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OCR A level Biology A

Second Edition

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Published by Pearson Education Limited, 80 Strand, London, WC2R 0RL.

www.pearsonschoolsandfecolleges.co.uk

Edited by Mary White, Jo Egré and Priscilla Goldby
Designed by Elizabeth Arnoux for Pearson Education Limited
Typeset by Tech-Set Ltd, Gateshead

Illustrated by Tech-Set Ltd, Gateshead and Peter Bull Art Studio
Cover design by Juice Creative
Picture research by Caitlin Swain and Ewout Buckens

First edition published 2008
This edition published 2015

18 17 16 15
10 9 8 7 6 5 4 3 2 1

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN 978 1 447 99080 2

Printed in Italy at Lego S.p.A

This resource is endorsed by OCR for use with specification OCR Level 3 Advanced GCE in Biology A (H420).

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Acknowledgements
Pearson would like to thank Peter Kennedy for his contribution to the previous edition.

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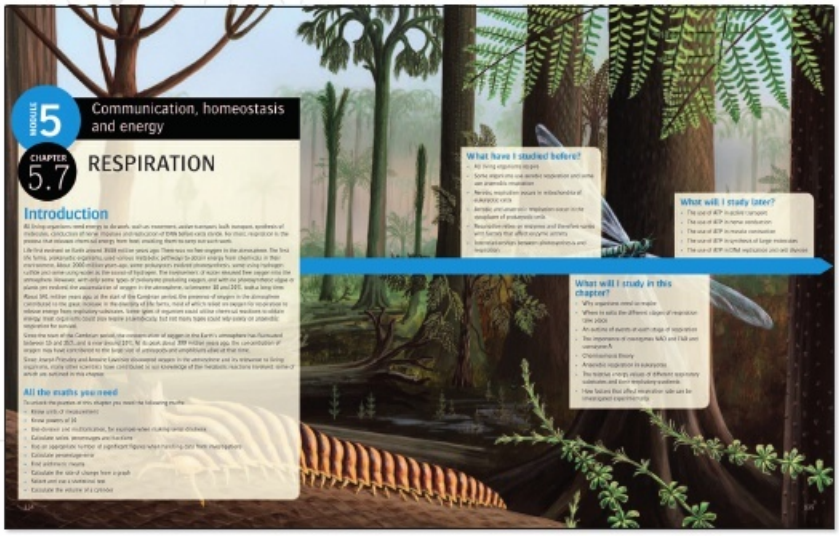
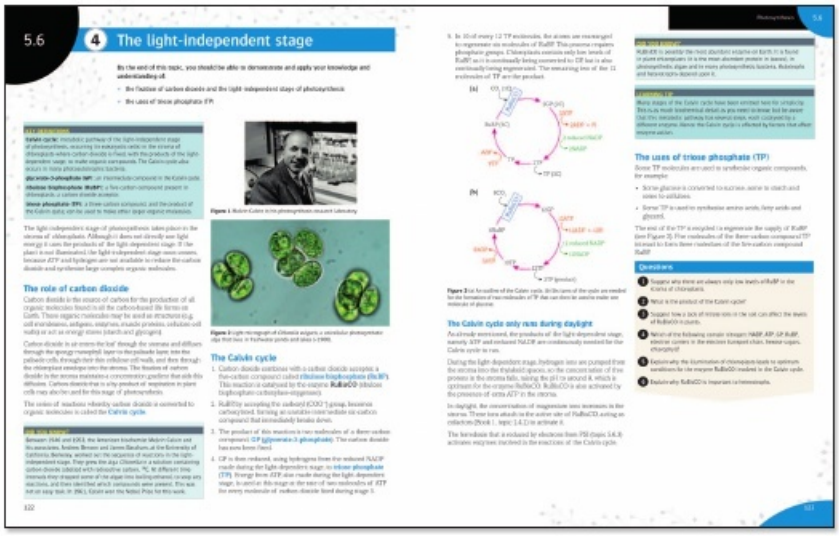
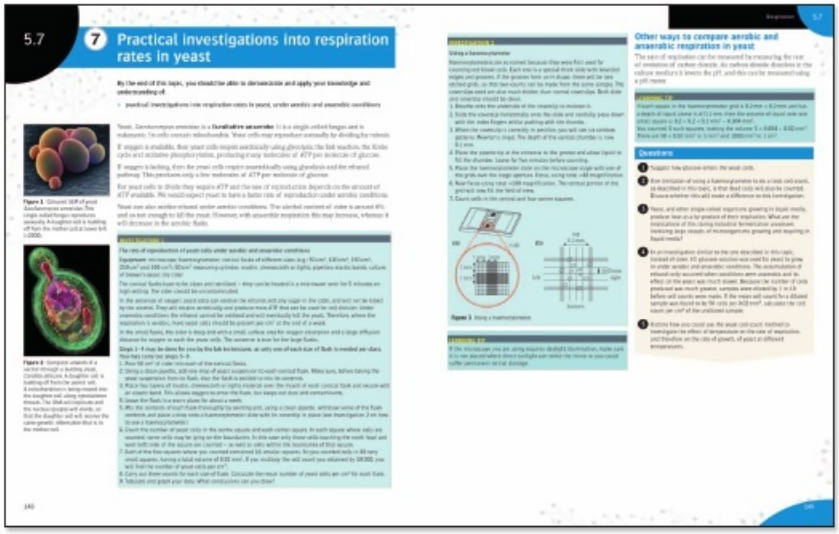






Welcome to your OCR A Level Biology A student book. In this book you will find a number of features designed to support your learning.

Chapter openers

Each chapter starts by setting the context for that chapter's learning.

- Links to other areas of Biology are shown, including previous knowledge that is built on in the chapter and future learning that you will cover later in your course.
- The **All the maths you need** checklist helps you to know what maths skills will be required.

Main content

The main part of the chapter covers all of the points from the specification you need to learn. The text is supported by diagrams and photos that will help you understand the concepts.

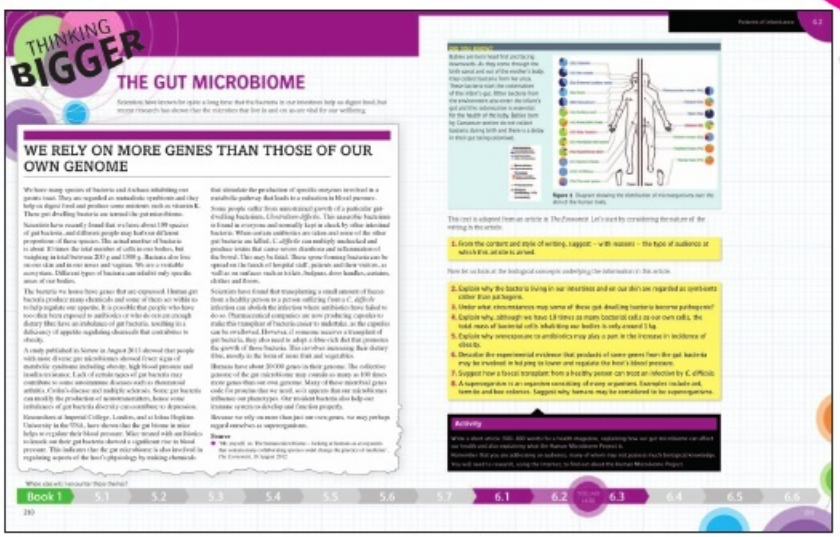
Within each topic, you will find the following features:

- **Learning objectives** at the beginning of each topic highlight what you need to know and understand.
- **Key terms** are shown in bold and defined within the relevant topic for easy reference.
- **Worked examples** show you how to work through questions, and how your calculations should be set out.
- **Investigations** provide a summary of practical experiments that explore key concepts.
- **Learning tips** help you focus your learning and avoid common errors.
- **Did you know?** boxes feature interesting facts to help you remember the key concepts.

At the end of each topic, you will find **questions** that cover what you have just learned. You can use these questions to help you check whether you have understood what you have just read, and to identify anything that you need to look at again. Answers to all questions in this student book are available at: http://www.pearsonschoolsandfecolleges.co.uk/Secondary/Science/16Biology/OCR-A-level-Science-2015/FreeResources/FreeResources.aspx

Thinking Bigger

At the end of each chapter there is an opportunity to read and work with real-life research and writing about science. These sections will help you to expand your knowledge and develop your own research and writing techniques. The questions and tasks will help you to apply your knowledge to new contexts and to bring together different aspects of your learning from across the whole course. The timeline at the bottom of the spread highlights which other chapters of your book the material relates to.



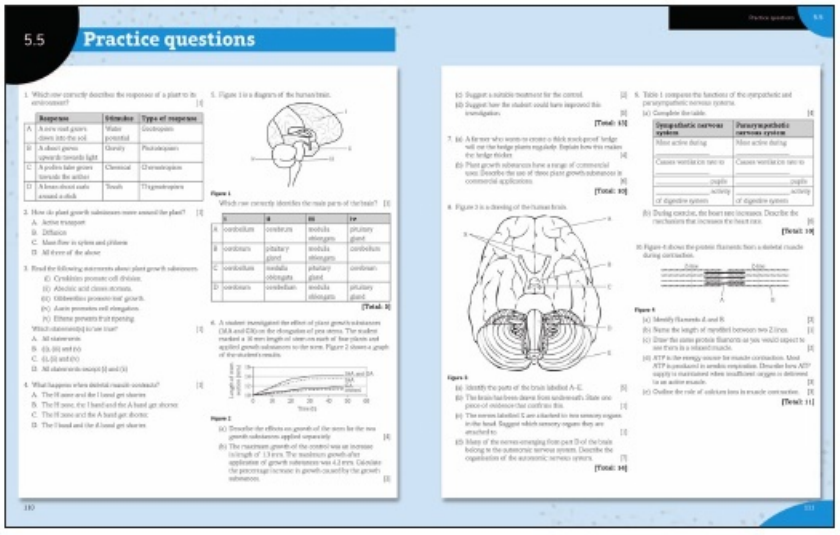
These spreads will give you opportunities to:

- read real-life material that's relevant to your course
- analyse how scientists write
- think critically and consider relevant issues
- develop your own writing
- understand how different aspects of your learning piece together.

Practice questions

At the end of each chapter, there are practice questions to test how fully you have understood the learning.

Answers to all questions in this student book are available at: http://www.pearsonschoolsandfecolleges.co.uk/Secondary/Science/16Biology/OCR-A-level-Science-2015/FreeResources/FreeResources.aspx



Maths Skills

At the end of the book there is a **Maths Skills** section that focuses on key mathematical concepts to provide greater depth of explanation and enhance your understanding through worked examples.

Preparing for your exams

The book concludes with a section that offers some practical advice about preparing for your exams, including sample questions and answers that allow you to see where common mistakes are made and how you can improve your responses.

Getting the most from your ActiveBook

Your ActiveBook is the perfect way to personalise your learning as you progress through your OCR A Level Biology course. You can:

- access your content online, anytime, anywhere
- use the inbuilt highlighting and annotation tools to personalise the content and make it really relevant to you
- search the content quickly.

Highlight tool

Use this to pick out key terms or topics so you are ready and prepared for revision.

Annotations tool

Use this to add your own notes, for example, links to your wider reading, such as websites or other files. Or make a note to remind yourself about work that you need to do.

MODULE 5

Communication, homeostasis and energy

CHAPTER 5.1

COMMUNICATION AND HOMEOSTASIS

Introduction

All organisms are able to respond to stimuli. Stimuli are changes in the environment that elicit a response. These could be:

- changes to the external environment, such as changes in temperature, sounds, or the appearance of a predator
- changes inside the organism, such as a change in temperature, pH or water potential.

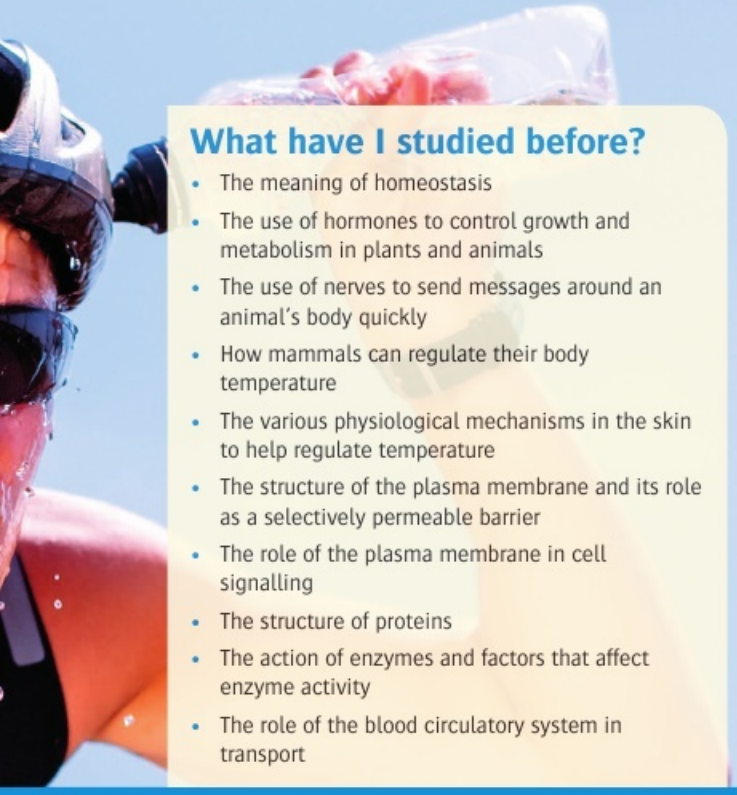
A response can be brought about by communication between cells within the body. This is known as cell signalling. Communication may be chemical and/or electrical, and any suitable response will improve the chances of survival.

Internal conditions may change as a result of changing external conditions or as a result of cell activity. When internal conditions change, the new conditions could affect the activity of enzymes and, therefore, the metabolism in the body. Homeostasis is the maintenance of a constant internal environment despite any external changes. Homeostasis ensures that conditions inside the body remain at the optimum for enzyme activity. Communication between cells is fundamental to homeostasis and organisms use both chemical and electrical systems to monitor and respond to any deviation from the body's steady state.

All the maths you need

To unlock the puzzles of this chapter you need the following maths:

- Recognise and make use of appropriate units in calculations
- Recognise and use expressions in decimal and standard form
- Use ratios, fractions and percentages
- Estimate results
- Use an appropriate number of significant figures
- Construct and interpret frequency tables and diagrams, bar charts and histograms
- Understand and use the symbols: =, <, <<, >>, >, ~
- Calculate the circumferences, surface areas and volumes of regular shapes



What have I studied before?

- The meaning of homeostasis
- The use of hormones to control growth and metabolism in plants and animals
- The use of nerves to send messages around an animal's body quickly
- How mammals can regulate their body temperature
- The various physiological mechanisms in the skin to help regulate temperature
- The structure of the plasma membrane and its role as a selectively permeable barrier
- The role of the plasma membrane in cell signalling
- The structure of proteins
- The action of enzymes and factors that affect enzyme activity
- The role of the blood circulatory system in transport

What will I study later?

- How nerve cells carry messages
- How nerve cells communicate with each other
- How hormones are released
- How hormones act upon their target cells

What will I study in this chapter?

- The need for communication systems
- The need for a constant internal state (homeostasis)
- Maintenance of a constant internal state by negative feedback
- Temperature regulation in ectotherms and endotherms

5.1 1 The need for communication systems

By the end of this topic, you should be able to demonstrate and apply your knowledge and understanding of:

* the need for communication systems in multicellular organisms
* the communication between cells by cell signalling

KEY DEFINITION

cell signalling: the way in which cells communicate with each other.

Survival and activity

You may recall from your AS level work that cell metabolism relies on enzymes and that enzymes need a specific set of conditions in which to work efficiently. All living things need to maintain a certain limited set of conditions inside their cells. These include:

- a suitable temperature
- a suitable pH
- an aqueous environment that keeps the substrates and products in solution
- freedom from toxins and excess inhibitors.

Without these conditions the cells will become inactive and die. In multicellular organisms, cells are specialised and rely upon one another; therefore they must be able to communicate in order to coordinate their activities.

The threat from changing environments

Changing external environments

All living organisms have an external environment that consists of the air, water or soil around them. This external environment changes, which may place stress on the living organism. For instance, a cooler environment will cause greater heat loss. If the organism is to remain active and survive, the changes in the environment must be monitored and the organism must change its behaviour or physiology to reduce the stress. The environmental change is a **stimulus** and the way in which the organism changes its behaviour or physiology is its **response**.

The environment may change slowly as the seasons pass. These changes elicit a gradual response. For example, the arctic fox (*Alopex lagopus*) has a much thicker white coat in winter and a thinner grey/brown coat in summer. The change in the coat provides greater insulation and camouflage in winter, ensuring the animal can survive. Yet in summer, the animal does not overheat.

DID YOU KNOW?

The winter coat of the arctic fox is efficient enough to keep the animal warm while lying asleep. Therefore the fox may actually have a problem overheating when it runs around looking for prey.

(a) (b)

Figure 1 Arctic fox with (a) winter coat and (b) summer coat.

However, the environment may change much more quickly. The appearance of a predator or moving from a burrow into the sunlight are rapid changes. Again, the change (a stimulus) must be monitored and the organism must respond to the change.

Changing internal environments

Most multicellular organisms have a range of tissues and organs. Many of the cells and tissues are not exposed to the external environment – they are protected by epithelial tissues and organs such as skin or bark. In many animals the internal cells and tissues are bathed in tissue fluid. This is the environment of the cells.

As cells undergo their various metabolic activities, they use up substrates and create new products. Some of these compounds may be unwanted or even toxic. These substances move out of the cells into the tissue fluid. Therefore, the activities of the cells alter their own environment.

For example, one waste product is carbon dioxide. If this is allowed to build up in the tissue fluid outside the cells, it will alter the pH of the tissue fluid and could disrupt the action of enzymes and other proteins. The accumulation of excess waste or toxins in this internal environment must act as a stimulus to cause removal of these waste products so that the cells can survive. In this example, the reduced pH of the blood stimulates greater breathing activity that expels the carbon dioxide from the body (see topic 5.5.9).

This build-up of waste products in the tissue fluid may also act directly on the cells, which respond by reducing their activities so that less waste is produced. However, this response may not be good for the whole organism.

Maintaining the internal environment

The composition of the tissue fluid is maintained by the blood. Blood flows throughout the body and transports substances to and from the cells. Any wastes or toxins accumulating in the tissue fluid are likely to enter the blood and be carried away. In order to prevent their accumulation in the blood they must be removed from the body by excretion (see topic 5.2.1).

It is important that the concentrations of waste products and other substances in the blood are monitored closely. This ensures that the body does not excrete too much of any useful substance but removes enough of the waste products to maintain good health. It also ensures that the cells in the body are supplied with the substrates they need.

Coordinating the activities of different organs

A multicellular organism is more efficient than a single-celled organism, because its cells are differentiated. This means that its cells are specialised to perform particular functions. Groups of cells specialised to perform a particular function form tissues and organs. The cells that monitor the blood may be in a different part of the body well away from the source of the waste product. They may also be some distance from the tissue or organ specialised to remove the waste from the body. Therefore, a good communication system is required to ensure that these different parts of the body work together effectively.

A good communication system will:

- cover the whole body
- enable cells to communicate with each other
- enable specific communication
- enable rapid communication
- enable both short-term and long-term responses.

Cell signalling

Cells communicate with each other by the process of **cell signalling**. This is a process in which one cell will release a chemical that is detected by another cell. The second cell will respond to the signal released by the first cell.

The two major systems of communication that work by cell signalling are the:

- **neuronal system:** an interconnected network of neurones that signal to each other across synapse junctions. The neurones can conduct a signal very quickly and enable rapid responses to stimuli that may be changing quickly.
- **hormonal system:** a system that uses the blood to transport its signals. Cells in an endocrine organ release the signal (a hormone) directly into the blood. The hormone is transported throughout the body, but is only recognised by specific target cells. The hormonal system enables longer-term responses to be coordinated.

You may recall from your AS level work that cell signalling involves molecules that have a specific shape which is complementary to that of the cell surface receptor. This is essential to enable signals to be specific.

LEARNING TIP

Remember that the shape of the signalling molecule is complementary to the shape of the receptor molecule. Do not say 'similar shape' or 'complementary to receptor'.

Questions

1 (a) State three examples of a stimulus and a corresponding response in animals.
(b) For each of your examples, suggest whether it uses the neuronal system or the hormonal system for communication, and state why.

2 Describe two examples of a stimulus and response in plants.

3 List the organs that are associated with excretion.

4 List the organs that are associated with maintaining the internal environment of a mammal, stating what role each organ plays.

5 Explain why a good communication system must:
(a) cover the whole body
(b) enable specific communication
(c) enable rapid communication, and
(d) enable both short- and long-term responses.

5.1 2 Homeostasis

By the end of this topic, you should be able to demonstrate and apply your knowledge and understanding of:

* the principles of homeostasis

KEY DEFINITIONS

effector: a cell, tissue or organ that brings about a response.
homeostasis: maintaining a constant internal environment despite changes in external and internal factors.
negative feedback: the mechanism that reverses a change, bringing the system back to the optimum.
positive feedback: the mechanism that increases a change, taking the system further away from the optimum.
sensory receptors: cells/sensory nerve endings that respond to a stimulus in the internal or external environment of an organism and can create action potentials.

Homeostasis

Homeostasis is used in many living organisms to maintain conditions inside the body, despite changes in external and internal factors. Aspects maintained by homeostasis may include:

- body temperature
- blood glucose concentration
- blood salt concentration
- water potential of the blood
- blood pressure
- carbon dioxide concentration.

The mechanism of homeostasis

Any response to changes in the environment requires a complex mechanism, which may involve a series of tissues and organs that are coordinated through cell signalling. The standard response pathway is:

stimulus → receptor → communication pathway (cell signalling) → effector → response

A number of specialised structures are required for this pathway to work:

- **Sensory receptors** such as temperature receptors. These receptors may be on the surface of the body, such as temperature receptors in the skin. They monitor changes in the external environment. Other receptors are internal to monitor conditions inside the body, for example, temperature receptors in the brain. When one of these receptors detects a change it will be stimulated to send a message to an effector.
- A communication system such as the neuronal system or the hormonal system. This acts by signalling between cells. It is used to transmit a message from the receptor cells to the effector cells via a coordination centre which is usually in the brain. The messages from the receptor to the coordination centre are known as the input. The messages sent to the effectors are known as the output.
- **Effector** cells such as liver cells or muscle cells. These cells will bring about a response.

Feedback

When the effectors respond to the output from the coordination centre, they bring about a response that will change the conditions inside the body. Such changes will be detected by the receptors. This will have an effect upon the response pathway. In effect, the input will change. This effect is known as feedback.

Negative feedback

In order to maintain a constant internal environment, any change away from optimum conditions must be reversed. In this way, conditions inside the body will be returned to the optimum. This mechanism that brings the conditions back towards the optimum is known as **negative feedback** (see Figure 1).

When conditions change, the receptors detect this stimulus and send an input to the coordination centre. The coordination centre sends an output to the effectors and the effectors respond to this output. When the effectors bring about a change that reverses the initial change in conditions, the system moves closer to the optimum and the stimulus is reduced. The receptors detect the reduction in stimulus and reduce the input to the coordination centre. The output from the coordination centre to the effectors is also reduced, so the effectors reduce their activity. As the system gets closer to the optimum, the response is reduced.

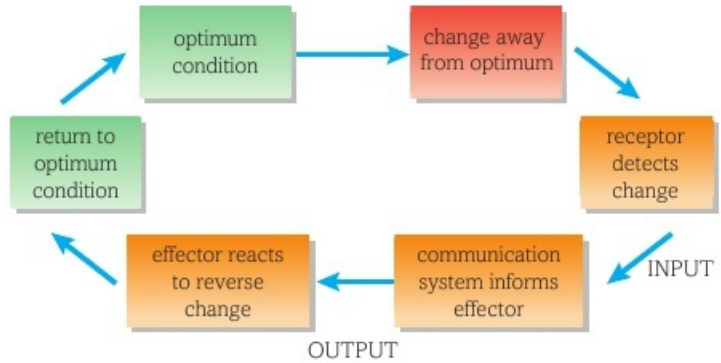


Figure 1 Negative feedback.

For example, if the internal temperature rises too high, the response is to do something that brings the body back towards its optimum temperature (see Figure 2). As a result the stimulus is reduced.

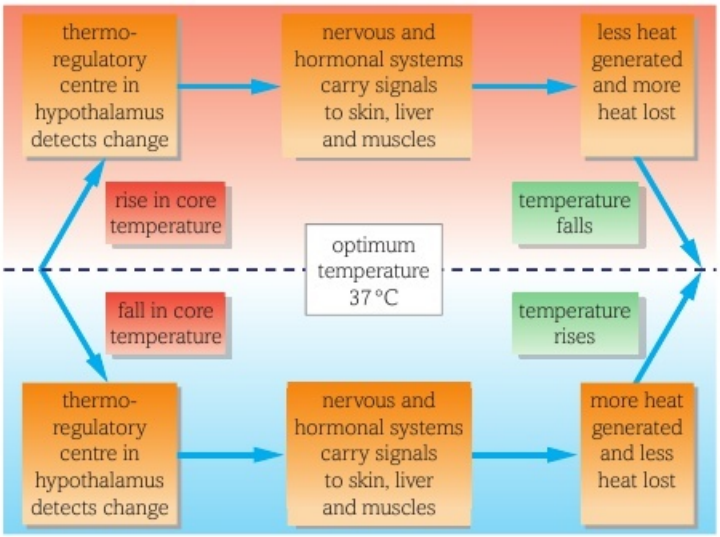


Figure 2 Temperature control by negative feedback.

For negative feedback to work, a number of processes must occur:

1. A change to the internal environment must be detected.
2. The change must be signalled to other cells.
3. There must be an effective response that reverses the change in conditions.

DID YOU KNOW?

Negative feedback can cause some interesting phenomena – for instance, when you are too hot it can be better to have a hot drink, because this warms the blood internally and stimulates a cooling response in the skin.

Maintaining a constant internal environment

A negative feedback system can maintain a reasonably constant set of conditions. However, the conditions will never remain perfectly constant: there will be some variation around the optimum condition. When a stimulus occurs it may take time to respond and the response may cause a slight 'overshoot'. However, as long as this variation is not too great, the conditions will remain acceptable. A thermostatically controlled heated room will never get too cold or too hot. Similarly, when negative feedback is applied to living systems, the conditions inside a living organism will remain within a relatively narrow range. The conditions will remain 'warm' enough to allow enzymes to continue functioning efficiently, but 'cool' enough to avoid damage to the body's many other proteins.

LEARNING TIP

Remember that conditions do not stay perfectly level – there is always some fluctuation around the set point.

Positive feedback

Positive feedback is less common than negative feedback. When positive feedback occurs, the response is to increase the original change. This destabilises the system and is usually harmful.

For example, below a certain core body temperature enzymes become less active and the **exergonic** reactions that release heat are slower and release less heat. This allows the body to cool further and slows the enzyme-controlled reactions even more. This causes the body temperature to spiral downwards.

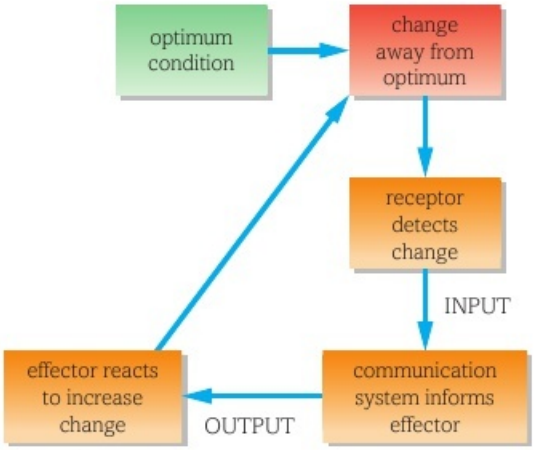


Figure 3 Positive feedback.

There are, however, some occasions when positive feedback can be beneficial. Positive feedback is used to stimulate an increase in a change.

An example is seen at the end of pregnancy to bring about dilation of the cervix. As the cervix begins to stretch this causes the posterior pituitary gland to secrete the hormone oxytocin. Oxytocin increases the uterine contractions which stretch the cervix more, which causes secretion of more oxytocin. Once the cervix is fully dilated, the baby can be born. The birth ends the production of oxytocin.

The activity of neurones also relies on positive feedback.

Questions

1. Define the term homeostasis.
2. The first paragraph in this topic lists six conditions that are maintained in homeostasis. For each condition explain why maintaining an optimum is essential.
3. What is the role of (a) the sensory receptors and (b) the effectors?
4. What is meant by input and output?
5. Explain the difference between negative feedback and positive feedback.
6. Describe and explain the effect of positive feedback on an animal if its body temperature rises too high.

3 Temperature control in ectotherms

By the end of this topic, you should be able to demonstrate and apply your knowledge and understanding of:

* the behavioural responses involved in temperature control in ectotherms

KEY DEFINITIONS

ectotherm: an organism that relies on external sources of heat to maintain body temperature.

endotherm: an organism that uses heat from metabolic reactions to maintain body temperature.

Controlling body temperature

Changes in body temperature can have a dramatic effect upon the activity of cell processes. As temperature rises, molecules have more kinetic energy. They move about more quickly and collide more frequently. This means that essential chemical reactions occur more quickly. However, in cooler conditions the opposite is true and chemical reactions slow down.

The structure of proteins can also be affected by changes – especially increases – in body temperature. Many proteins have a metabolic function; for example, enzymes increase the rate of biological reactions. Enzymes are globular proteins and have a very specific tertiary structure, giving them a specific three-dimensional shape. In the case of enzymes, the shape of the active site is complementary to the shape of the substrate and any change in shape will affect their ability to function normally. If temperature is allowed to increase too much, enzymes change shape and their function is lost.

Some enzymes are very sensitive to temperature change. If the body temperature drops by 10 °C, the rate of enzyme-controlled reactions falls by half. Many reactions in cells release heat, which can help to maintain the temperature, but if the temperature drops and reactions slow down, less heat is released. This allows the body to cool further. This is a form of positive feedback. As the body cools, the organism is less and less able to function normally. However, if the temperature rises just a few degrees above the optimum, enzymes may denature and cease to function.

The core temperature is the important factor, as all the vital organs are found in the centre of the body. Peripheral parts of the body may be allowed to increase or decrease in temperature to some extent without affecting the survival of the organism.

Endotherm or ectotherm?

DID YOU KNOW?

Many ectotherms can successfully maintain their body temperature at over 30 °C. It is therefore not appropriate to call them 'cold-blooded'.

Endotherms control their body temperature within very strict limits. They use a variety of mechanisms to control body temperature and are largely independent of external temperatures (see topic 5.1.4).

Ectotherms are not able to control their body temperature as effectively as endotherms. They rely on external sources of heat and their body temperature fluctuates with the external temperature. However, using various behavioural mechanisms, some ectotherms are able to control their body temperature in all but the most extreme conditions.

Temperature control in ectotherms

Ectotherms do not use internal energy sources to maintain their body temperature when cold. However, once they are active their muscle contractions will generate some heat from increased respiration. Temperature regulation relies upon behavioural responses that can alter the amount of heat exchanged with the environment.

If ectotherms are not warm enough, they try to absorb more heat from the environment. They may:

- move into a sunny area
- lie on a warm surface
- expose a larger surface area to the sun.

If ectotherms are too hot they try to avoid gaining more heat and try to increase heat loss to the environment. They may:

- move out of the sun
- move underground
- reduce the body surface exposed to the sun.

Some examples

Example	Behavioural adaptation	Benefit
Snake	Basks in the sun. In the UK, adders can often be found lying on an exposed path beside vegetation.	Absorbs heat directly from the sun.
Locust	In the early morning, locusts sit side-on to the sun exposing a large surface area, but at midday they face the sun head-on exposing a smaller surface area. They may also climb to the top of a plant at midday to get away from the soil surface.	In the cool morning they can absorb more heat, but at midday when the sun is hotter they absorb less heat. The soil surface gets hot and radiates heat; if the locust moves away from the soil it gains less heat from the soil.
	Increases both the rate of breathing and the depth of breathing movements when it is hot.	More water evaporates from the tracheal system, cooling the body.
Lizard	Many lizards use burrows or crevices between rocks. They will hide in the burrow during the hottest part of the day and the coolest part of the night.	An underground burrow tends to have a more stable temperature than the air. In the hottest part of the day it will be cooler in the burrow, but at night the burrow may be warmer than the air outside.
Horned lizard	Can change its shape by expanding or contracting its ribcage.	Expanding the ribcage increases the surface area exposed to the sun, so more heat can be absorbed.

Table 1 Behavioural adaptations of ectotherms to maintain body temperature.

Figure 1 A locust will climb up a twig to get away from the hot soil.

Figure 2 A horned lizard basking in the sun.

Advantages and disadvantages of ectothermy

Advantages

Ectotherms rely on external sources of heat to keep warm. They do not use up energy to keep warm. Therefore:

- Less of their food is used in respiration.
- More of the energy and nutrients gained from food can be converted to growth.
- They need to find less food.
- They can survive for long periods without food.

Disadvantages

They are less active in cooler temperatures. This means that they are at risk from predators while they are cold and unable to escape and they cannot take advantage of food that is available while they are cold.

DID YOU KNOW?

Bees are ectotherms. However, the temperature of a bee swarm or colony is successfully maintained at 35 °C. The bees keep open passages through the swarm to allow movement of air. Some worker bees move about to generate heat and others flap their wings at the entrances to the air passages causing the air to circulate.

Questions

1. Explain why the body temperature must be controlled.
2. Suggest why it is easier to catch a fly early in the morning than at midday.
3. Early in the morning dragonflies can often be seen flapping their wings but not taking off or flying. Suggest why they may flap their wings in this way.
4. Explain how basking on a hot rock in the sun can help a lizard to control its body temperature.
5. In the search to find ways of producing sufficient food for the human population, many scientists believe that insects may be the best source of protein. Explain why ectotherms can produce protein more efficiently than endotherms.

4 Temperature control in endotherms

By the end of this topic, you should be able to demonstrate and apply your knowledge and understanding of:

* the physiological and behavioural responses involved in temperature control in endotherms

KEY DEFINITION

hypothalamus: the part of the brain that coordinates homeostatic responses.

Endotherms

Endotherms do not rely on external sources of heat – they can use physiological adaptations and behavioural means to control their body temperature.

Temperature regulation mechanisms

Temperature regulation relies on effectors in the skin and muscles. The skin is the organ in contact with the external environment. Therefore, many of the physiological adaptations to control body temperature involve the skin. The changes that take place in the skin alter the amount of heat being lost to the environment.

Many chemical reactions in the body are exergonic – they release energy in the form of heat. Endotherms can increase respiration (an exergonic reaction) in the muscles and liver simply to release heat – they are using some of their energy intake to stay warm. They also have other useful physiological mechanisms, such as directing blood towards or away from the skin to alter the amount of heat lost to the environment.

Tables 1 and 2 show the range of physiological and behavioural responses used by endothermic organisms to maintain their constant body temperature.

Behaviour if too hot	Behaviour if too cold
Hide away from sun in the shade or in a burrow.	Lie in the sun.
Orientate body to reduce surface area exposed to sun.	Orientate body towards sun to increase surface area exposed.
Remain inactive and spread limbs out to enable greater heat loss.	Move about to generate heat in the muscles or, in extreme conditions, roll into a ball shape to reduce surface area and heat loss.
Wet skin to use evaporation to help cool the body. Cats lick themselves and elephants spray water over their bodies.	Remain dry.

Table 2 Behavioural adaptations used by endotherms to maintain body temperature.

LEARNING TIP

The rate of respiration is maintained at a constant, as temperature is constant. Remember that more respiration means more glucose being fed into the respiration pathway to produce more heat.

Organ	Response if body too hot	Response if body too cold
Skin	Sweat glands secrete fluid onto the skin surface; as this evaporates it uses heat from the blood as the latent heat of vaporisation.	Less sweat is secreted, so less evaporation means less heat is lost.
	Hairs and feathers lie flat to reduce insulation and allow greater heat loss.	Hairs and feathers stand erect to trap air, which insulates the body.
	Vasodilation of arterioles and precapillary sphincters directs blood to the skin surface so more heat can be radiated away from the body (see Figure 1).	Vasoconstriction of arterioles and precapillary sphincters leading to skin surface (see Figure 1). Blood is diverted away from the surface of the skin and less heat is lost.
Gaseous exchange system	Some animals pant, increasing evaporation of water from the surface of the lungs and airways. Evaporation uses heat from the blood as the latent heat of vaporisation.	Less panting, so less heat is lost.
Liver	Less respiration takes place, so less heat is released.	Increased respiration in the liver cells means that more energy from food is converted to heat.
Skeletal muscles	Fewer contractions mean that less heat is released.	Spontaneous muscle contractions (shivering) release heat.
Blood vessels	Dilation to direct blood to the extremities so that more heat can be lost.	Constriction to limit blood flow to the extremities, so that blood is not cooled too much – this can lead to frostbite in extreme conditions.

Table 1 Physiological mechanisms used by endotherms to maintain body temperature.

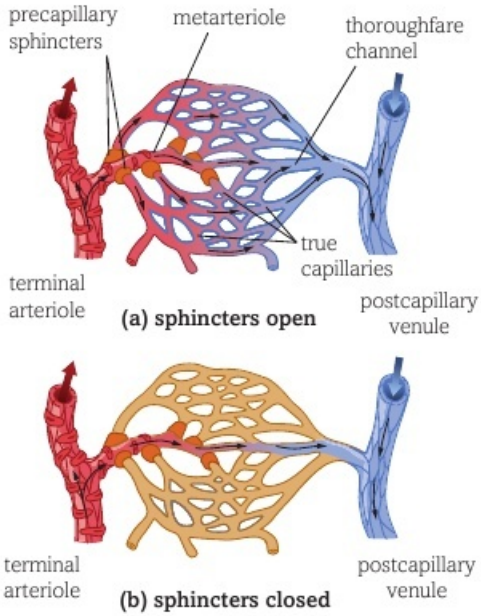


Figure 1 (a) Vasodilation and (b) vasoconstriction.

Advantages and disadvantages of endothermy

Advantages

There are many advantages. Endotherms can:

- maintain a fairly constant body temperature whatever the temperature externally
- remain active even when external temperatures are low, which means they can take advantage of prey that may be available or escape from potential predators
- inhabit colder parts of the planet.

Disadvantages

However, there are disadvantages. Endotherms:

- use a significant part of their energy intake to maintain body temperature in the cold
- need more food
- use for growth a lower proportion of the energy and nutrients gained from food
- may overheat in hot weather.

DID YOU KNOW?

A shrew has to eat almost its own body mass of food each day to avoid starving to death.

Control of temperature regulation

The maintenance of a core body temperature is important. If the core temperature changes this alters the temperature of the blood. Temperature receptors in the **hypothalamus** of the brain detect this change. The hypothalamus then sends out impulses to cause different responses that will reverse the change. Some responses need to be quick in order to prevent further change in body temperature – the neuronal system transmits the output from the hypothalamus in order to make these responses rapid. Other responses may need to be longer term; the hormonal system transmits the output to cause these responses.

If the core temperature is too low, the hypothalamus will bring about:

- changes in the skin to reduce heat loss
- release of heat through extra muscular contraction
- increased metabolism in order to release more heat from exergonic reactions.

If the core temperature rises above the optimum, the hypothalamus will bring about the opposite changes. This is an example of negative feedback (see Figure 2 in topic 5.1.2).

The role of peripheral temperature receptors

The thermoregulatory centre in the hypothalamus monitors blood temperature and detects changes in the core body temperature. However, an early warning that the body temperature may change could help the hypothalamus to respond more quickly and reduce variation in the core body temperature. If the extremities start to cool down or warm up this may eventually affect the core body temperature. Peripheral temperature receptors in the skin monitor the temperature in the extremities. This information is fed to the thermoregulatory centre in the hypothalamus. If the thermoregulatory centre signals to the brain that the external environment is very cold or very hot, the brain can initiate behavioural mechanisms for maintaining the body temperature, such as moving into the shade.

Questions

1. Explain how vasodilation and vasoconstriction in the skin help to control the body temperature.
2. Elephants have large ears. Explain the role of these ears in temperature regulation.
3. Penguins in Australia are about 25 cm in height, while those found in Antarctica can be over a metre tall. The size difference is an adaptation to the environment. Explain why these birds are so different in size.
4. Explain why a shrew needs to eat its own body weight per day, while an elephant can survive by eating less than one per cent of its body weight per day.
5. Suggest why the arctic fox has little or no fur on its lower legs in winter.

THINKING BIGGER

WHAT IS A MESOTHERM?

The view of dinosaurs in the Victorian period and the early part of the twentieth century was as large lizard-like animals that were slow and lumbering. In 1968 Robert T. Bakker, a young palaeontologist, wrote a brief article entitled 'The Superiority of Dinosaurs', in which he suggested that dinosaurs were 'fast, agile, energetic creatures'. Ever since then scientists have argued about whether dinosaurs were endotherms or ectotherms.

SCIENTISTS SOLVE THE MYSTERY OF WHETHER DINOSAURS WERE HOT OR COLD BLOODED

The hot question of whether dinosaurs were warm-blooded like birds and mammals or cold-blooded like reptiles, fish and amphibians finally has a good answer.

Dinosaurs, for eons Earth's dominant land animals until being wiped out by an asteroid 65 million years ago, were in fact somewhere in between.

Scientists evaluated the metabolism of numerous dinosaurs using a formula based on their body mass as revealed by the bulk of their thigh bones and their growth rates as shown by growth rings in fossil bones akin to those in trees.

The study, published in the journal *Science*, assessed 21 species of dinosaurs including super predators *Tyrannosaurus* and *Allosaurus*, long-necked *Apatosaurus*, duckbilled *Tenontosaurus* and bird-like *Troodon* as well as a range of mammals, birds, bony fish, sharks, lizards, snakes and crocodiles.

'Our results showed that dinosaurs had growth and metabolic rates that were actually not characteristic of warm-blooded or even cold-blooded organisms,' said University of Arizona evolutionary biologist and ecologist Brian Enquist.

'They did not act like mammals or birds nor did they act like reptiles or fish.

'Instead, they had growth rates and metabolisms intermediate to warm-blooded and cold-blooded organisms of today. In short, they had physiologies that are not common in today's world.'

There has been a long-standing debate about whether dinosaurs were slow, lumbering cold-blooded animals – as scientists first proposed in the 19th century – or had a uniquely advanced, more warm-blooded physiology.

As scientists unearthed remains of more and more fast-looking dinosaurs like *Velociraptor*, some championed the idea dinosaurs were as active and warm-blooded as mammals and birds.

The realisation that birds arose from small feathered dinosaurs seemed to support that view.

University of New Mexico biologist John Grady said the idea that creatures must be either warm-blooded or cold-blooded is too simplistic when looking over the vast expanse of time.

'Like dinosaurs, some animals alive today like the great white shark, leatherback sea turtle and tuna do not fit easily into either category', Grady added.

'A better answer would be 'in the middle.' By examining animal growth and rates of energy use, we were able to reconstruct a metabolic continuum, and place dinosaurs along that continuum. Somewhat surprisingly, dinosaurs fell right in the middle,' Grady said.

Meet the mesotherms

The researchers called creatures with this medium-powered metabolism mesotherms, as contrasted to ectotherms (cold-blooded animals with low metabolic rates that do not produce much heat and bask in the sun to warm up) and endotherms (warm-blooded animals that use heat from metabolic reactions to maintain a high, stable body temperature).

Grady said an intermediate metabolism may have allowed dinosaurs to get much bigger than any mammal ever could.

Warm-blooded animals need to eat a lot so they are frequently hunting or munching on plants. 'It is doubtful that a lion the size of *T. rex* could eat enough to survive,' Grady said.

Source

- Prigg, M. (2014) Scientists solve the mystery of whether dinosaurs were hot or cold blooded. *Daily Mail* (http://www.dailymail.co.uk/sciencetech/article-2656673/Scientists-solve-mystery-dinosaurs-hot-cold-blooded-reveal-between.html)

Where else will I encounter these themes?

Let's start by considering the nature of the writing in the article.

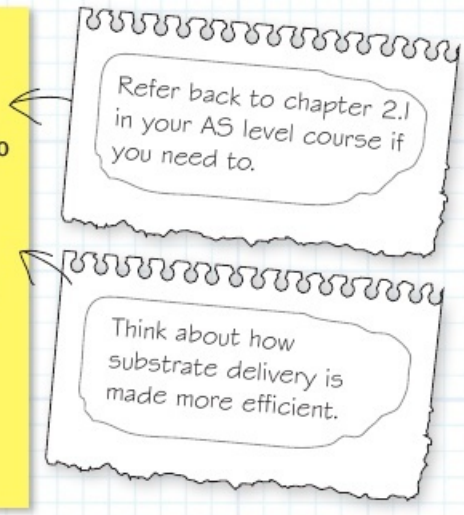
1. The writer uses the terms 'warm-blooded' and 'cold-blooded'. Explain why scientists no longer use this language.
2. The term 'mesotherm' is used to describe the dinosaurs. Explain what it means.

DID YOU KNOW?

Very large organisms can maintain their body temperature much more easily than smaller organisms because of their small surface area to volume ratio. Thus, large dinosaurs may have been able to maintain a high body temperature despite being ectothermic. This phenomenon is known as 'gigantothermy'.

Now we will look at the biology in, or connected to, this article. Don't worry if you are not ready to give answers to these questions yet. You may like to return to the questions once you have covered other topics later in the book. Use the timeline at the bottom of the page to help you to put this work in context with what you have already learned and what is ahead in your course.

3. Animals obtain energy for living processes from their food. What process inside cells releases energy from food? (Note: this is covered in detail later in this book.)
4. What organelle is involved in releasing energy from food?
5. Cells release energy in the form of ATP. What additional element do cells need in order to produce a lot of ATP?
6. How is the circulatory system of mammals adapted to supply sufficient substrates to enable their cells to produce enough heat to stay warm?
7. List the physiological mechanisms that mammals use to stay warm that are not found in reptiles.
8. What were the main advantages to dinosaurs of being able to keep their body temperature higher than their surroundings?
9. Use the theory of evolution by natural selection to explain how this feature may have evolved.



Activity

Devise a flow diagram to explain how scientists work using the debate over dinosaur body temperature as an example. Your diagram should explain why new ideas are not always accepted at first but may become accepted once more research and evidence is accumulated.

Your flow diagram should explain why a scientist:

- makes observations
- suggests a hypothesis
- attempts to explain the hypothesis with scientific knowledge
- sets out to test the hypothesis
- conducts an investigation to find evidence
- reports the findings of the investigation in peer journals
- invites other scientists to comment or repeat the investigation.

5.1 Practice questions

1. All responses follow a pattern. Which row correctly identifies this pattern? [1]
   A. stimulus – sensory neurone – relay neurone – motor neurone – response
   B. stimulus – sensory receptor – coordination – effector – response
   C. sensory neurone – central nervous system – motor neurone – effector – response
   D. sensory receptor – sensory neurone – motor neurone – effector – response

2. The following are examples of feedback.
   (i) When core temperature gets too high, the animal will behave in a way that brings its core temperature down.
   (ii) When the water potential of the blood rises, the animal produces more urine.
   (iii) If the core temperature drops too low, enzyme activity decreases so metabolism releases less heat.
   (iv) When a blood vessel is damaged, platelets start to cling to the injured site and release chemicals that attract more platelets.
   (v) A low pH in the blood causes increased ventilation, which removes carbon dioxide from the blood.

   Which row correctly identifies examples of positive and negative feedback? [1]

Row	Positive feedback	Negative feedback
A	iii only	i, ii, iv and v
B	v only	i, ii, iii and iv
C	iii and iv	i, ii and v
D	iii and v	i, ii and iv

3. The following statements describe an animal's responses to temperature change:
   (i) increased sweating
   (ii) hides in a burrow
   (iii) hair becomes erect
   (iv) vasodilation in the skin
   (v) basks in the sun.

   Which row correctly identifies the responses shown by ectotherms and endotherms? [1]

Row	Ectotherms only	Endotherms only	Both
A		i, iii and iv	ii and v
B	v	i, iii and iv	ii
C	ii and v	i, iii and iv	
D	i, iii and iv	ii and v	

4. Sensory receptors are known as transducers. What is the role of a sensory receptor? [1]
   A. To inform the brain of changes in the environment
   B. To alter the local environment after a change
   C. To release hormones
   D. To convert stimuli into nervous impulses

5. What is the correct definition of negative feedback? [1]
   A. A response that reverses a change
   B. A response that enhances a change
   C. A response that removes the stimulus
   D. A response that reduces a stimulus

[Total: 5]

6. (a) Define the term 'homeostasis'. [3]
   (b) List three organs involved in homeostasis and state their role in homeostasis. [6]
   (c) Explain why positive feedback is not normally a feature of homeostatic mechanisms. [3]

[Total: 12]

7. (a) State precisely where the centre for temperature regulation is situated in a mammal. [1]

   (b) Describe the role in homeostasis of the centre for temperature regulation. [3]

   (c) List three responses to a rise in body temperature seen in an endotherm such as a human. [3]

   (d) You are trekking at high altitude in the Himalayas when your guide warns that a storm is approaching and it will be accompanied by a sudden drop in temperature. You do not have time to walk to the nearest village. Suggest what you should do to prepare, and justify your decision. [4]

[Total: 11]

8. Figure 1 shows the core temperature of two camels that were kept together during the day. Camel A had recently been allowed access to water, but camel B had not had water.

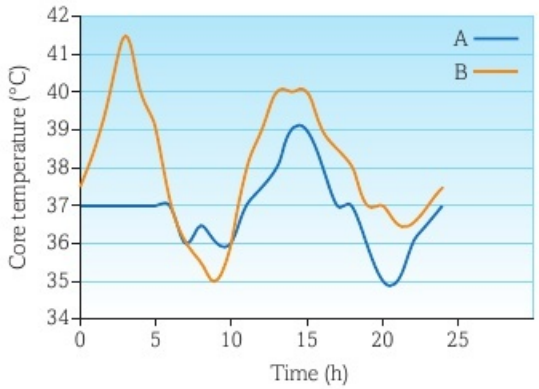


Figure 1

   (a) Suggest why the graph records core temperature rather than skin temperature. [2]

   (b) Describe the temperature changes seen in camel A throughout the 24 hour period. [3]

   (c) Suggest at what time external temperatures were at their highest. [1]

   (d) Explain why the core temperature of camel B fluctuates more than that of camel A. [3]

[Total: 9]

9. (a) The table below shows some responses to changes in core body temperature in ectotherms.

   Explain how each response helps to regulate body temperature. [4]

Response	Explanation
A lizard will go underground or hide in a crevice when temperatures are high.	
Adders are venomous snakes found in the UK. They can often be found in sunny patches on a footpath.	
The horned lizard can expand its rib cage when lying in the sun.	
Early in the morning a dragonfly can be seen sitting on a plant stem flapping its wings.	

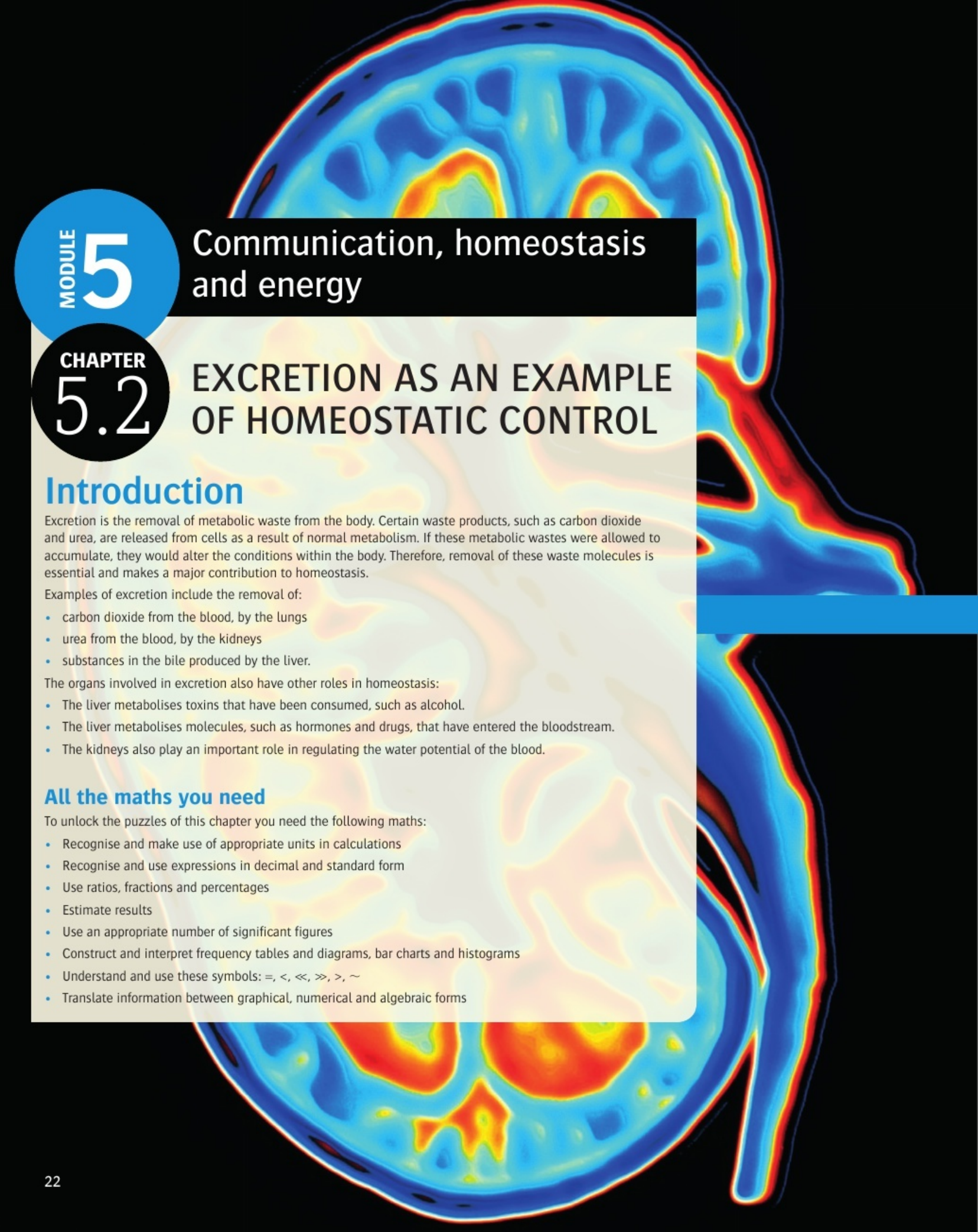
   (b) Describe the role of skin temperature receptors in mammals. [3]

[Total: 7]

10. Negative feedback is used to regulate body temperature. Use your knowledge of negative feedback to describe the possible responses of a small mammal such as the jerboa (Figure 2), which lives in deserts where the temperature can fluctuate between freezing and 40 °C. [8]

Figure 2 A jerboa.

[Total: 8]



MODULE 5

Communication, homeostasis and energy

CHAPTER 5.2

EXCRETION AS AN EXAMPLE OF HOMEOSTATIC CONTROL

Introduction

Excretion is the removal of metabolic waste from the body. Certain waste products, such as carbon dioxide and urea, are released from cells as a result of normal metabolism. If these metabolic wastes were allowed to accumulate, they would alter the conditions within the body. Therefore, removal of these waste molecules is essential and makes a major contribution to homeostasis.

Examples of excretion include the removal of:

- carbon dioxide from the blood, by the lungs
- urea from the blood, by the kidneys
- substances in the bile produced by the liver.

The organs involved in excretion also have other roles in homeostasis:

- The liver metabolises toxins that have been consumed, such as alcohol.
- The liver metabolises molecules, such as hormones and drugs, that have entered the bloodstream.
- The kidneys also play an important role in regulating the water potential of the blood.

All the maths you need

To unlock the puzzles of this chapter you need the following maths:

- Recognise and make use of appropriate units in calculations
- Recognise and use expressions in decimal and standard form
- Use ratios, fractions and percentages
- Estimate results
- Use an appropriate number of significant figures
- Construct and interpret frequency tables and diagrams, bar charts and histograms
- Understand and use these symbols: =, <, ≪, ≫, >, ~
- Translate information between graphical, numerical and algebraic forms

What have I studied before?

- The gross structure of the kidney and its role in excretion
- Factors that affect the volume of urine produced
- The role of ADH in controlling water potential
- The role of the lungs in excreting carbon dioxide
- The structure of the plasma membrane and its role as a selectively permeable barrier
- The role of the plasma membrane in cell signalling
- Active transport, osmosis and diffusion
- Homeostasis and negative feedback
- The role of the blood circulatory system in transport

What will I study later?

- How nerve cells carry messages
- How nerve cells communicate with each other
- How hormones are released
- How hormones act upon their target cells

What will I study in this chapter?

- Excretion
- Structure and function of the liver
- Structure and function of the kidneys
- Control of water potential in the blood
- Treatment of kidney failure

5.2 1 Excretion

By the end of this topic, you should be able to demonstrate and apply your knowledge and understanding of:

* the term excretion and its importance in maintaining metabolism and homeostasis

KEY DEFINITIONS

excretion: the removal of metabolic waste from the body.
metabolic waste: a substance that is produced in excess by the metabolic processes in the cells; it may become toxic.

Excretion is the removal of **metabolic waste** from the body. This means the removal from the body of the unwanted products of cell metabolism.

What products must be excreted?

Many substances need to be excreted. Almost all products that are formed in excess by the chemical processes occurring in the cells must be removed from the body, so that they do not build up and inhibit enzyme activity or become toxic. The main excretory products are:

- carbon dioxide from respiration
- nitrogen-containing compounds, such as urea (i.e. nitrogenous waste)
- other compounds, such as the bile pigments found in faeces.

LEARNING TIP

Do not confuse excretion with egestion. Egestion is the elimination of faeces from the body. Faeces are the undigested remains of food and are not metabolic products.

The excretory organs

The lungs

Every living cell in the body produces carbon dioxide as a result of respiration. Carbon dioxide is passed from the cells of respiring tissues into the bloodstream, where it is transported (mostly in the form of hydrogencarbonate ions) to the lungs. In the lungs the carbon dioxide diffuses into the alveoli to be excreted as you breathe out (see Book 1, topic 3.2.8).

The liver

The liver is directly involved in excretion. It has many metabolic roles and some of the substances produced will be passed into the bile for excretion with the faeces, for example, the pigment bilirubin (see topics 5.2.2 and 5.2.3).

The liver is also involved in converting excess amino acids to urea. Amino acids are broken down by the process of deamination. The nitrogen-containing part of the molecule is then combined with carbon dioxide to make urea.

The kidneys

The urea is passed into the bloodstream to be transported to the kidneys. Urea is transported in solution – dissolved in the plasma. In the kidneys the urea is removed from the blood to become a part of the urine (see topics 5.2.4–5.2.6). Urine is stored in the bladder before being excreted from the body via the urethra.

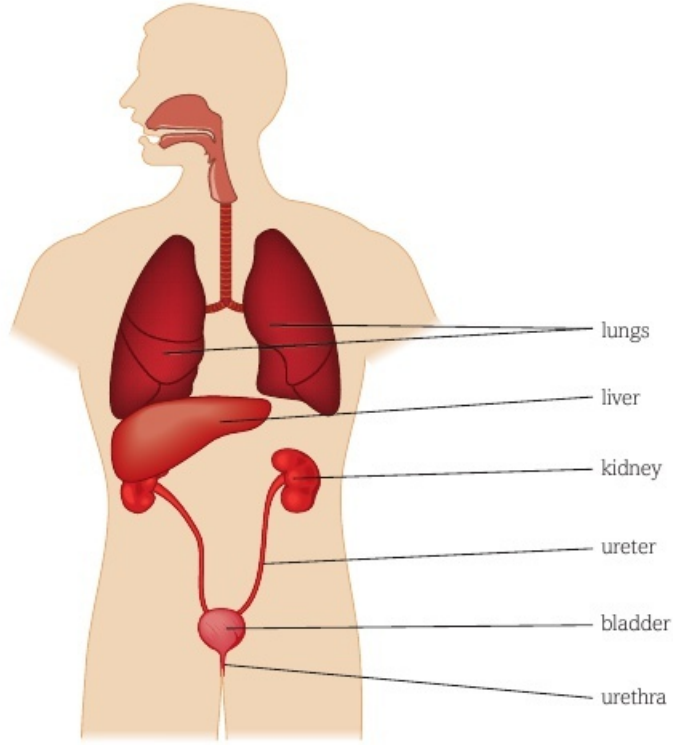


Figure 1 The main organs involved in excretion.

The skin

The skin is also involved in excretion, but excretion is not the primary function of the skin. Sweat contains a range of substances including salts, urea, water, uric acid and ammonia. Urea, uric acid and ammonia are all excretory products. The loss of water and salts may be an important part of homeostasis – maintaining the body temperature and the water potential of the blood (see topics 5.1.2 and 5.1.4).

The importance of excretion

Allowing the products of metabolism to build up could be fatal. Some metabolic products such as carbon dioxide and ammonia are toxic. They interfere with cell processes by altering the pH, so that normal metabolism is prevented. Other metabolic products may act as inhibitors and reduce the activity of essential enzymes.

Carbon dioxide

Most carbon dioxide is transported in the blood as hydrogencarbonate ions. However, from your AS level work you may recall that forming hydrogencarbonate ions also forms hydrogen ions:

$$CO_2 + H_2O \rightarrow H_2CO_3 \text{ (carbonic acid)}$$

The carbonic acid dissociates to release hydrogen ions:

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

This occurs inside the red blood cells, under the influence of the enzyme carbonic anhydrase, but can also occur in the blood plasma.

The hydrogen ions affect the pH of the cytoplasm in the red blood cells. The hydrogen ions interact with bonds within haemoglobin, changing its three-dimensional shape. This reduces the affinity of haemoglobin for oxygen, affecting oxygen transport. The hydrogen ions can then combine with haemoglobin, forming haemoglobinic acid. The carbon dioxide that is not converted to hydrogencarbonate ions can combine directly with haemoglobin, producing carbaminohaemoglobin. Both haemoglobinic acid and carbaminohaemoglobin are unable to combine with oxygen as normal – reducing oxygen transport further.

In the blood plasma, excess hydrogen ions can reduce the pH of the plasma. Maintaining the pH of the blood plasma is essential, because changes could alter the structure of the many proteins in the blood that help to transport a wide range of substances around the body. Proteins in the blood act as buffers to resist the change in pH.

If the change in pH is small then the extra hydrogen ions are detected by the respiratory centre in the medulla oblongata of the brain. This causes an increase in the breathing rate to help remove the excess carbon dioxide.

However, if the blood pH drops below 7.35 it may cause headaches, drowsiness, restlessness, tremor and confusion. There may also be a rapid heart rate and changes in blood pressure. This is respiratory acidosis. It can be caused by diseases or conditions that affect the lungs themselves, such as emphysema, chronic bronchitis, asthma or severe pneumonia. Blockage of the airway due to swelling, a foreign object, or vomit can also induce acute respiratory acidosis.

DID YOU KNOW?

People taking statins to reduce blood cholesterol are advised not to drink grapefruit juice. Some components of grapefruit juice bind to the enzymes that break down statins in the liver. This inhibits the enzymes and leads to increased concentrations of statins in the body.

Nitrogenous compounds

The body cannot store excess amino acids. However, amino acids contain almost as much energy as carbohydrates. Therefore, it would be wasteful simply to excrete excess amino acids. Instead they are transported to the liver and the potentially toxic amino group is removed (deamination). The amino group initially forms the very soluble and highly toxic compound, ammonia. This is converted to a less soluble and less toxic compound called urea, which can be transported to the kidneys for excretion. The remaining keto acid can be used directly in respiration to release its energy or it may be converted to a carbohydrate or fat for storage.

Deamination: amino acid + oxygen → keto acid + ammonia

Formation of urea: ammonia + carbon dioxide → urea + water

$$2NH_3 + CO_2 \rightarrow (NH_2)_2CO + H_2O$$

Questions

1. List the excretory products found in sweat.
2. What effects could the build-up of excess salts have in the blood?
3. Explain how the waste products of cell metabolism can affect enzyme action.
4. Explain why the majority of waste eliminated as faeces is not considered to be excretion.
5. Suggest why fish can excrete nitrogenous waste in the form of ammonia, while mammals convert it to urea.

5.2 2 The structure of the liver

By the end of this topic, you should be able to demonstrate and apply your knowledge and understanding of:

- the structure and functions of the mammalian liver
- the examination and drawing of stained sections to show the histology of liver tissue

Blood supply to the liver

The liver cells (hepatocytes) carry out many hundreds of metabolic processes, so the liver has an important role in homeostasis (see topics 5.1.2 and 5.2.3). It is therefore essential that the liver has a good supply of blood. The internal structure of the liver ensures that as much blood as possible flows past as many liver cells as possible. This enables the liver cells to remove excess or unwanted substances from the blood and return substances to the blood to ensure concentrations are maintained.

Blood flow to and from the liver

The liver is supplied with blood from two sources:

- **The hepatic artery**: Oxygenated blood from the heart travels from the aorta via the hepatic artery into the liver. This supplies the oxygen that is essential for aerobic respiration (see Chapter 5.7). The liver cells are very active, because they carry out many metabolic processes. Many of these processes require energy, in the form of ATP, so it is important that the liver has a good supply of oxygen for aerobic respiration.
- **The hepatic portal vein**: Deoxygenated blood from the digestive system enters the liver via the hepatic portal vein. This blood is rich in the products of digestion. The concentrations of various substances will be uncontrolled as they have just entered the body from the products of digestion in the intestines. The blood may also contain toxic compounds that have been absorbed from the intestine. It is important that such substances do not continue to circulate around the body before their concentrations have been adjusted.

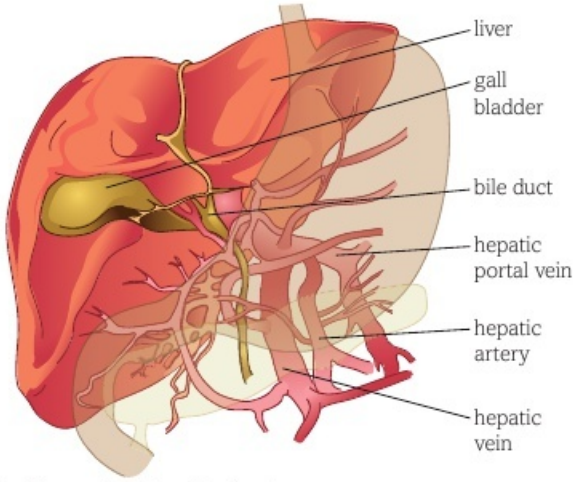


Figure 1 The supply of blood to the liver.

Blood leaves the liver via the hepatic vein. The hepatic vein rejoins the vena cava and the blood returns to the body's normal circulation.

A fourth vessel is connected to the liver. However, it is not a blood vessel – it is the bile duct. Bile is a secretion from the liver which has functions in digestion and excretion. The bile duct carries bile from the liver to the gall bladder, where it is stored until required to aid the digestion of fats in the small intestine. Bile also contains some excretory products such as bile pigments like bilirubin, which will leave the body with the faeces.

Histology of the liver

Structure of the liver

The cells, blood vessels and chambers inside the liver are arranged to ensure the greatest possible contact between the blood and the liver cells. The liver is divided into lobes which are further divided into lobules. The lobules are cylindrical.

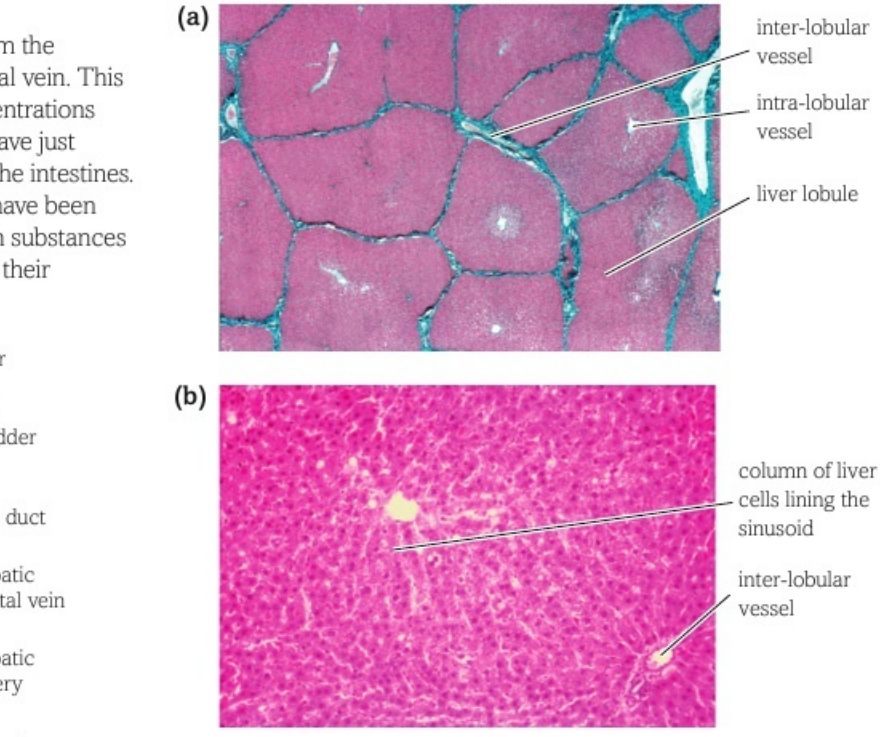


Figure 2 (a) Liver lobules (×20) and (b) the arrangement of cells in the lobule (×45).

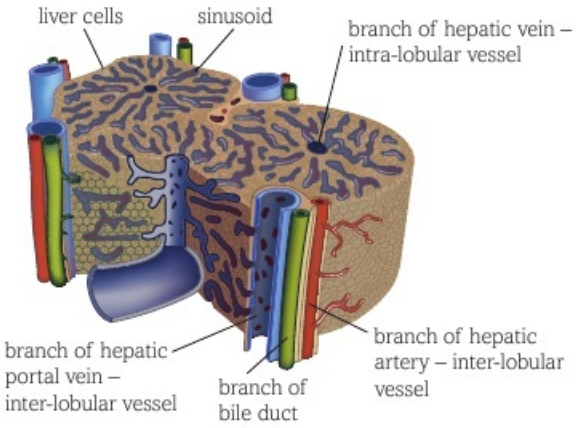


Figure 3 Arrangement of liver cells into cylindrical lobules.

As the hepatic artery and hepatic portal vein enter the liver, they split into smaller and smaller vessels. These vessels run between and parallel to the lobules – they are known as inter-lobular vessels. At intervals, branches from the hepatic artery and the hepatic portal vein enter the lobules. The blood from the two blood vessels is mixed and passes along a special chamber called a sinusoid, which is lined with liver cells. As the blood flows along the sinusoid it is in close contact with the liver cells. These cells are able to remove substances from the blood and return other substances to the blood.

DID YOU KNOW?

Portal vessels are unusual because they have capillaries at each end. There are also portal vessels in parts of the brain to facilitate hormonal communication.

Specialised macrophages called Kupffer cells move about within the sinusoids. Their primary function appears to be to breakdown and recycle old red blood cells. One of the products of haemoglobin breakdown is bilirubin, which is one of the bile pigments excreted as part of the bile.

Bile is made in the liver cells and released into the bile canaliculi. The bile canaliculi join together to form the bile duct, which transports the bile to the gall bladder.

When the blood reaches the end of the sinusoid, the concentrations of many of its components have been modified and regulated. At the centre of each lobule is a branch of the hepatic vein known as the intra-lobular vessel. The sinusoids empty into this vessel. The branches of the hepatic vein, from different lobules, join together to form the hepatic vein, which drains blood from the liver.

LEARNING TIP

Many cell specialisations are not obvious – many cells specialise for different functions by having larger numbers of particular organelles rather than by adopting a specialised shape.

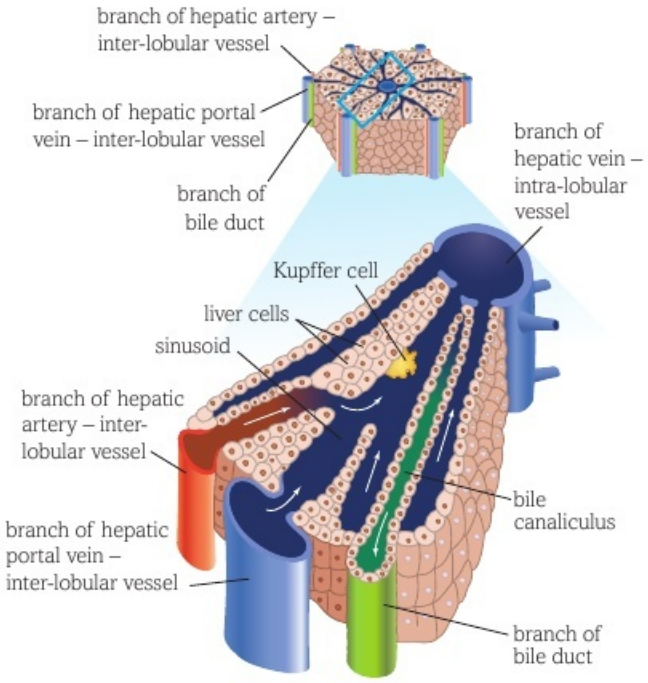


Figure 4 Arrangement of cells in a lobule.

Liver cells

Liver cells, or hepatocytes, appear to be relatively unspecialised. They have a simple cuboidal shape with many microvilli on their surface. However, their many metabolic functions include protein synthesis, transformation and storage of carbohydrates, synthesis of cholesterol and bile salts, detoxification and many other processes. This means that their cytoplasm must be very dense and is specialised in the numbers of certain organelles that it contains.

Questions

1. Explain why the liver has two supplies of blood.
2. Why might blood in the hepatic portal vein contain toxins?
3. Explain why the concentrations of substances in the blood of the hepatic portal vein may change during the day.
4. Use a flow diagram to describe the route taken by blood as it flows from the hepatic artery to the hepatic vein.
5. Describe how the structure of the liver ensures that blood flows past as many liver cells as possible.
6. Suggest which organelles may be particularly common in the cytoplasm of hepatocytes.

5.2

3 Liver function

By the end of this topic, you should be able to demonstrate and apply your knowledge and understanding of:

* the structure and functions of the mammalian liver

KEY DEFINITION

ornithine cycle: a series of biochemical reactions that convert ammonia to urea.

Many metabolic functions

The liver is metabolically very active and carries out a wide range of functions, including:

- control of blood glucose levels, amino acid levels, lipid levels
- synthesis of bile, plasma proteins, cholesterol
- synthesis of red blood cells in the fetus
- storage of vitamins A, D and B12, iron, glycogen
- detoxification of alcohol, drugs
- breakdown of hormones
- destruction of red blood cells.

Storage of glycogen

The liver stores sugars in the form of glycogen. It is able to store approximately 100–120 g of glycogen, which makes up about 8% of the fresh weight of the liver. The glycogen forms granules in the cytoplasm of the hepatocytes. This glycogen can be broken down to release glucose into the blood as required. The control of blood glucose concentrations is described in topic 5.4.4.

LEARNING TIP

The structure of glycogen as a storage molecule was covered at AS level. Remember that your AS level knowledge will be tested in your final exams. Glycogen is compact, it does not affect the water potential and it has many terminals from which sugars can be released quickly.

Detoxification

One important role of the liver is to detoxify substances that may cause harm. Some of these compounds, such as hydrogen peroxide, are produced in the body. Others, such as alcohol, may be consumed as a part of our diet or may be taken for health or recreational reasons, for example, medicines and recreational drugs.

Toxins can be rendered harmless by oxidation, reduction, methylation or by combination with another molecule. Liver cells contain many enzymes that render toxic molecules less toxic.

These include:

- **catalase**, which converts hydrogen peroxide to oxygen and water. Catalase has a particularly high turnover number (the number of molecules of hydrogen peroxide that one molecule of catalase can render harmless in one second) of five million.
- **cytochrome P450**, which is a group of enzymes used to breakdown drugs including cocaine and various medicinal drugs. The cytochromes are also used in other metabolic reactions such as electron transport during respiration. Their role in metabolising drugs can interfere with other metabolic roles and cause the unwanted side effects of some medicinal drugs.

DID YOU KNOW?

The P450 enzymes show a lot of variation between individuals. As they breakdown various medicinal drugs, different end products may be produced. This is why some people suffer side effects that others do not experience.

Detoxification of alcohol

Alcohol, or ethanol, is a drug that depresses nerve activity. In addition, alcohol contains chemical potential energy, which can be used for respiration.

Alcohol is broken down in the hepatocytes by the action of the enzyme ethanol dehydrogenase. The resulting compound is ethanal. This is dehydrogenated further by the enzyme ethanal dehydrogenase. The final compound produced is ethanoate (acetate). This acetate is combined with coenzyme A to form acetyl coenzyme A, which enters the process of aerobic respiration. The hydrogen atoms released from alcohol are combined with another coenzyme, called NAD, to form reduced NAD (see topic 5.7.4).

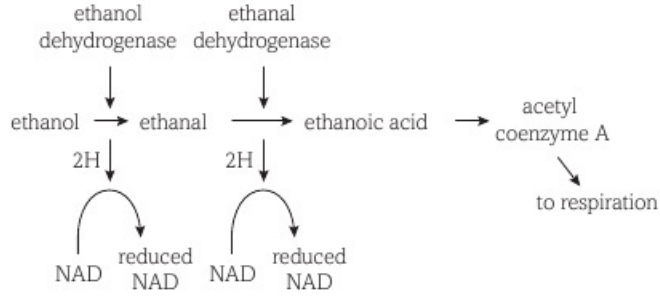


Figure 1 Detoxification of alcohol.

NAD is also required to oxidise and breakdown fatty acids for use in respiration (see topic 5.7.8). If the liver has to detoxify too much

alcohol, it uses up its stores of NAD and has insufficient left to deal with the fatty acids. These fatty acids are then converted back to lipids and stored as fat in the hepatocytes, causing the liver to become enlarged. This is a condition known as 'fatty liver', which can lead to alcohol-related hepatitis or to cirrhosis.

Formation of urea

Every day we each need 40–60 g of protein. However, most people in developed countries eat far more than this. Excess amino acids cannot be stored, because the amino groups make them toxic. However, the amino acid molecules contain a lot of energy, so it would be wasteful to excrete the whole molecule. Therefore excess amino acids undergo treatment in the liver to remove and excrete the amino component. This treatment consists of two processes: deamination followed by the **ornithine cycle**.

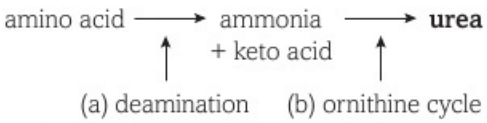


Figure 2 Formation of urea.

Deamination

The process of deamination removes the amino group and produces ammonia. Ammonia is very soluble and highly toxic. Therefore, ammonia must not be allowed to accumulate. Deamination also produces an organic compound, a keto acid, which can enter respiration directly (see topic 5.2.1) to release its energy.

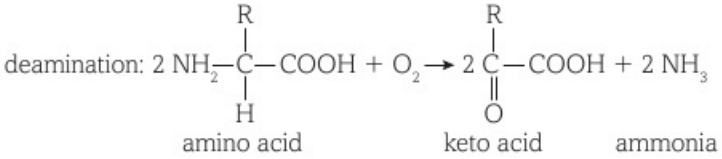


Figure 3 Deamination.

The ornithine cycle

Because ammonia is so soluble and toxic, it must be converted to a less toxic form very quickly. The ammonia is combined with carbon dioxide to produce urea. This occurs in the ornithine cycle. Ammonia and carbon dioxide combine with the amino acid ornithine to produce citrulline. This is converted to arginine by addition of further ammonia. The arginine is then re-converted to ornithine by the removal of urea.

Urea is both less soluble and less toxic than ammonia. It can be passed back into the blood and transported around the body to the kidneys. In the kidneys the urea is filtered out of the blood and concentrated in the urine. Urine can be safely stored in the bladder until it is released from the body.

The ornithine cycle can be summarised as:

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

ammonia + carbon dioxide → urea + water

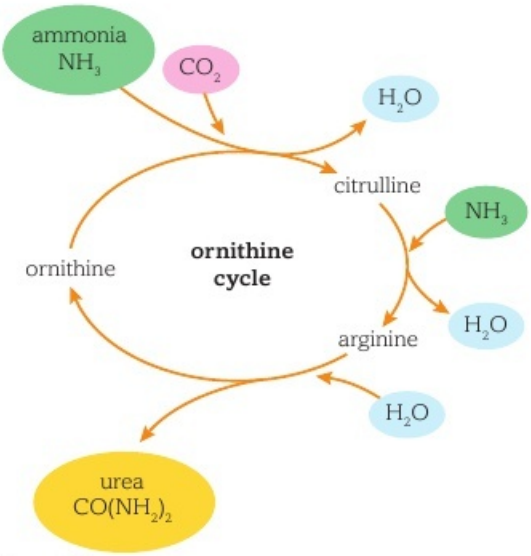


Figure 4 The ornithine cycle.

Questions

1. How can the sugars released from glycogen be used?
2. Explain why substances such as alcohol and excess amino acids should not simply be excreted.
3. Explain why it is essential that ammonia is converted to urea as quickly as possible.
4. Suggest why the hepatocytes contain many mitochondria.
5. Suggest why the hepatocytes contain many ribosomes.

5.2

4 Kidney structure

By the end of this topic, you should be able to demonstrate and apply your knowledge and understanding of:

- the structure, mechanisms of action and functions of the mammalian kidney
- the dissection, examination and drawing of the external and internal structure of the kidney
- the examination and drawing of stained sections to show the histology of nephrons (continued in topics 5.2.5 and 5.2.6)

KEY DEFINITIONS

nephron: the functional unit of the kidney.
ultrafiltration: filtration of the blood at a molecular level under pressure.

The structure of the kidney

Most people have two kidneys. These are positioned on each side of the spine, just below the lowest rib. Each kidney is supplied with blood from a renal artery and is drained by a renal vein.

The role of the kidneys is excretion. The kidneys remove waste products from the blood and produce urine. The urine passes out of the kidney down the ureter to the bladder where it can be stored until it is released.

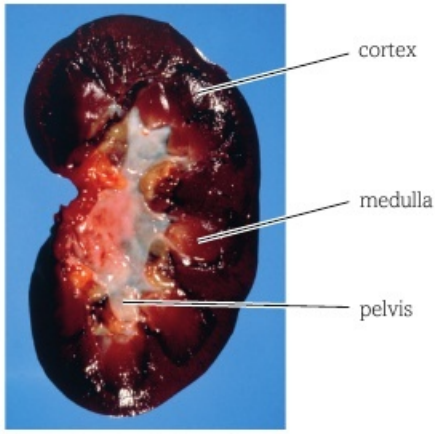


Figure 1 A kidney in longitudinal section.

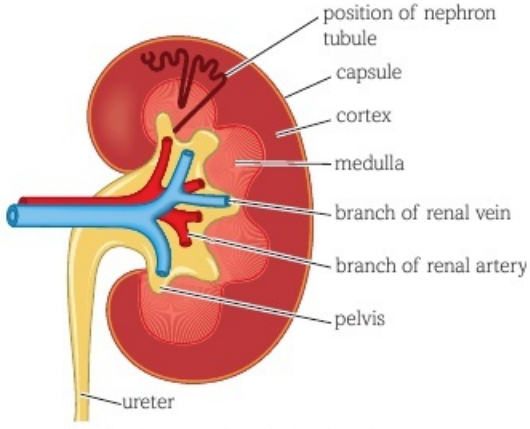


Figure 2 A drawing of a kidney in longitudinal section.

In a longitudinal section you can see that the kidney consists of three regions surrounded by a tough capsule.

- The outer region is called the cortex.
- The inner region is called the medulla.
- The centre is the pelvis, which leads into the ureter.

Fine structure of the kidney

The bulk of each kidney consists of tiny tubules called **nephrons**. Each kidney contains about one million nephrons. Each nephron starts in the cortex at a cup-shaped structure called the Bowman's capsule. The remainder of the nephron is a coiled tubule that passes through the cortex, forms a loop down into the medulla and back to the cortex, before joining a collecting duct that passes back down into the medulla.

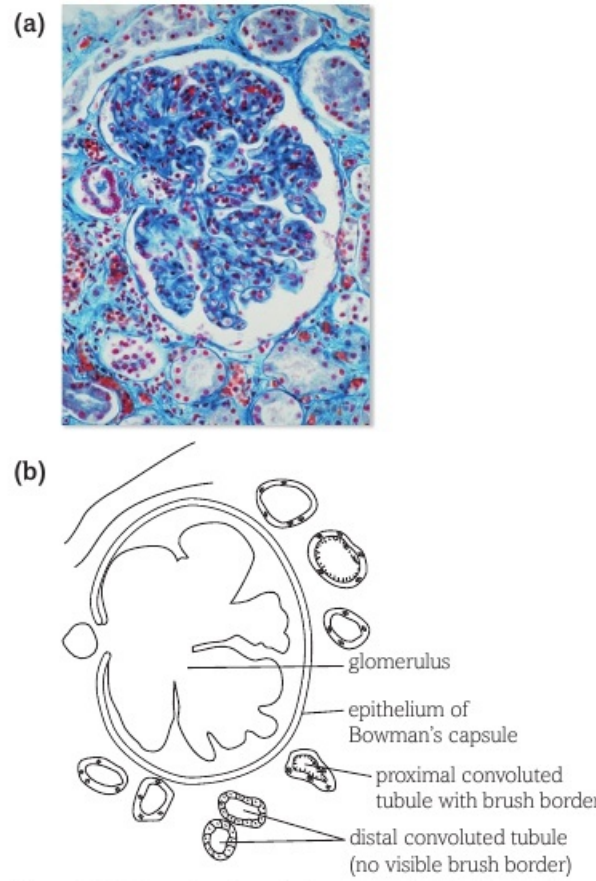


Figure 3 (a) A section through the cortex showing Bowman's capsule and (b) how this might be drawn from a slide.