Lesson Eleven

Homeostasis and Excretion

Aims

The aims of this lesson are to enable you to:

- understand the concepts of excretion and homeostasis, and list the most important examples of each in human beings
- recall the structure and functions of the skin, and explain its role in thermoregulation
- explain how the renal system, especially the kidney, contributes to both osmoregulation and the excretion of nitrogenous wastes

Context

This lesson covers elements (a) to (n) of Section 10 (Homeostatic mechanisms) of the Edexcel specification.

Edexcel IGCSE Human Biology, chapter 8, pages 106-113 and 116-120.

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Introduction

If life is to continue, conditions inside the body – indeed inside each cell of the body – must remain almost constant. Cells will only work if temperature, pH, concentration, and chemical composition remain steady within very narrow limits. We say that the body must maintain a "constant **internal environment**".

However, the external environment keeps changing (for example it gets hotter and colder), and the activities of the cells themselves tend to change their conditions (for example, they use up oxygen and make carbon dioxide as they respire). So the body must continually **respond** to these changes to maintain the constant internal environment. These responses are called **homeostasis**. Homeostasis is the activity of keeping the internal environment constant in the face of its tendency to change.

As cells live they produce wastes, called **metabolic wastes** because they are made by the cell's chemistry or metabolism. Part of homeostasis is the getting rid of these wastes in a process called **excretion**. The two main wastes produced by human beings are carbon dioxide and nitrogenous (nitrogen-containing) waste:

- carbon dioxide is made in all of the cells during respiration and is excreted from the body by the lungs

- nitrogenous waste is made in the liver and is excreted from the body mainly by the kidneys

Apart from the lungs, the two main organs of excretion and homeostasis are the **skin** and the **kidneys**. In this lesson we shall study each of these organs in detail.

Get it right!

1. Getting rid of waste food as faeces is not excretion. Excretion is getting rid of *metabolic* wastes, i.e. ones made by the cells themselves. Most of the faeces is simply the undigested parts of the food – the cells have not made it. Getting rid of faeces is called **egestion**, not excretion.

2. You will often see textbooks (and your Specification!) saying that losing water in the urine is excretion. This is technically correct, because water is made by the cells during respiration. However, it is much better to think of the body as *controlling the amount of* its water rather than just getting rid of it as a waste.

Skin Structure and Functions

Skin looks simple. But in fact it is a complicated organ that carries out several functions essential to our survival. You can no more survive without skin that without your kidneys or your brain.

Figure 8.15 on page 117 of *Edexcel IGCSE Human Biology* shows the structure of skin in section, with the outside at the top of the picture. Notice on the left that it has three different layers, the **epidermis**, **dermis** and **hypodermis**.

Epidermis

This has cells which are continually dividing, and then dying to form a layer of dead cells on the outside. This dead layer

- prevents loss of water (it is waterproof) and
- prevents the entry of pathogens and poisons

Hypodermis

This consists mainly of cells filled with lipids, the subcutaneous fat. This layer

- is the body's long-term energy store
- is a thermal insulating layer, i.e. it slows up heat loss

- provides some cushioning to prevent damage of the organs below

Dermis

This contains many structures which between them have two main functions:

- sensitivity: providing information about the external environment (touch, pain and temperature receptors)
- temperature control or thermoregulation

It is on the skin's role in thermoregulation that we will now concentrate.

The Skin and Temperature Control

Our core body temperature needs to remain almost constant at about 37°C. This only happens if the amount of heat made and the amount of heat lost are the same:

heat made > heat lost ----> temperature rises

heat made < heat lost ----> temperature falls

heat made = heat lost ----> temperature remains constant

If our core body temperature changes this is detected by the **thermoregulatory centre** in the **hypothalamus** of the brain. This centre sends electrical impulses down the nerves, largely to the skin, to correct the problem.

Body too hot

1. The impulses make the muscles in the walls of the skin arterioles (smaller arteries) relax. The arterioles widen (called **vasodilation**) so more blood flows up through the **capillary loops** near the skin surface. The skin surface warms up, so more heat is lost from the surface by radiation into the surrounding air.

2. The impulses make the **sweat glands** extract more sweat from the blood and pump it up through pores on to the

skin surface. As the water in the sweat evaporates it takes heat from the skin surface. Sweat contains dissolved salt and urea as well as water. Urea is a waste mainly removed by the kidneys, so sweating is also a minor form of excretion.

Both of these effects tend to cool the overheated body back down. This is an example of **negative feedback**: a change stimulates its reversal. Negative feedback is always essential to achieve homeostasis.

> *Get it right!* Sweating does not cool you down. It is only the evaporation of the water in the sweat which cools you.

Body too cold

1. Impulses make the muscles in the walls of the arterioles contract. The arterioles narrow (called **vasoconstriction**) so less blood flows up near the skin surface. The skin surface cools down, so less heat is lost from it by radiation into the surrounding air.
2. Impulses make the hair **erector muscles** contract, pulling the hairs upright. In furry animals like cats this traps a thicker layer of insulating air next to the skin, reducing heat loss. In humans, who have lost most of their hair, it is pretty useless and just produces “goose bumps”!
3. If the body temperature falls too far, impulses make the large muscles attached to the skeleton contract and relax rapidly, causing **shivering**. This increases the rate of respiration in these muscles, generating extra heat.

These three effects tend to warm the overcooled body back up, another example of negative feedback.

Log on to Twig and look at the film titled: **What are Goosebumps?**

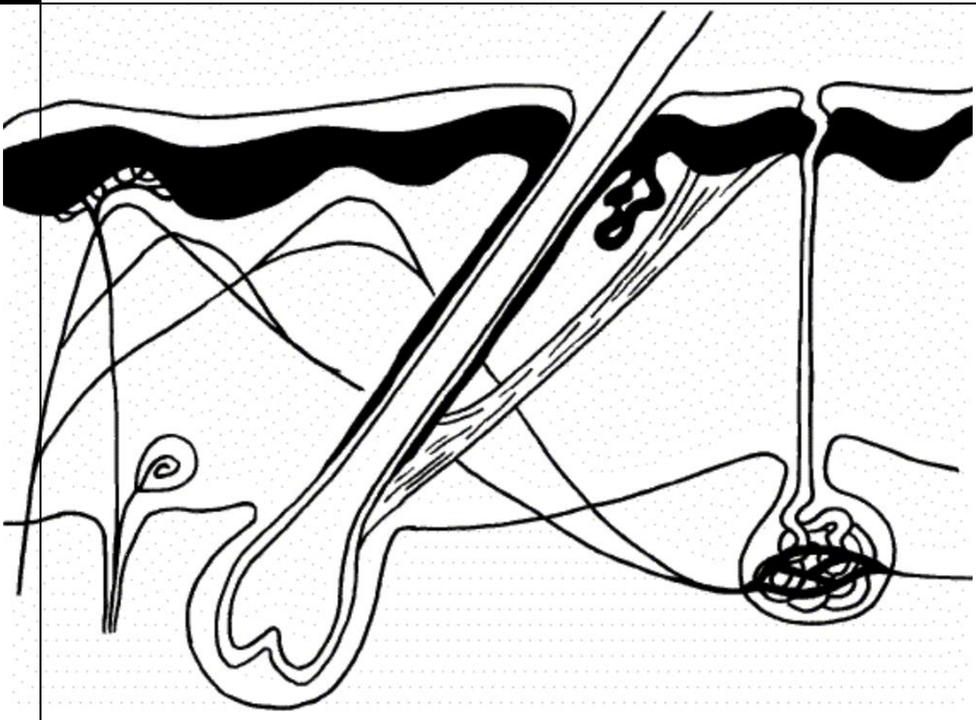
www.ool.co.uk/959tz

The human body has an inbuilt thermostat system which helps regulate our temperature. Discover how sweating keeps us cool, and the intricate reaction that produces goosebumps.

Activity 1

Put the following labels on the diagram, and then check your answers from page 117 of the textbook.

sweat gland
epidermis
dermis
hair erector muscle
capillary loop
fat layer
oil gland
fat layer
hair
pressure receptor



The Renal System

The **renal system**, also called the **urinary system**, is shown in figure 8.2 on page 108 of *Edexcel IGCSE Human Biology*. Its central organ is the **kidney**, which has two functions:

- **excretion**: of nitrogenous waste, especially **urea**
- **homeostasis**: control of blood plasma concentration and therefore the salt and water content of the body (**osmoregulation**), and control of the pH of the blood

Each kidney is supplied with blood through a **renal artery**. It extracts a liquid called **urine** from the blood plasma, before releasing the blood down a **renal vein**. The urine travels down the **ureter** and is stored temporarily in the **bladder** before being released to the outside through the **urethra**.

Log on to Twig and look at the film titled: **Kidneys**

www.ool.co.uk/1016yr

Learn about how the kidneys function, regulate the salt levels in our bodies, filter our blood, and ultimately keep us alive.

Get it right!

The ureter runs from the kidney to the bladder.
The urethra runs from the bladder to the outside.

Kidney Structure

The internal structure of a kidney is shown in figure 8.3 on page 109 of *Edexcel IGCSE Human Biology*. It has:

- a lighter outer **cortex**
- a darker **medulla**
- a central **pelvis** leading into the ureter

Running through the cortex and medulla are a large number of similar microscopic **nephrons**, each of which produces urine. The structure of a single nephron is shown at the bottom of the page, and you should follow this as we study how the urine is produced.

Urine Production by a Nephron

A nephron produces urine in several steps, and the different regions of a nephron carry out different tasks in this process.

Bowman's Capsule

The **Bowman's capsule** contains a tangle of blood capillaries called the **glomerulus**. The arteriole bringing blood into the glomerulus is wider than the arteriole taking it away. This, plus the pressure from the heart, means that the blood in the glomerulus is under particularly high pressure.

This high pressure forces fluid out of the glomerulus across its single-celled wall, through a layer called the **basement membrane**, and into the central cavity of the Bowman's capsule through the gaps between its loosely-fitting cells (see fig 8.5 0n page 110 of *Edexcel IGCSE Human Biology*). This process is called **ultrafiltration**, and the liquid produced is called the **glomerular filtrate**.

The basement membrane only has very small holes in it, so only substances made of small particles can escape like this. Others remain in the blood.

- Water, ions (e.g. sodium, potassium, chloride), glucose and urea escape in the filtrate.

- Cells, platelets and protein molecules stay in the blood.

The composition of the filtrate is therefore approximately the same as that of the blood plasma, minus its dissolved proteins.

The Bowman's capsules are all located in the cortex of the kidney.

Proximal convoluted tubule

The rest of the nephron, between the Bowman's capsule and the collecting duct, is sometimes called the kidney **tubule**, and the first part is called the **proximal convoluted tubule**. "Proximal" means near the start, and "convoluted" means coiled or twisted.

A huge amount of glomerular filtrate is produced – about 180 dm^3 a day in an adult – and if this was all lost in the urine the person would rapidly dehydrate and die. The main job of the tubule is **selective reabsorption**: taking water and other valuable materials back into the blood to avoid its loss, while leaving behind materials that the body wants to lose.

This starts right away at the proximal convoluted tubule, which has two main jobs:

- About *80% of the water* is reabsorbed into the blood here. This happens by **osmosis,** because the blood, having retained its dissolved proteins, is more concentrated than the filtrate. (See Lesson 2 to remind yourself about osmosis if you are unclear about this.)

- *All of the glucose* is reabsorbed into the blood here. This happens by **active transport**, because the glucose must move up a concentration gradient. (Again, see Lesson 2 to remind yourself about active transport if you are unclear.) This avoids the body losing valuable glucose in the urine. Although some energy is needed for the active transport, it is less than the energy which can be generated later on from the glucose in respiration.

Like the Bowman's capsules, all the proximal convoluted tubules are located in the cortex of the kidney.

Activity 2	Answer question 6 on page 18 of *Edexcel IGCSE Human Biology*.

Loop of Henlé and collecting duct

The **loop of Henlé** starts in the cortex and dips down into the medulla before ending in the cortex again. It alters the concentration of the fluid outside the tubules, so that as you move down towards the pelvis this fluid becomes more and more concentrated. (This is achieved in a notoriously complicated way, and fortunately you do not need to know how it is done!)

Several tubules empty into a common **collecting duct**. The walls of the collecting duct are permeable to water. As the fluid in the collecting duct moves down towards the pelvis, it is exposed to more and more concentrated solution outside because of the action of the loop of Henlé, so more and more of its water is reabsorbed by osmosis. By the time the fluid, now called urine, reaches the pelvis about 99% of the water it had in the Bowman's capsule has been reabsorbed.

Activity 3

Study carefully figure 8.6 on page 111 of *Edexcel IGCSE Human Biology*, and the four paragraphs of text which follow it. Make sure you understand how the concentrations of protein, glucose, urea and Na^+ shown in the diagram come about.

N.B. the concentration of a solute like urea may be increased <u>either</u> by adding more urea <u>or</u> by removing some of the water.

Log on to Twig and look at the film titled: **Urea**

www.ool.co.uk/819hf

An organic compound containing nitrogen that plays an important role in animal metabolism, and is excreted in the urine of mammals.

Composition of Urine

Table 8.1 on page 107 of *Edexcel IGCSE Human Biology* shows the average composition of human urine. Each dm^3 of urine contains about 40g of solutes dissolved in water:

- Urea, ammonia and "other nitrogenous wastes" are different forms of toxic waste made from the breakdown of amino acids in the liver (see Lesson 13). They all contain the element nitrogen (N), as do amino acids. One of the main functions of the kidney is to excrete these, because otherwise they build up in the bloodstream and eventually kill you. Although some of these are reabsorbed by accident in the tubule, the urine is a much more concentrated solution of them than is the blood plasma, so the kidney effectively removes them.

- Sodium chloride, potassium and phosphate are different forms of **ions** found in blood plasma. The amount of these in the urine varies. If the plasma has too much, more is lost in the urine, and vice versa: another example of homeostasis.

The pH of the urine also varies widely, which helps to keep the pH of the blood plasma constant. If the plasma is too acid the urine becomes more acidic to lose the excess acids, and vice versa.

Get it right!

Atoms, molecules and ions are all "particles". A molecule is a particle consisting of two or more atoms joined together e.g. O_2 or CO_2. An ion is a molecule or ion which carries an electrical charge e.g. Na^+ or HCO_3^-.

<u>ADH and the control of water loss</u>

As well as containing a thermoregulatory centre, the hypothalamus in the brain also has an **osmoregulatory centre**. This centre continuously monitors the concentration of the blood plasma flowing through it.

Too concentrated

If the blood plasma becomes too concentrated (which means either too little water, or too many dissolved ions, or both) the hypothalamus sends nervous impulses to the **pituitary gland**, also in the brain. The pituitary gland then releases a hormone called **ADH** (**anti-diuretic hormone**) into the blood. This acts on the collecting ducts in the kidneys, making their walls *more permeable* to water. More water is reabsorbed as the filtrate passes down the collecting ducts, so less water is lost in the urine. The urine becomes more concentrated, because it will still have the same amount of solutes absorbed in less water, and it will appear yellow.

The ADH also stimulates the thirst centre in the brain, making you feel thirsty so that you drink water to make up the shortfall.

Too dilute

If the blood plasma becomes too dilute (usually caused by drinking excess water or other drinks) the hypothalamus again sends nervous impulses to the pituitary gland. The pituitary gland stops releasing ADH into the blood. The walls of the collecting ducts become less permeable to water, less water is reabsorbed and more is lost in the urine. The urine becomes more dilute, because it will still have the same amount of solutes absorbed in more water, and will appear colourless.

ADH is named after the process **diuresis** which is the biological name for urine production. Chemicals which promote urine production are called **diuretics**. Both caffeine (contained in tea, coffee and chocolate) and ethanol (alcohol) are diuretics, as you may have noticed!

Activity 4	Water can enter and leave the body in a variety of ways. Make a list of all the ways in which it can (a) enter (b) leave. Put a star next to the way(s) which are altered to control the amount of water in the body.

Now is the time to read through chapter 8 pages 106 – 113 and 116 – 120 of *Edexcel IGCSE Human Biology*. It covers the same topics as this lesson, so will add to your understanding of the material.

Keywords

Internal environment

Excretion

Negative feedback

Vasodilation

Renal artery

Bowman's capsule

Glomerular filtrate

ADH

Proximal convoluted tubule

Collecting duct

Osmoregulation

Homeostasis

Thermoregulation

Vasoconstriction

Nephron

Glomerulus

Ultrafiltration

Selective reabsorbtion

Diuretic

Loop of Henlé

Ion

Summary

Lesson Eleven: Homeostasis and Excretion

HOMEOSTASIS

SKIN	-------	structure
	-------	thermoregulation
KIDNEY	-------	urinary system
	-------	nephron
	-------	ultrafiltration and selective reabsorption
	-------	ADH and osmoregulation

What you need to know

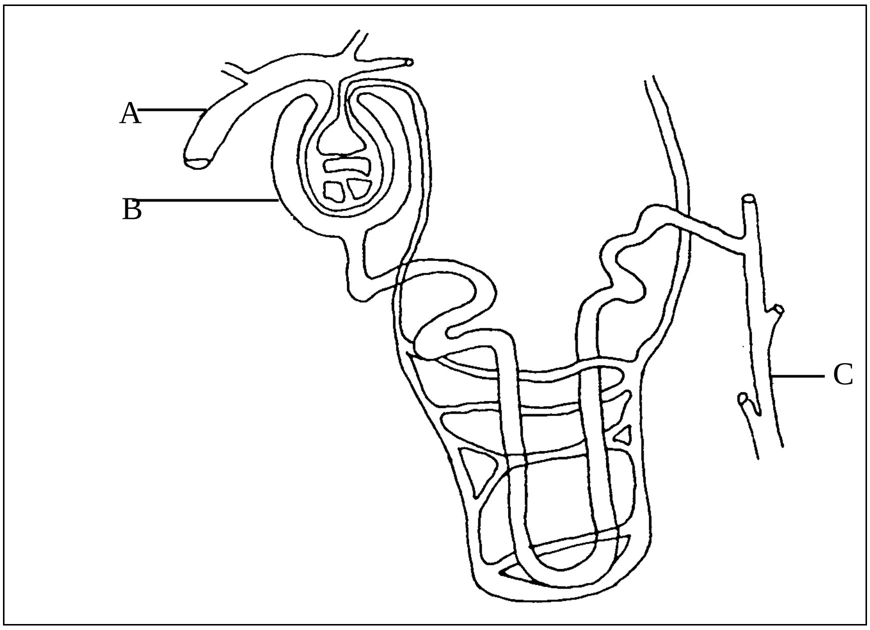
- Structure of the skin and the functions of its different parts
- Structure of the urinary system, kidney and nephron
- The contents of urine and how it can vary

What you might be asked to do

- Label a diagram of skin
- Explain how the skin achieves thermoregulation
- Label a diagram of the urinary system, a kidney or a nephron
- Explain how ultrafiltration and selective reabsorption occur in a nephron
- Explain the composition of liquid found at various points along a nephron
- Explain the role of ADH is osmoregulation

Self-Assessment Test: Lesson Eleven

(1) Look at the following structure, which shows part of the kidney.



(a) Name the structures B and C.

(b) Name the structure found <u>between</u> B and C.

(c) Name the fluids found in A, B and C.

(d) Suggest why

(i) you produce more urine in winter than summer

(ii) marathon runners get dehydrated, even when running in cold weather

(2) Suggest why

(a) You often feel colder on getting out of a swimming pool than you were in the water

(b) When walking up a mountain in the rain wearing a waterproof, you get bathed in sweat but still feel too hot.

Suggested Answers to Activities

Activity 2

(a) Respiration. They make the ATP needed for active transport at A.

(b) Active transport. The glucose in the blood is more concentrated than in the cell, so it must be pumped against a concentration gradient using energy (see Lesson 2).

(c) Diffusion. The glucose inside the tubule is at a higher concentration in the cell, *because* the cell is pumping glucose by active transport into the blood. Diffusion occurs down a concentration gradient (see Lesson 2 again).

(d) It increases its surface area, so diffusion is faster.

Activity 4

(a) Enter

- * drinking any liquid
- eating most foods (most foods contain some water)

(b) Leave

- * urine
- faeces
- sweat
- breathing
- occasionally through cuts, nasal discharge, vomiting etc.

Suggested Answers to Self-Assessment Test

(1) (a) B Bowman's capsule

C collecting duct

(b) a (kidney) tubule

(c) A blood

B glomerular filtrate

C urine

d) (i) In winter, less water is lost in sweat

(ii) Water is lost during breathing. They breathe harder to get in the extra oxygen needed for respiration to run. This causes more water loss than sweating, especially in cold weather.

(2) (a) Water evaporates into the air, taking heat from your skin – especially if it is windy!

(b) Walking uphill generates a lot of extra heat from respiration in the leg muscles. You sweat to try to lose the extra heat. Unfortunately the sweat cannot evaporate, because of the waterproof layer, so you just get hotter. That makes you sweat even more.