microscope.

4 In practice, the theoretical resolving power of an electron microscope cannot always be achieved. Explain why not.

5 VR In a photomicrograph, an organelle measures 25 mm when its actual size is 5 µm. Calculate the magnification of this photomicrograph.

Maths link VR

MS 1.8, see Chapter 11.

Maths link VR

MS 2.2 and 1.8, see Chapter 11.

3.4 Eukaryotic cell structure

Each cell can be regarded as a metabolic compartment, a separate place where the chemical processes of that cell occur. Cells are often adapted to perform a particular function. Depending on that function, each cell type has an internal structure that suits it for its job. This is known as the **ultrastructure** of the cell. **Eukaryotic** cells have a distinct nucleus and possess membrane-bounded organelles. They differ from **prokaryotic** cells, such as bacteria. More details of these differences are given in Topic 3.6. Using an electron microscope, we can see the structure of organelles within cells, details of which are described below. The most important of these organelles are described below, with the exception of the cell-surface membrane.

The nucleus

The nucleus (Figure 1) is the most prominent feature of a eukaryotic cell, such as an epithelial cell. The nucleus contains the organism's hereditary material and controls the cell's activities. Usually spherical and between 10 and 20 µm in diameter, the nucleus has a number of parts.

- The **nuclear envelope** is a double membrane that surrounds the nucleus. Its outer membrane is continuous with the endoplasmic reticulum of the cell and often has ribosomes on its surface. It controls the entry and exit of materials in and out of the nucleus and contains the reactions taking place within it.
- **Nuclear pores** allow the passage of large molecules, such as messenger RNA, out of the nucleus. There are typically around 3000 pores in each nucleus, each 40–100 nm in diameter.
- **Nucleoplasm** is the granular, jelly-like material that makes up the bulk of the nucleus.
- **Chromosomes** consist of protein-bound, linear DNA.
- The **nucleolus** is a small spherical region within the nucleoplasm. It manufactures ribosomal RNA and assembles the ribosomes. There may be more than one nucleolus in a nucleus.

The functions of the nucleus are to:

- act as the control centre of the cell through the production of mRNA and tRNA and hence protein synthesis (see Topic 8.4)
- retain the genetic material of the cell in the form of DNA and chromosomes
- manufacture ribosomal RNA and ribosomes.

The mitochondrion

Mitochondria (Figures 2 and 3) are usually rod-shaped and 1–10 µm in length. They are made up of the following structures:

- Around the organelle is a **double membrane** that controls the entry and exit of material. The inner of the two membranes is folded to form extensions known as cristae.

Learning objectives

- Describe the structure and functions of the nucleus, mitochondria, chloroplasts, rough and smooth endoplasmic reticulum, Golgi apparatus, Golgi vesicles and lysosomes.
- Describe the structure and function of the cell wall in plants, algae and fungi.
- Describe the structure and function of the cell vacuole in plants.

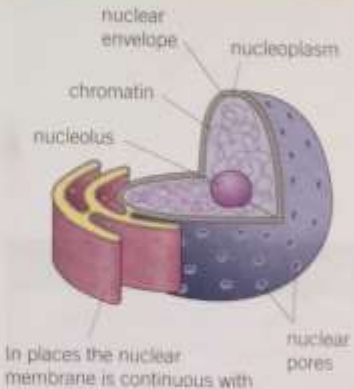
Specification reference: 3.2.1.1

Hint

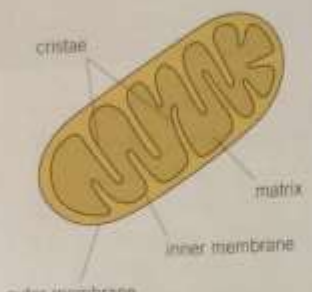
When you look at a group of animal cells, such as epithelial cells, under a light microscope you cannot see the cell-surface membrane because it is too thin to be observed. What you actually see is the boundary between cells.

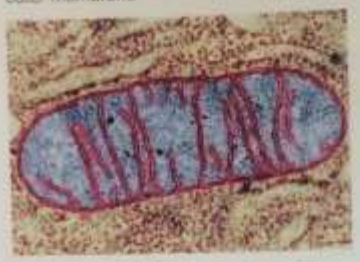
Synoptic link

The cell-surface membrane is covered in Topic 4.1, and DNA is covered in Topics 2.1, 2.2 and 8.2.



▲ **Figure 1** *The nucleus*

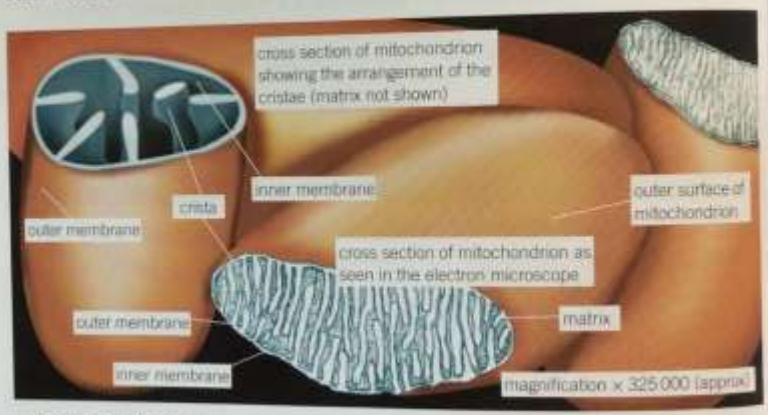




▲ **Figure 2** *The basic structure of a mitochondrion (top); false-colour TEM of a mitochondrion (bottom)*

- **Cristae** are extensions of the inner membrane, which in some species extend across the whole width of the mitochondrion. These provide a large surface area for the attachment of enzymes and other proteins involved in respiration.
- The **matrix** makes up the remainder of the mitochondrion. It contains protein, lipids, ribosomes and DNA that allows the mitochondria to control the production of some their own proteins. Many enzymes involved in respiration are found in the matrix.

Mitochondria are the sites of the aerobic stages of respiration (the Krebs cycle and the oxidative phosphorylation pathway. They are therefore responsible for the production of the energy-carrier molecule, **ATP**, from respiratory substrates such as glucose. Because of this, the number and size of the mitochondria, and the number of their cristae, are high in cells that have a high level of metabolic activity and therefore require a plentiful supply of ATP. Examples of metabolically active cells include muscle and epithelial cells. Epithelial cells in the intestines require a lot of ATP in the process of absorbing substances from the intestines by **active transport**.



▲ **Figure 3** *Mitochondria*

Chloroplasts

Chloroplasts (Figure 4) are the organelles that carry out photosynthesis (see Topic 11.2). They vary in shape and size but are typically disc-shaped, 2–10 µm long and 1 µm in diameter. The following are their main features:

- **The chloroplast envelope** is a double plasma membrane that surrounds the organelle. It is highly selective in what it allows to enter and leave the chloroplast.
- **The grana** are stacks of up to 100 disc-like structures called **thylakoids**. Within the thylakoids is the photosynthetic pigment called **chlorophyll**. Some thylakoids have tubular extensions that join up with thylakoids in adjacent grana. The grana are where the first stage of photosynthesis (light absorption) takes place.
- **The stroma** is a fluid-filled matrix where the second stage of photosynthesis (synthesis of sugars) takes place. Within the stroma are a number of other structures, such as starch grains.

Chloroplasts are adapted to their function of harvesting sunlight and carrying out photosynthesis in the following ways:

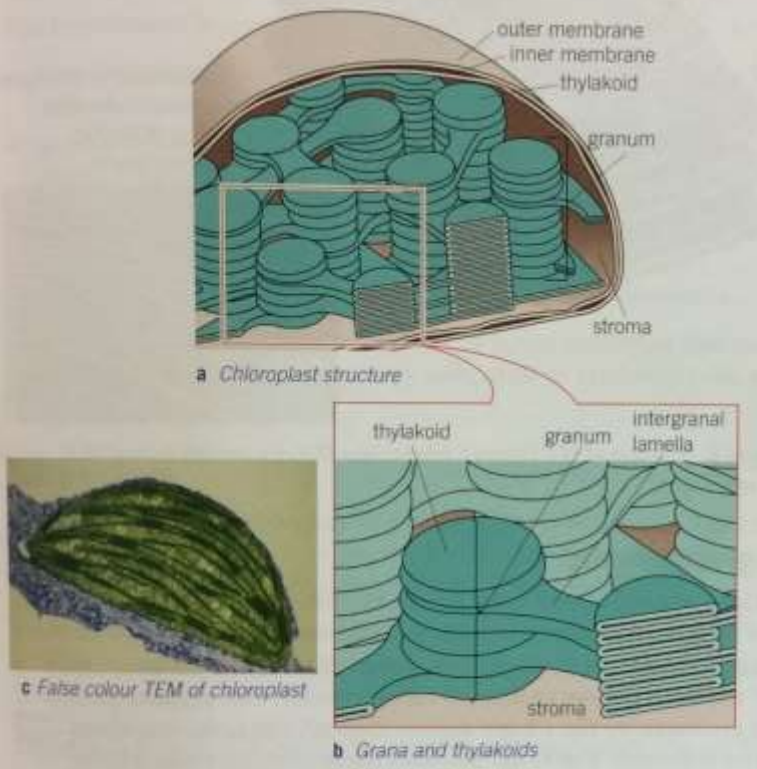
Hint

Chloroplasts have DNA and may have evolved from free-living prokaryotic cells, but they are organelles, not cells.

- The granal membranes provide a large surface area for the attachment of chlorophyll, electron carriers and enzymes that carry out the first stage of photosynthesis. These chemicals are attached to the membrane in a highly ordered fashion.
- The fluid of the stroma possesses all the enzymes needed to make sugars in the second stage of photosynthesis.
- Chloroplasts contain both DNA and ribosomes so they can quickly and easily manufacture some of the proteins needed for photosynthesis.

Study tip

Not all plant cells have chloroplasts. Think about root cells. These are below the soil surface where light rarely penetrates and so no photosynthesis is possible.



a *Chloroplast structure*

c *False colour TEM of chloroplast*

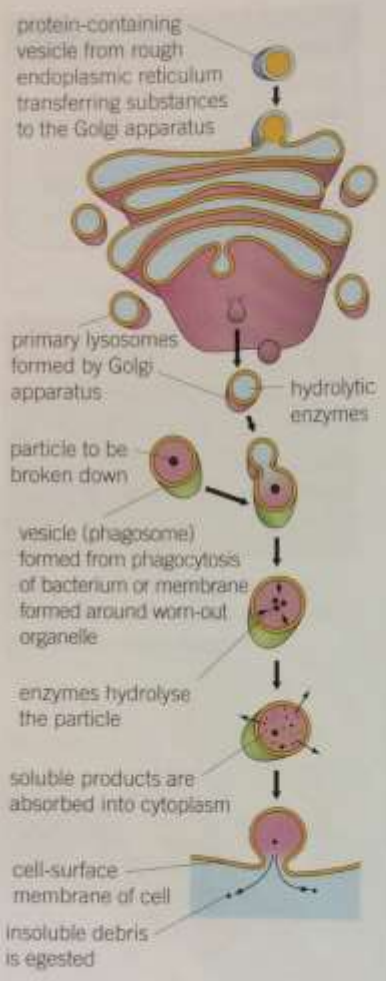
b *Grana and thylakoids*

▲ **Figure 4** *Chloroplast structure*

Endoplasmic reticulum

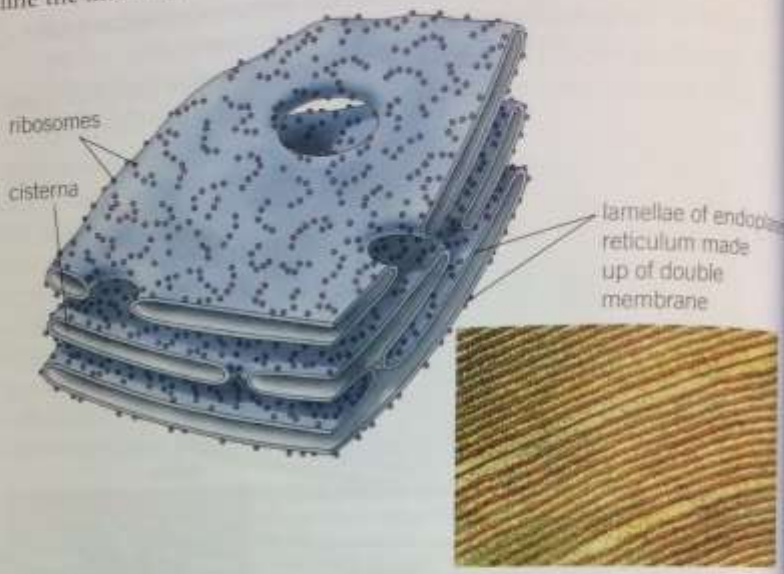
The endoplasmic reticulum (ER) is an elaborate, three-dimensional system of sheet-like membranes, spreading through the cytoplasm of the cells. It is continuous with the outer nuclear membrane. The membranes enclose a network of tubules and flattened sacs called cisternae (see Figure 5). There are two types of ER:

- **Rough endoplasmic reticulum (RER)** has ribosomes present on the outer surfaces of the membranes. Its functions are to:
  - a provide a large surface area for the synthesis of proteins and glycoproteins
  - b provide a pathway for the transport of materials, especially proteins, throughout the cell.
- **Smooth endoplasmic reticulum (SER)** lacks ribosomes on its surface and is often more tubular in appearance. Its functions are to:
  - a synthesise, store and transport lipids
  - b synthesise, store and transport carbohydrates.



▲ **Figure 6** *The Golgi apparatus and the formation and functioning of a lysosome (top); false-colour TEM of a Golgi apparatus (orange) (bottom)*

It follows that cells that manufacture and store large quantities of carbohydrates, proteins and lipids have a very extensive ER. Such cells include liver and secretory cells, for example the epithelial cells that line the intestines.



▲ **Figure 5** *Structure of RER (above); false-colour TEM of a section through RER (RER; red) (right)*

Golgi apparatus

The Golgi apparatus occurs in almost all eukaryotic cells and is similar to the SER in structure except that it is more compact. It consists of a stack of membranes that make up flattened sacs, or **cisternae**, with small rounded hollow structures called vesicles. The proteins and lipids produced by the ER are passed through the Golgi apparatus in strict sequence. The Golgi modifies these proteins often adding non-protein components, such as carbohydrate, to them. It also 'labels' them, allowing them to be accurately sorted and sent to their correct destinations. Once sorted, the modified proteins and lipids are transported in Golgi vesicles which are regularly pinched off from the ends of the Golgi cisternae (Figure 6). These vesicles may move to the cell surface, where they fuse with the membrane and release their contents to the outside.

The functions of the Golgi apparatus are to:

- add carbohydrate to proteins to form glycoproteins
- produce secretory enzymes, such as those secreted by the pancreas
- secrete carbohydrates, such as those used in making cell walls in plants
- transport, modify and store lipids
- form lysosomes.

The Golgi apparatus is especially well developed in secretory cells, such as the epithelial cells that line the intestines.

Lysosomes

Lysosomes are formed when the vesicles produced by the Golgi apparatus contain enzymes such as proteases and lipases. They also contain lysozymes, enzymes that hydrolyse the cell walls of certain bacteria. As many as 50 such enzymes may be contained in a single lysosome. Up to 1.0 µm in diameter, lysosomes isolate these enzymes from the rest of the cell before releasing them, either to the outside or into a **phagocytic** vesicle within the cell (Figure 6).

The functions of lysosomes are to:

- hydrolyse material ingested by phagocytic cells, such as white blood cells and bacteria
- release enzymes to the outside of the cell (exocytosis) in order to destroy material around the cell
- digest worn out organelles so that the useful chemicals they are made of can be re-used
- completely break down cells after they have died (autolysis).

Given the roles that lysosomes perform, it is not surprising that they are especially abundant in secretory cells, such as epithelial cells, and in **phagocytic** cells.

Hint

To help you understand the functions of the Golgi apparatus, think of it as the cell's post office, but receiving, sorting and delivering proteins and lipids, rather than letters.

Hint

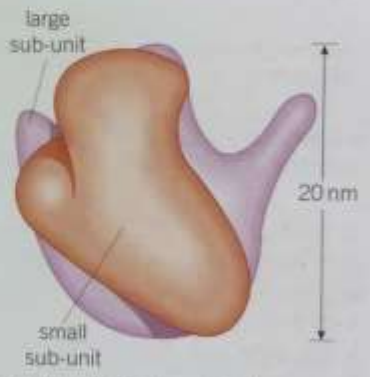
Lysosomes can be thought of as refuse disposal operatives. They remove useless and potentially dangerous material (e.g., bacteria) and reuse the useful parts, disposing of only that which cannot be recycled.

Ribosomes

Ribosomes are small cytoplasmic granules found in all cells. They may occur in the cytoplasm or be associated with the RER. There are two types, depending on the cells in which they are found:

- **80S** – found in eukaryotic cells, is around 25 nm in diameter.
- **70S** – found in prokaryotic cells, mitochondria and chloroplasts, is slightly smaller.

Ribosomes have two subunits – one large and one small (Figure 7) – each of which contains ribosomal RNA and protein. Despite their small size, they occur in such vast numbers that they can account for up to 25 % of the dry mass of a cell. Ribosomes are the site of in protein synthesis.



▲ **Figure 7** *Structure of a ribosome*

Cell wall

Characteristic of all plant cells, the cell wall consists of microfibrils of the polysaccharide cellulose, embedded in a matrix. Cellulose microfibrils have considerable strength and so contribute to the overall strength of the cell wall. Cell walls have the following features:

- They consist of a number of polysaccharides, such as cellulose.
- There is a thin layer, called the **middle lamella**, which marks the boundary between adjacent cell walls and cements adjacent cells together.

The functions of the cellulose cell wall are:

- to provide mechanical strength in order to prevent the cell bursting under the pressure created by the osmotic entry of water

Synoptic link

Look back to Topic 1.4, to refresh your knowledge of cellulose. Osmosis will be covered in Topic 4.3.

Study tip

Plant cells have a cell-surface membrane *and* a cell wall, not just a cell wall.

- to give mechanical strength to the plant as a whole
- to allow water to pass along it and so contribute to the movement of water through the plant.

The cell walls of algae are made up of either cellulose or glycoproteins, or a mixture of both.

The cell walls of fungi do not contain cellulose but comprise a mixture of a nitrogen-containing polysaccharide called **chitin**, a polysaccharide called glycan and glycoproteins.

Vacuoles

A fluid-filled sac bounded by a single membrane may be termed a vacuole. Within mature plant cells there is usually one large central vacuole. The single membrane around it is called the **tonoplast**. A plant vacuole contains a solution of mineral salts, sugars, amino acids, wastes and sometimes pigments such as anthocyanins.

Plant vacuoles serve a variety of functions:

- They support herbaceous plants, and herbaceous parts of woody plants, by making cells turgid.
- The sugars and amino acids may act as a temporary food store.
- The pigments may colour petals to attract pollinating insects.

Relating cell ultrastructure to function

As each organelle has its own function, it is possible to deduce, with reasonable accuracy, the role of a cell by looking at the number and size of the organelles it contains. For example, as mitochondria produce ATP that is used as a temporary energy store, it follows that cells with many mitochondria are likely to require a lot of ATP and therefore have a high rate of metabolism. Even within each mitochondrion, the more dense and numerous the cristae, the greater the metabolic rate of the cell possessing these mitochondria.

Summary questions

1 State in which process ribosomes are important.

2 List **three** carbohydrates that are absorbed by an epithelial cell of the small intestine.

3 State the organelle that is being referred to in each of the following descriptions:

- **a** It possesses structures called cristae.
- **b** It contains chromatin.
- **c** It synthesises glycoproteins.
- **d** It digests worn out organelles.

4 The following list gives a type of cell and a brief description of its role. Suggest *two* organelles that might be numerous and/or well developed in each of the cells.

- **a** A sperm cell swims a considerable distance carrying the male chromosomes.
- **b** One type of white blood cell engulfs and digests foreign material.
- **c** Liver cells manufacture proteins and lipids at a rapid rate.

Who can I contact for help?

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