The big picture

? Guiding question(s)

- How are constant internal conditions maintained in humans?
- What are the benefits to organisms of maintaining constant internal conditions?

Keep the guiding questions in mind as you learn the science in this subtopic. You will be ready to answer them at the end of this subtopic. The guiding questions require you to pull together your knowledge and skills from different sections, to see the bigger picture and to build your conceptual understanding.

Sweat is produced by sweat glands in the skin and is released onto the surface of the skin (**Figure 1**). Anhidrosis is a condition that affects the body's ability to produce sweat. People with anhidrosis cannot produce sweat.

Overview (/study/ap 422- cid- 755105/o

Figure 1. Sweat on the skin.

Credit: Ada Summer, Getty Images

When we exercise or spend time in a hot environment, our sweat glands start producing sweat to counteract the effect of the rise in body temperature. The sweat evaporates from our skin and cools us down. However, individuals with anhidrosis may face some challenges, especially during physical activity or in hot environments. In severe cases, medication or other treatments can be necessary to stimulate sweat production.

Why do you think the deficit of sweat production is a challenging medical condition? How might not sweating impact the quality of life of a person and overall health?

Prior learning

Before you study this subtopic make sure that you understand the following:

- The process of diffusion (see section B2.1.1—3 (/study/app/bio/sid-422-cid-755105/book/lipid-bilayers-id-44634/)).
- The process of osmosis and the role of aquaporins (see section B2.1.4—5 (/study/app/bio/sid-422-cid-755105/book/membrane-proteins-and-their-functions-id-44638/)).
- The effects of pH and temperature on protein structure (see section B1.2.4—5 (/study/app/bio/sid-422-cid-755105/book/protein-structure-id-45487/)).

Student view

Homeostasis and negative feedback

Learning outcomes

By the end of this section you should be able to:

- Define the concept of homeostasis in relation to specific examples of variables.
- Explain the role of negative feedback mechanisms in maintaining homeostasis.

For most of the year, ice-bathing is part of some Nordic people's morning routine (**Figure 1**). Having an ice bath involves immersing your body in extremely cold conditions, probably close to 2–5 °C, or even closer to zero. Usually, your body functions in a fairly limited temperature range around 37 °C. But what is your core body temperature in an ice bath?

Figure 1. Ice-bathing is part of a daily routine for some people.

Credit: Paolo Graziosi, Getty Images

There are many factors that contribute to an organism's metabolism. These factors are constantly changing in both the internal and external environments of organisms. Organisms have developed mechanisms to maintain a relatively constant internal environment to balance

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these changes. The process of these mechanisms is known as homeostasis. Homeostatic mechanisms aim to keep the variables of the body within preset limits, despite fluctuations in the environment.

Examples of internal conditions that are monitored and maintained in humans include body temperature, blood pH, blood glucose concentration and blood osmotic concentration (see **Table 1** for typical values).

Table 1. Typical values for internal conditions inside the human body.

Internal conditions	Typical value or range
Body temperature	37°C
Blood pH	7.4
Blood glucose concentration	70—100 mg/100 mL
Blood osmotic concentration	290—300 mOsm/L

Feedback mechanisms

Organisms continuously monitor the values of variables in their body. Any move outside of the preset range of any variable triggers homeostatic mechanisms. These mechanisms work against the change of the variable in order to keep it within the range.

When a change occurs, systems may produce a response to or against this change. A response by the system to influence the activity of the same system is called feedback. If feedback supports the change, it is called positive feedback. If feedback opposes a change, it is called negative feedback (**Figure 2**).

See section C2.1.14 (/study/app/bio/sid-422-cid-755105/book/regulation-of-cell-signalling-pathways-by-positive-and-negative-feedback-hl-id-46250/) for feedback mechanisms in signalling pathways.

Study skills

The word ‘negative’ implies the feedback has a counteracting effect, whereas ‘positive’ implies a strengthening effect.

Student view

Overview (/study/ap 422-cid-755105/o

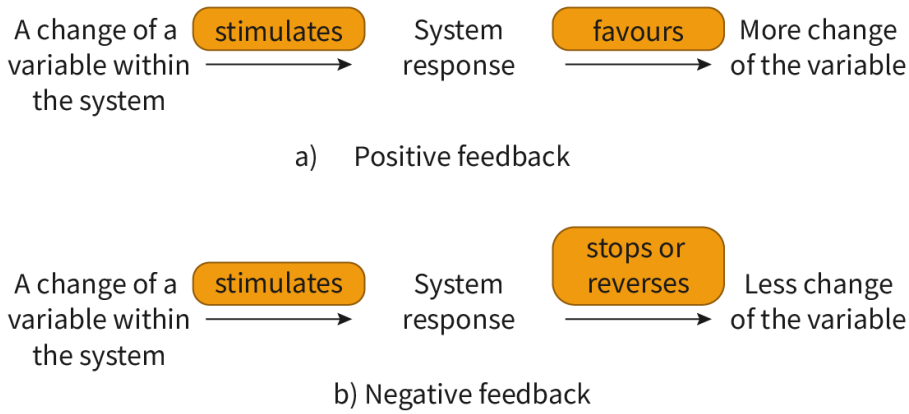


Figure 2. Positive (a) and negative (b) feedback.

More information for figure 2

The process of childbirth is an example of positive feedback.

- As the pregnancy approaches the end, the growing foetus's head applies pressure against the cervix.
- The increased pressure stretches the cervix wall and stimulates the nerves. These nerves inform the hypothalamus, which stimulates the pituitary gland.
- The pituitary gland releases the hormone oxytocin.
- Oxytocin travels to the uterus and stimulates it to contract.
- The contraction of the uterus pushes the foetus to the cervix, which causes more pressure on the cervix wall.
- This pressure causes the nerves to stimulate the pituitary gland to release more oxytocin.

Regulation via negative feedback plays a major role in homeostasis. For instance:

- When you exercise, the metabolic activity in your muscles increases.
- As a result, your body temperature begins to rise.
- In response to this rise, your body activates cooling mechanisms (negative feedback).
- The body temperature decreases to within the normal range.

If the body is unable to counteract the rise of temperature properly, this can be life-threatening.

Another example occurs when you eat a meal that is high in carbohydrates:

- Your blood sugar levels begin to rise.

Student view

Overview (/study/ap 422- cid- 755105/o

- In response, your body activates mechanisms to decrease sugar levels in the blood (negative feedback).
- Your blood sugar levels begin to decrease.

If the body is unable to decrease its blood sugar levels properly, this can lead to conditions such as diabetes.

These are just two examples of how negative feedback responses support homeostasis to maintain optimal conditions. Try the activity below to categorise feedback mechanisms according to whether they are positive or negative.

Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Thinking skills — Applying key ideas and facts in new contexts
- **Time required to complete activity:** 10 minutes
- **Activity type**: Individual activity

Below are several examples of feedback loops. For each example, state whether it describes positive or negative feedback.

- When body temperature rises, the body releases sweat, then the body temperature falls.
- A ripening apple releases ethylene, which promotes ripening and the further release of ethylene.
- When blood pressure is too low, the brain stimulates the heart to increase the heart rate, which increases the blood pressure.
- Less precipitation over time decreases the number of trees in an ecosystem. Wind causes the open soil to erode. Erosion promotes more tree loss, which causes less precipitation.
- Blood glucose level decreases several hours after a meal. The decreased blood glucose level stimulates the pancreas to release glucagon, which stimulates the liver to release glucose into blood. The blood glucose level increases.

6 section questions

Student view

Overview (/study/ap 422-cid-755105/o

Regulation of blood glucose

D3.3.3: Regulation of blood glucose D3.3.4: Physiological changes of type 1 and type 2 diabetes

Learning outcomes

By the end of this section you should be able to:

- Outline the role of pancreatic hormones in regulating blood glucose.
- Outline the role of negative feedback mechanisms in regulating blood glucose.
- Describe the physiological changes that form the basis of type 1 and type 2 diabetes.

The cells in the body use glucose as an immediate energy source during respiration. To keep running smoothly, the body needs a continuous supply of glucose. As cells are continuously absorbing glucose from the blood, the body needs to maintain a blood glucose level of 70–100 mg/dL, which increases during exercise or stress.

While supplying glucose to our cells is crucial for maintaining normal body functioning, it is also important to prevent our blood sugar levels from dropping too low (hypoglycaemia) or rising too high (hyperglycaemia).

To maintain optimal blood glucose levels, the body uses a system of hormonal and metabolic mechanisms that work together to regulate blood glucose.

Hormones secreted by the pancreas

The pancreas is an organ located behind the stomach, on the left of the abdomen (**Figure 1**).

Student view

Overview (/study/ap 422- cid- 755105/o

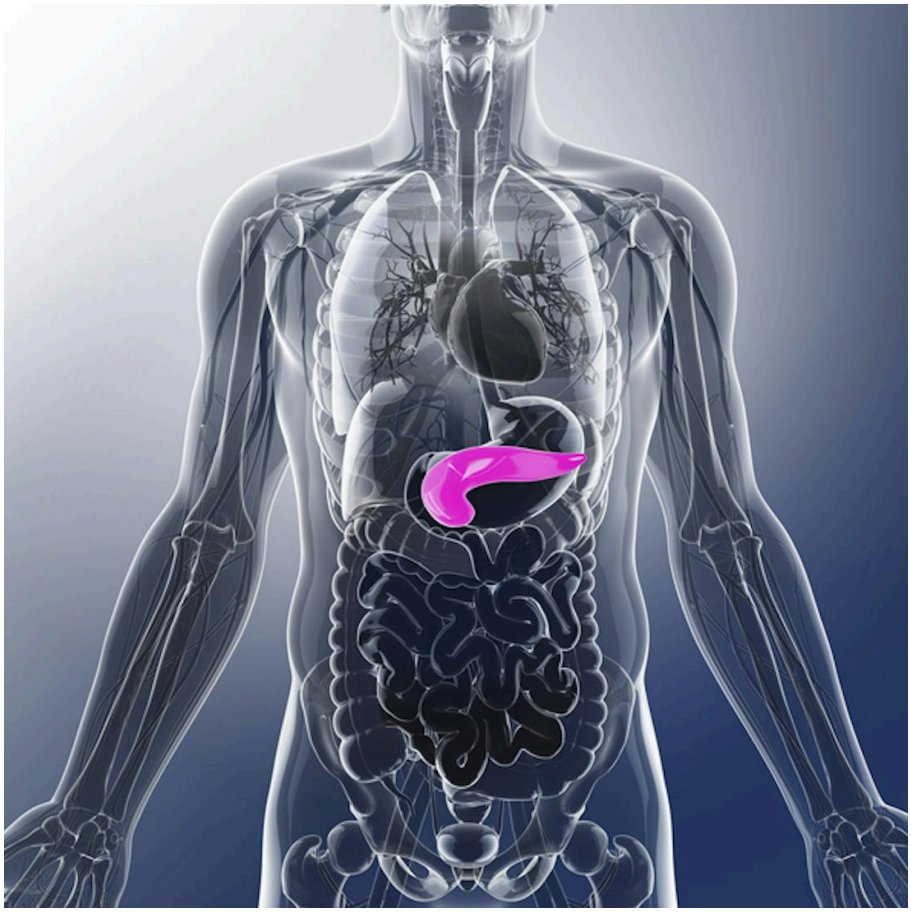


Figure 1. Location of the pancreas.

Credit: PIXOLOGICSTUDIO, Getty Images

The exocrine tissue of the pancreas produces enzymes for digestion, while the endocrine tissue produces two of the human body's most important hormones

The pancreatic endocrine cells are called islets of Langerhans or pancreatic islets (**Figure 2**).

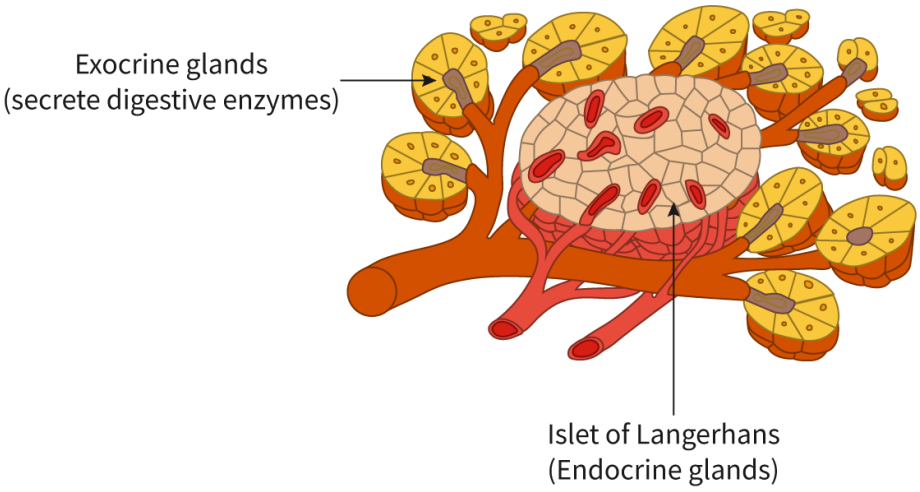


Figure 2. The islets of Langerhans.

Student view

Two hormones, insulin and glucagon, are produced by the islets of Langerhans and are responsible for maintaining and controlling blood glucose concentrations:

- Insulin is produced and secreted by the beta cells of the islets of Langerhans in response to **rising** blood glucose levels. It stimulates glucose uptake from the blood into the cells.
- Glucagon is produced and secreted by the alpha cells of the islets of Langerhans in response to **decreasing** glucose levels. It stimulates the liver to release stored glucose into the bloodstream.

Regulation of blood glucose

The relationship between the pancreas and blood glucose levels is an important example of homeostasis using negative feedback. The opposing actions of glucagon and insulin keep the blood glucose level fluctuating within a range (**Table 1**).

If the blood glucose level rises **above** the normal range:

- Beta cells of the islets of Langerhans release insulin into the bloodstream.
- Insulin promotes (mainly) cells of the liver, muscles and fat tissue to take up glucose from the blood to decrease the blood glucose level. The glucose is stored as glycogen in the cells of muscle and liver, or as fat in the cells of fat tissue, for later use.
- As the blood glucose levels decrease, the secretion of insulin also decreases.

If the blood glucose level falls **below** the normal range:

- Alpha cells of the islets of Langerhans release glucagon into the bloodstream.
- Glucagon promotes (mainly) the cells of liver and fat tissue to break down glycogen and lipids and release the glucose into the blood until the level of blood glucose increases to the normal range.
- As the blood glucose levels increase, the secretion of glucagon also decreases.

Table 1. Features of insulin and glucagon.

Feature	Insulin	Glucagon
Produced and secreted by	Beta cells	Alpha cells

Overview (/study/ap 422-cid-755105/o

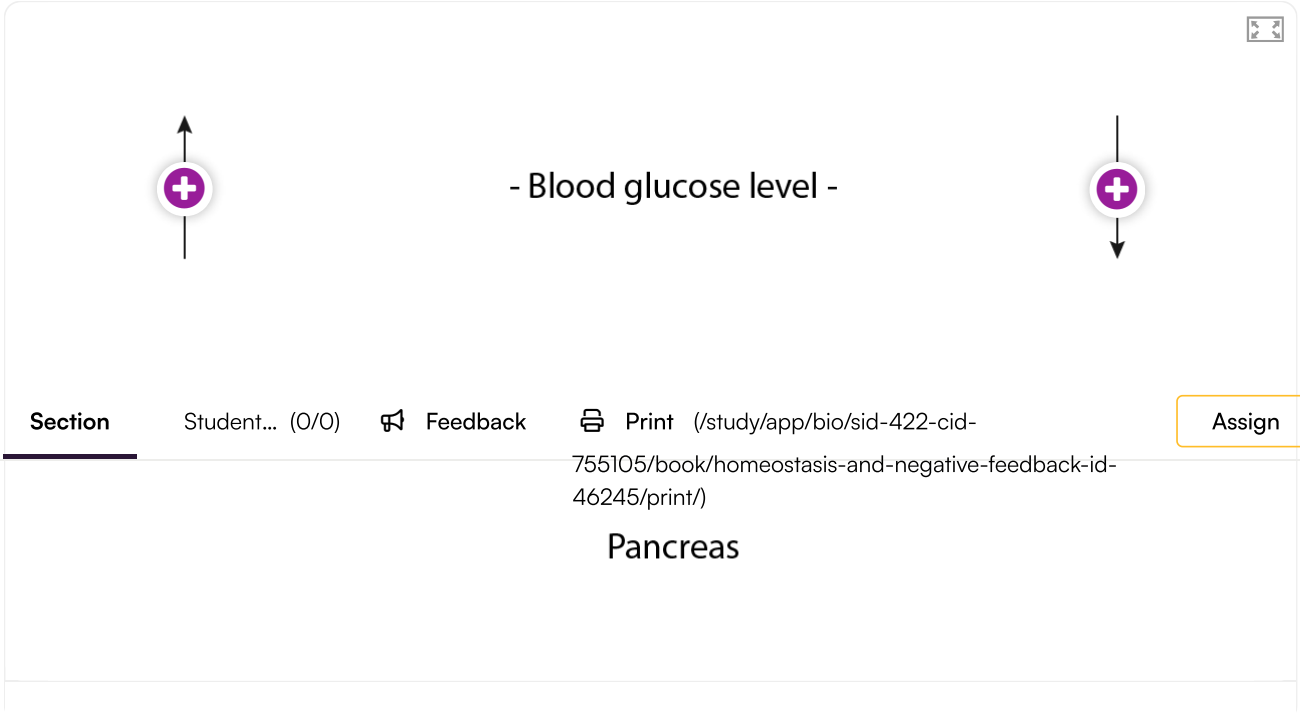
Feature	Insulin	Glucagon
Secreted when	Blood glucose level increases	Blood glucose level decreases
Target	Body cells, mainly muscle and liver	Body cells, mainly liver
Stimulates	Transport of glucose from the bloodstream into the stores	Transport of glucose from stores to bloodstream
Effect	Decreases the blood glucose level	Increases the blood glucose level

Study skills

You need to recall that:

- Insulin stimulates muscle tissue to store glucose as glycogen, when blood glucose is higher than normal.
- Since there are no known glucagon receptors on skeletal muscle, glucagon does not stimulate muscle tissue to hydrolyse the glycogen stored, when blood glucose is lower than normal.

View **Interactive 1** to see how blood glucose levels are controlled by hormones of the pancreas.



Interactive 1. Secretion of Insulin and Glucagon by Pancreas.

More information for interactive 1

Student view

Overview (/study/ap 422-cid-755105/o

Diabetes

Insulin promotes the movement of glucose from blood to cells. Insufficient insulin production or ineffective use of insulin will result in high levels of blood glucose. Continued high blood glucose concentration is called hyperglycaemia. The hormonal disorder that causes hyperglycaemia is called diabetes.

In individuals with diabetes, the cells cannot obtain enough glucose from the blood. Cells start to burn the body's supply of fats and proteins. Since the digestive system continues to absorb glucose, the glucose concentration in the blood can become extremely high.

The kidneys start filtering excess glucose from the blood. Kidneys also draw water from blood to dilute the urine which causes dehydration of the body. The person becomes unusually and continually thirsty. Thus, two early signs of diabetes are excessive urination (with sugar) and excessive thirst.

Continued presence of high glucose in blood damages cells and their processes. Hyperglycaemia due to untreated diabetes can cause dehydration, blindness, cardiovascular and kidney disease and nerve damage.

There are two types of diabetes with different mechanisms.

Type 1: Insulin-dependent or early onset diabetes

In some individuals the immune system mistakenly attacks and destroys the beta cells in the pancreas. As a result, individuals with this autoimmune disorder are unable to produce insulin. Insufficient insulin production leads to chronically elevated levels of glucose in the bloodstream – hyperglycaemia.

Although it can occur at any age, type 1 diabetes is typically diagnosed in childhood or adolescence, so it is sometimes called early onset diabetes. There is no known cure for type 1 diabetes, and individuals with the condition must manage their blood glucose levels through a combination of insulin therapy, dietary modifications and regular exercise.

Type 2: Insulin-independent or late-onset diabetes

In some individuals, although insulin is produced and secreted into the blood, cells are insensitive to insulin and they are said to be 'insulin resistant'. In response to reduced sensitivity to insulin, pancreatic beta cells start to produce more insulin and become exhausted.

Student view

Overview (/study/ap 422-cid-755105/o

Most of the time, type 2 diabetes can be reversed by moderate weight loss, regular physical activity and a healthy diet.

Risk factors

Several risk factors contribute to the development of diabetes:

- **Family history:** Having a family history of diabetes increases the risk of developing the condition. If a close family member, such as a parent or sibling, has diabetes, the risk is higher.
- **Body weight:** Being overweight or obese is a significant risk factor for developing type 2 diabetes. Excess body weight increases insulin resistance and impairs glucose metabolism. Adopting and maintaining a healthy weight through a balanced diet and regular physical activity is one of the most effective ways to prevent type 2 diabetes. Losing even a small amount of weight (around 5–7% of body weight) can significantly reduce the risk.
- **Lifestyle:** Lack of physical activity or a sedentary lifestyle is linked to an increased risk of type 2 diabetes. Regular exercise helps maintain a healthy weight, improves insulin sensitivity and reduces the risk of developing diabetes.
- **Diet:** Consuming a diet high in processed foods, sugary beverages and unhealthy fats increases the risk of developing type 2 diabetes. A diet low in fruits, vegetables and whole grains contributes to weight gain and insulin resistance.
- **Age:** The risk of developing diabetes increases with age. Type 2 diabetes is more common in adults over the age of 45, although it is increasingly being diagnosed in younger individuals as well.

Nature of Science

Aspect: Science as a shared endeavour

Glucose sensors are scientific inventions that use technology to detect the presence and concentration of glucose in a sample. This is important for people with diabetes, who need to monitor their blood glucose levels to manage their condition.

The development of glucose sensors involved a combination of scientific principles and methods, including chemistry, engineering, and biology. Scientists used their knowledge of the properties of glucose and the reactions that occur when glucose interacts with certain chemicals to design sensors that could detect glucose in biological samples. These scientists worked together to design and test the sensors, share their findings and collaborate to make improvements.

Student view

Overview (/study/ap 422- cid- 755105/o

Creativity, activity, service

Strand: Activity and Service
Learning outcome: Demonstrate how to initiate and plan a CAS experience

Get Active, Be Aware!

Physical activity has many positive contributions to your health. It can:

- help control blood sugar levels
- support the maintenace of a healthy weight
- keep your mood up
- help you sleep better.

Being physically active also is very beneficial against diabetes.

To start a physical activity programme and include it in your weekly calendar, begin researching the activity types and requirements for each type of activity. Define your goals and include the activity in your calendar.

By preparing brochures, meetings, a website or a social media account, you can make it a collaborative activity and raise awareness about diabetes and the benefits of being active.

You can make this planning a group work and start a school-wide CAS project: Gather your team and plan the details. You may get help from your physical education teachers. You could organise a community event to raise awareness and funds for diabetes and diabetes research. Perhaps organise a run or another physical activity to get people moving.

Try the activity below to record your family's weekly sugar intake.

Activity

- **IB learner profile attribute:** Communicator
- **Approaches to learning:** Communication skills — Presenting data appropriately, Delivering constructive criticism appropriately
- **Time required to complete activity:** 20 minutes
- **Activity type:** Individual activity

Student view

Overview (/study/ap 422-cid-755105/o

Most of the foods we consume include carbohydrates, but since they are not visible, most of us are not aware of how much sugar we consume daily. One effective way of helping people to make healthy choices is by making the sugar content of foods visible.

Explain to your family members about blood glucose levels and why being aware of sugar consumption is important.

- Ask them whether they know the amount of sugar they consume per week (in cubes of sugar), and if yes, record their answers (in cubes of sugar).
- For the most popular canned drink consumed in your home, determine the amount of sugar, using the nutritional information label on the packaging — look for the 'carbohydrates' listing. Choose a different sweet treat if it is more popular in your household.
- Convert grams into cubes of sugar. Approximately 4 grams of sugar is equal to 1 cube of sugar.
- Record the number of cans consumed by each family member in a week.
- Calculate the weekly sugar consumption (from the favourite canned drink) of each family member.
- Draw a bar graph of sugar levels for each family member.

Theory of Knowledge

Instead of talking in grams of sugar, cubes of sugar can be used as a visual tool to represent the amount of sugar consumed.

Discuss, while sharing scientific knowledge, why the construction and use of visual models, and other representations, can be a better way to communicate with people.

5 section questions

D3. Continuity and change: Organisms / D3.3 Homeostasis

Thermoregulation

D3.3.5: Thermoregulation as an example of negative feedback control D3.3.6: Thermoregulation mechanisms in humans

Student view

Learning outcomes

By the end of this section you should be able to:

Overview (/study/ap 422-cid-755105/o

- Describe the roles of thermoreceptors and the hypothalamus in regulating body temperature.
- Outline the mechanisms in regulating human body temperature.

Birds and mammals regulate their body temperatures. Birds keep their body temperature between 39 °C and 42 °C, and mammals keep it between 36 °C and 39 °C. Thermoregulation is an example of negative feedback supported by several physiological and behavioural mechanisms.

Thermoregulation is coordinated by the nervous system. The processes of temperature control are centred in the hypothalamus of the advanced animal brain. The hypothalamus is a small, almond-sized region located at the base of the brain, just above the brainstem. It is a crucial part of the central nervous system and plays a vital role in maintaining homeostasis and regulating various physiological processes in the body.

The pituitary gland is a pea-sized gland located at the base of the brain, just below the hypothalamus. The hypothalamus and the pituitary gland work together to regulate the production and release of hormones throughout the body. The hypothalamus acts as a control centre, while the pituitary gland acts as a major endocrine gland that releases hormones into the bloodstream.

Using specialised nerve cells called thermoreceptors, birds and mammals are able to detect differences in temperature. Thermoreceptors are dispersed throughout the body. The thermoreceptors in the skin are called **peripheral** thermoreceptors. Thermoreceptors inside the body are **central** thermoreceptors.

Mechanisms of thermoregulation

The hypothalamus integrates signals from the peripheral and central thermoreceptors and initiates physiological and behavioural responses as a negative feedback mechanism to regulate body temperature.

In cooler environments, your body starts losing heat. The peripheral thermoreceptors stimulate the hypothalamus to increase the metabolic rate to produce more heat.

- The hypothalamus stimulates the pituitary gland.
- The pituitary gland releases thyroid stimulating hormone (TSH) to stimulate the thyroid gland.

Student view

Overview (/study/ap 422- cid- 755105/o

- The thyroid gland produces a hormone called thyroxine. The primary role of thyroxine is to increase the metabolic rate of body cells, which will result in more heat.
- The production of TSH is an example of a negative feedback loop. The release of TSH is decreased and stopped if the levels of thyroxine produced are very high.
- When the body temperature increases, signals from peripheral and central thermoreceptors stop the pituitary from producing TSH.

Making connections

Refer to subtopics C1.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43208/) and C1.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43538/) to review how energy is released in the form of heat to increase body temperature.

International Mindedness

A pinch of iodine

Thyroxine was isolated in 1915. Before that, an extract from sheep thyroids was used to treat some patients with a swollen neck.

Hypothyroidism is a chronic disease as a result of deficiency in the thyroid hormone thyroxine. When the thyroid produces less thyroxine than required, it tries to replace the shortfall by physically growing. People with an enlarged thyroid have a swollen neck.

In ancient times, people with a swollen neck were often associated with supernatural or divine forces. For example, in ancient Greece, hypothyroidism was believed to be caused by the wrath of the gods, and treatments involved offerings to the gods and other superstitious practices. In medieval Europe, it was sometimes associated with witchcraft, and patients were often accused of being witches or demonically possessed.

Worldwide, iodine deficiency in nutrition is the most common cause of hypothyroidism. In developed countries there are initiatives to increase iodine intake with iodised salt programmes and fortification of foods with iodine; however, in developing parts of the world, the main cause of hypothyroidism is not getting enough iodine from food.

Thermoregulation in humans

Student view

Mammals, including humans, can regulate their body temperature by the following mechanisms:

Overview (/study/ap 422-cid-755105/o

- In cold conditions, skeletal muscles undergo repeated involuntary contractions, called shivering, which generates heat to raise the body temperature.
- When it's cold, muscles in the skin contract to make the hairs on the skin stand up, trapping heat in the layer of air between the skin and the hair. This increases the insulating effect of body hair.
- When it gets warm, the hairs on the skin lie flat.
- When the body produces heat, the glands in the skin secrete sweat. When water in sweat evaporates, it carries heat out of the body, in a mechanism called evaporative cooling. See section A1.1.6 (/study/app/bio/sid-422-cid-755105/book/living-things-and-water-id-43196/) to learn about the properties of water, including specific heat capacity.
- The circulatory system also plays a role in maintaining body temperature. The smooth muscles of the arteries can adjust the diameter of arteries to help the body retain or lose heat.
    - The widening or vasodilation of the blood vessels close to the skin brings more blood to the surface of the body. Blood carries heat to the body surface to increase heat loss via convection and conduction.
    - The narrowing of blood vessels, vasoconstriction, reduces blood flow in peripheral blood vessels, keeping blood close to the core and vital organs, conserving heat (**Figure 1**).

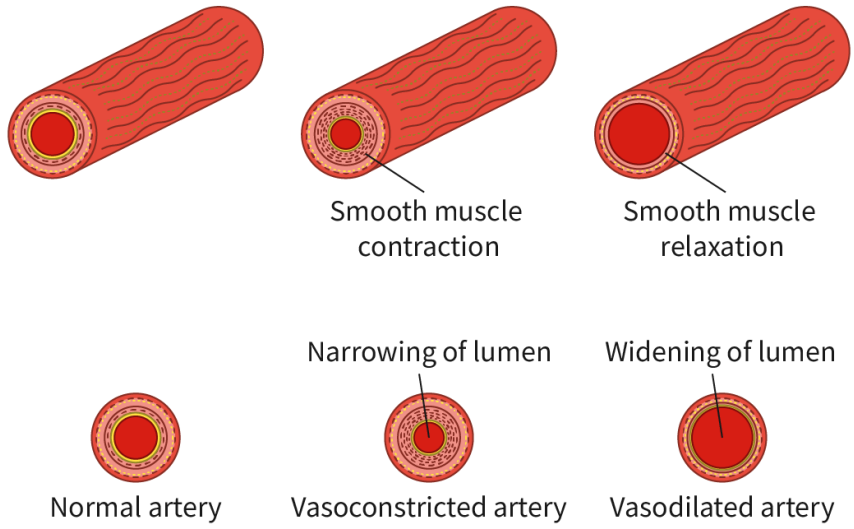


Figure 1. Three states of an artery: normal, vasoconstricted and vasodilated.

More information for figure 1

- Fat-storing adipose tissue also contributes to thermoregulation. Brown adipose tissue cells are full of mitochondria.
    - Normally, during aerobic respiration in mitochondria, monomers are broken down, and these energy-producing reactions are coupled with ATP production.

Student view

Overview (/study/ap 422-cid-755105/o

- However, the mitochondria in brown adipose tissue cells can release energy without producing ATP, to increase body heat when it is cold outside. This process is called uncoupled respiration (see section C1.2.4–6 (/study/app/bio/sid-422-cid-755105/book/understanding-cell-respiration-id-45980/) for more information on cell respiration).

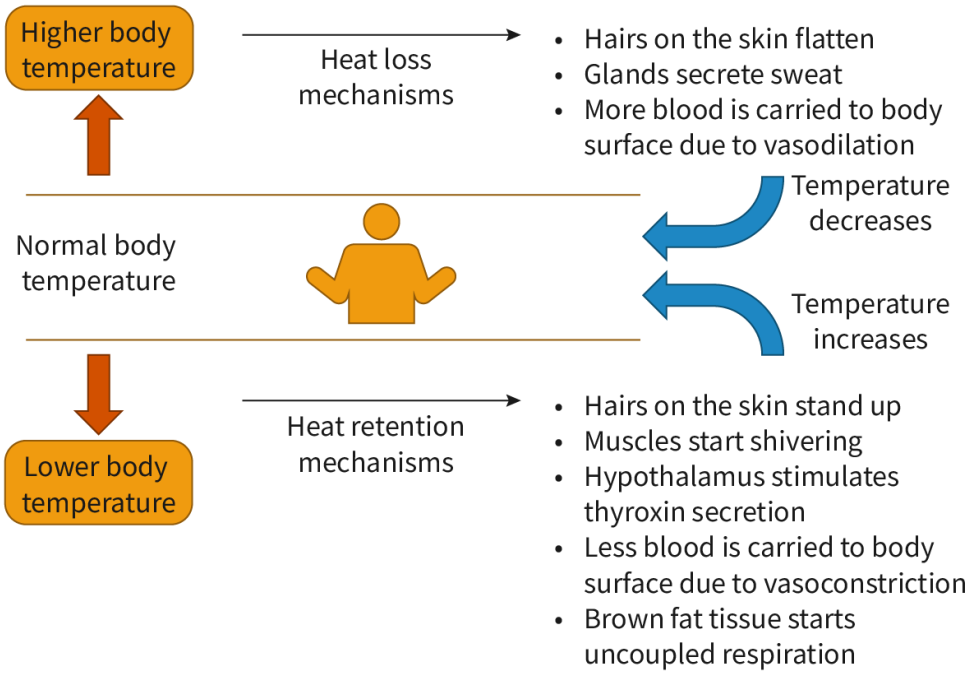


Figure 2. Mechanisms of human body temperature regulation.

More information for figure 2

Try the activity below to analyse data on body temperature.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Thinking skills — Providing a reasoned argument to support conclusions
- **Time required to complete activity:** 15 minutes
- **Activity type:** Individual activity

According to several studies, the mean adult body temperature is 36.5 °C. This value changes based on age, physical activity and health. Body temperature also changes throughout the day based on the time, food or fluid consumed.

A temperature of above 38 °C is accepted as fever.

Student view

Overview (/study/ap 422-cid-755105/o

Table 1 charts a person's mean body temperature recorded over 24 hours.

Table 1. Mean body temperature over 24 hours.

Time of the day	Temperature (°C)	Time of the day	Temperature (°C)
12:00 AM	36.04	12:00 PM	36.60
01:00 AM	36.37	01:00 PM	36.75
02:00 AM	36.36	02:00 PM	36.78
03:00 AM	36.40	03:00 PM	37.53
04:00 AM	36.32	04:00 PM	37.34
05:00 AM	36.30	05:00 PM	37.37
06:00 AM	36.04	06:00 PM	37.87
07:00 AM	36.18	07:00 PM	37.21
08:00 AM	36.36	08:00 PM	37.18
09:00 AM	36.35	09:00 PM	37.91
10:00 AM	36.28	10:00 PM	37.83
11:00 AM	36.44	11:00 PM	37.65

Task

1. Draw an appropriate graph of the data.
2. Describe the trend of the data.
3. Explain how food and fluids taken during the day can affect the mean body temperature.
4. Outline how and why 'mean body temperature' is calculated.

5 section questions

Student view

Excretion (HL)

Overview (/study/ap 422-cid-755105/o

D3.3.7: Role of the kidney in osmoregulation and excretion (HL)

D3.3.8: The glomerulus, Bowman's capsule and proximal convoluted tubule (HL)

Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Define osmoregulation and excretion.
- Explain the roles of the glomerulus, Bowman's capsule and proximal convoluted tubule in excretion.

As a universal solvent, water plays an essential role in the composition of the internal body fluids, as it is required for maintaining an appropriate environment for metabolic reactions (see subtopic A1.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43193/)). Water moves constantly in and out of the body through metabolism, evaporation, sweating, reabsorption and elimination through the urinary and digestive systems. How is this loss and gain balance maintained?

Regulation of water and solute concentrations of body fluids is called osmoregulation. The concentration of solute particles per unit volume of a solution – osmotic concentration – is usually expressed as osmoles per litre (osmolar, Osm/L) or milliosmoles per litre (millosmolar, mOsm/L).

Osmoregulation involves creating an equilibrium between water loss and gain in the body. The osmoregulatory organs of mammals are kidneys.

Kidneys are complex organs that perform multiple functions. The functions of the kidney include:

- regulation of water and ion balance (osmoregulation)
- removal of toxins and metabolic waste products (excretion)
- production of hormones, and control of blood pressure.

The kidneys are a pair of organs that are located on either side of the body cavity. Each of the kidneys contains more than a million functional units called nephrons. Nephrons are the main units that filter blood (**Figure 1)**.

Student view

Overview (/study/ap 422-cid-755105/o

Blood enters the kidney via the renal artery. Each artery forms smaller arterioles which connect to capillaries.

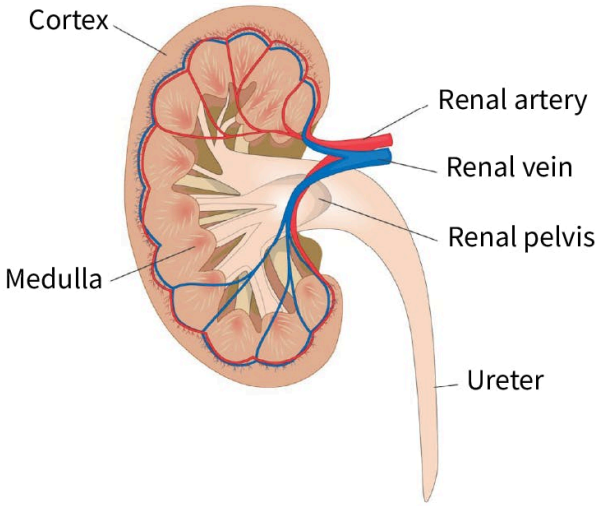


Figure 1. Structure of the kidney.

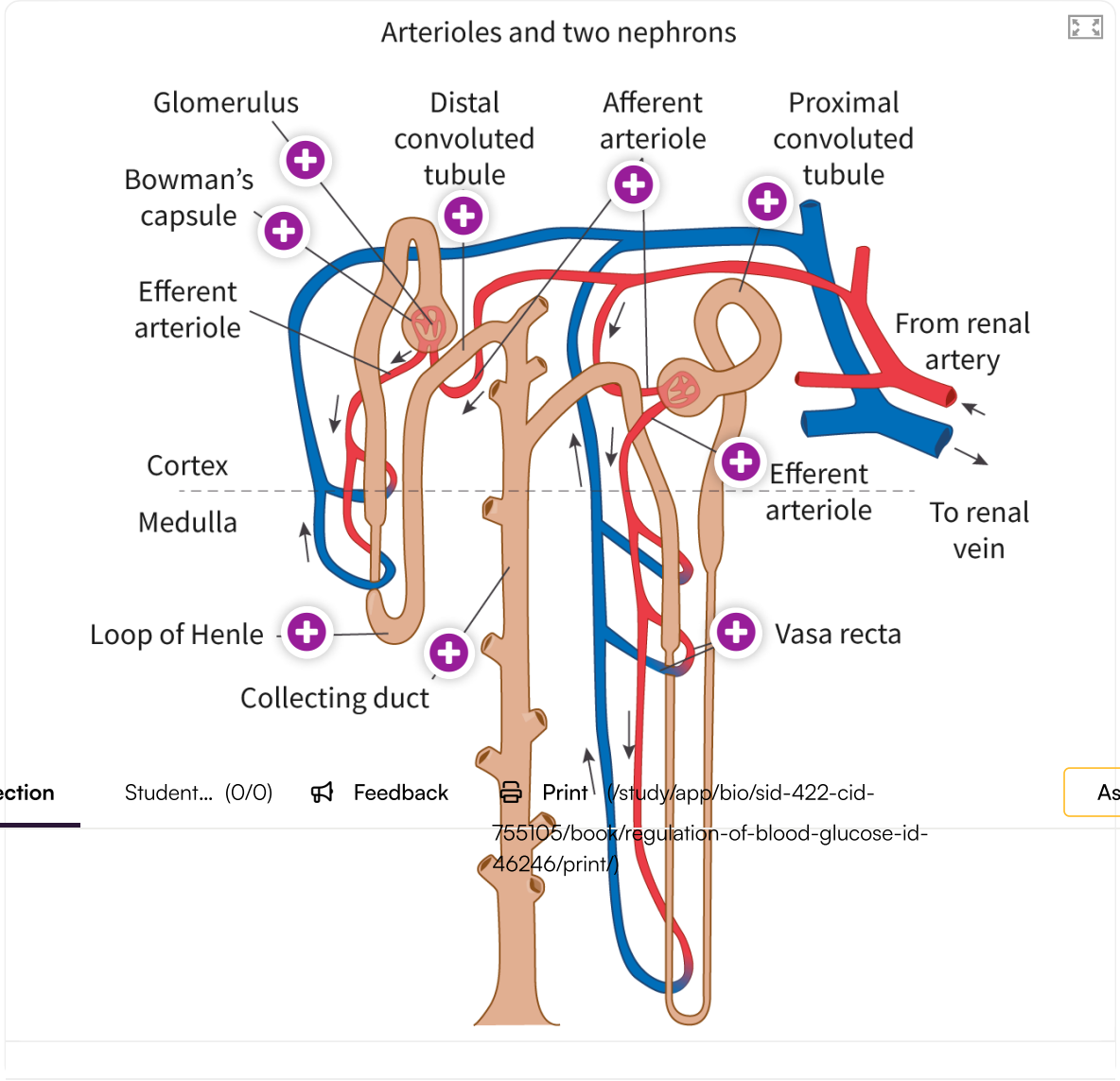
More information for figure 1

The nephron

The nephron is the basic functional unit of the kidney. The nephron is a long tube which starts at the Bowman's capsule and ends at the collecting duct, which drains into the renal pelvis. **Interactive 1** shows a nephron and the intertwining arterioles. Click on the hotspots to find out the function of each feature.

Student view

Overview (/study/ap 422-cid-755105/o



Interactive 1. Structure and Functions of the Nephron.

More information for interactive 1

Nephrons have three main functions:

- ultrafiltration
- reabsorption
- secretion.

Within the nephron, water and many solutes present in the blood leave the capillaries and enter the Bowman's capsule. The filtrate contains monomers (such as amino acids, glucose, vitamins), ions (such as sodium, calcium, chloride) and waste (such as urea).

As the filtrate moves through the tubules of the nephron, useful organic solutes are absorbed back into the capillaries. At this stage:

- nephrons absorb back most of the water and ions to regulate the water and ion balance of the blood (osmoregulation)

Student view

Overview (/study/ap 422-cid-755105/o

- waste is left in the tubule and collected in the bladder. The combination of waste and water is called urine (excretion).

Ultrafiltration

The first stage of urine production is ultrafiltration of blood.

The afferent arterioles carry the blood to each nephron. Each arteriole enters into the sac-like structure of the nephron (Bowman's capsule), forms a capillary network in the sac (glomerulus) and blood leaves via the efferent arterioles.

The glomerulus is the filtering unit. The glomerular capillaries sit in the Bowman's capsule. **Figure 2** gives the overall structure of the Bowman's capsule and the glomerulus.

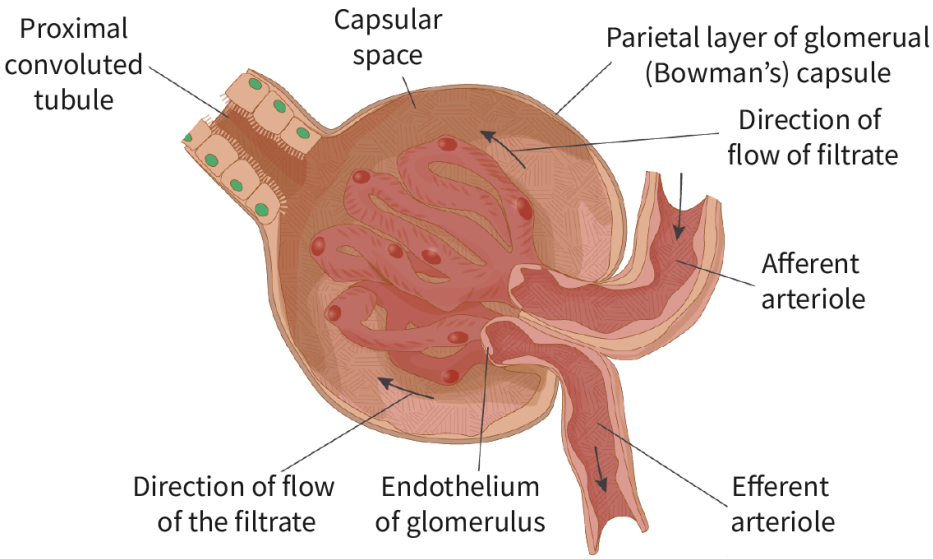


Figure 2. Bowman's capsule and glomerulus.

More information for figure 2

The glomerulus is a knot of intertwined capillaries which is enveloped by podocytes. Podocytes support the capillaries and regulate the filtration process. They are the cells of the inner wall of the Bowman's capsule. Podocytes have many extensions which fold around the blood capillary forming a network of filtration slits that hold back the blood cells during ultrafiltration with the help of the glomerular basement membrane.

Figure 3 shows how the podocytes envelop the capillaries.

Student view

Overview (/study/ap 422- cid- 755105/o

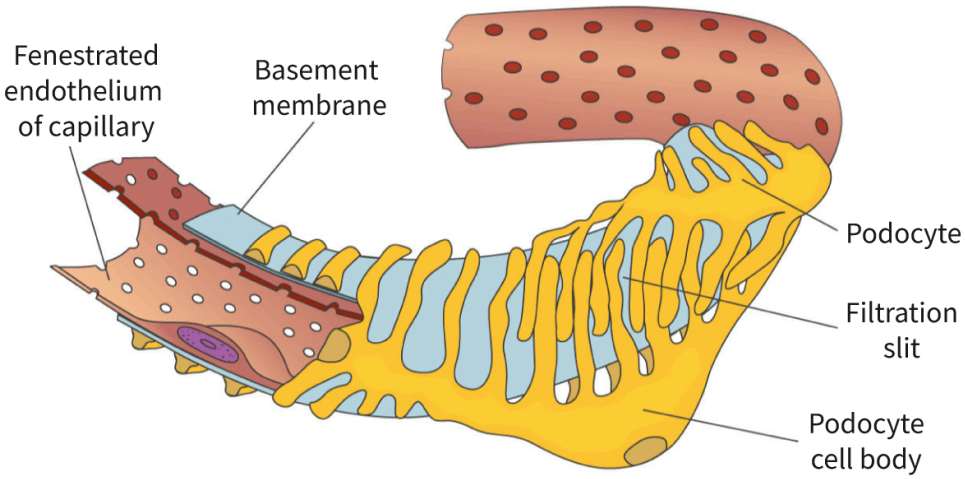


Figure 3. Podocyte and capillary.

More information for figure 3

The capillaries have small window-like openings called fenestrations (see **Figure 3**). Capillaries are also covered on the outside by a layer of extracellular material known as the basement membrane, which is mainly composed of glycoproteins. This is where ultrafiltration takes place; a process that is driven by the high pressure in the capillaries. The fenestrations in the capillary wall allow blood to flow out, however, the basement membrane acts like a sieve during the ultrafiltration process and stops the blood cells and large proteins. Thus, white and red blood cells cannot pass through, but small proteins, salts and nutrients can.

Study skills

The unusually high capillary pressure (that allows ultrafiltration to occur) is the result of the short, large diameter afferent arterioles conveying blood at high arterial pressure directly to the glomerular capillaries. The smaller diameter of the efferent arterioles leaving the glomerulus also helps maintain the pressure by restricting the outflow of blood.

Table 1 shows the composition of the blood that enters the glomerulus and the filtrate that flows, via the Bowman's capsule, into the proximal convoluted tubule.

Section Student (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/thermoregulation-id-46247/print/) Assign

Table 1. Composition of plasma compared to filtrate.

Student view

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Solutes	Plasma	Filtrate
Na^+ ions	151 mol/dL^3	144 mol/dL^3
Cl^- ions	110 mol/dL^3	110 mol/dL^3
Glucose	5 mol/dL^3	5 mol/dL^3
Urea	5 mol/dL^3	5 mol/dL^3
Proteins	750 mol/dL^3	3—4 mol/dL^3

Reabsorption

Connected to the Bowman's capsule is the proximal convoluted tubule. The filtrate passes to the proximal convoluted tubule from the Bowman's capsule.

The cells of the tubule select and absorb substances from the filtrate. These cells absorb back:

- all of the monomers such as glucose and amino acids
- most of the water and ions

from the filtrate to the blood.

The reabsorption of substances from the glomerular filtrate involves the membrane transport mechanisms of diffusion, facilitated diffusion, osmosis and active transport:

- The pumps use ATP for active transport to shuttle Na^+ (out of the tubule) and K^+ (into the tubule). As a result of this the $Cl^-$are attracted to the space outside the tubule because of the positively charged Na^+.
- Glucose and amino acids are absorbed along with Na^+ from the filtrate by specific carrier proteins down their concentration gradient. Since absorption of glucose and amino acids into the proximal convoluted tubule is powered by active transport of Na^+ into blood, it is referred to as secondary active transport.
- The glucose and amino acid concentration within the proximal convoluted tubule cells increases as they are absorbed from the filtrate. This concentration is higher than that of blood plasma, thus both glucose and amino acids are reabsorbed into blood by diffusion. Microvilli in the tubule wall cells greatly increase the surface area, which in turn enhances the diffusion process.

The structure of the proximal convoluted tubule has evolved to maximise reabsorption. **Figure 4** shows the processes that are involved in reabsorption.

Student view

Overview (/study/ap 422- cid- 755105/o

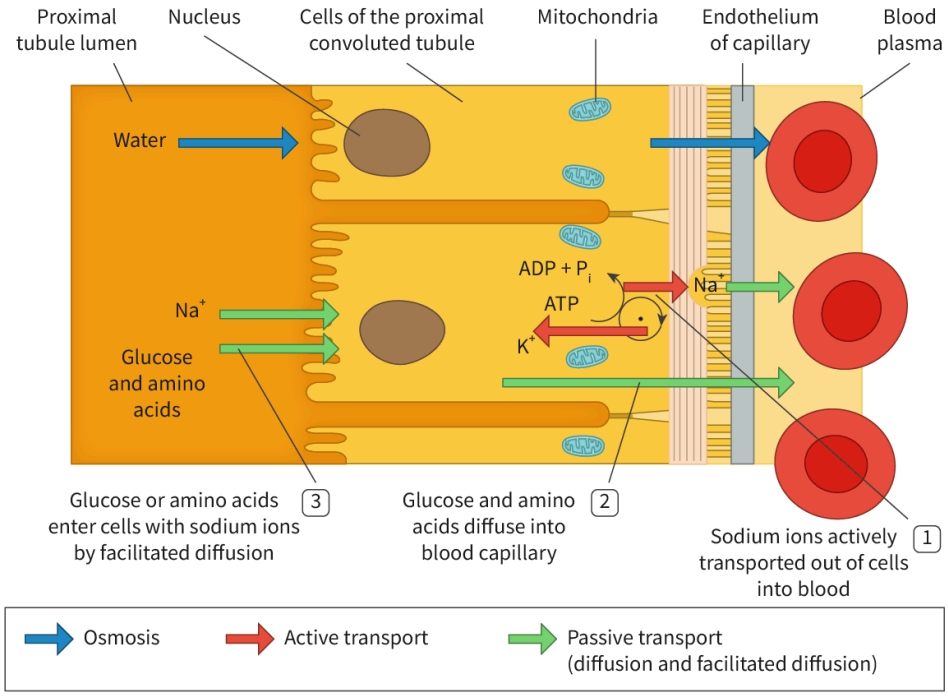

Figure 4. Proximal convoluted tubule and the reabsorption process.

More information for figure 4

See subtopic B2.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43205/) for more on mechanisms of membrane transport.

Nature of Science

Aspect: Observations

Observation is one of the most important aspects of science, because it is the foundation of all scientific knowledge. Most of the time observation involves using our senses but in some cases scientific instruments are required to gather data about the natural world. Accurate observations are essential for producing reliable data. Scientists use a variety of tools and techniques to ensure that their observations are as precise and accurate as possible.

In the mid-20th century, Danish physiologist Hans Ussing developed the technique of micropuncture, which involves inserting a fine glass micropipette into a nephron to collect samples of fluid and measure ion concentrations. This technique allowed researchers to study the function of individual nephrons in vivo and led to many important discoveries about the mechanisms of renal physiology.

Student view

Try the activity below to analyse some data on osmoregulation.

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Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Research skills — Evaluating information sources for accuracy, bias, credibility and relevance
- **Time required to complete activity:** 30 minutes
- **Activity type:** Individual activity

Table 2 shows the mean concentration values of some substances from a male patient.

Table 2. Mean concentrations of substances (mg/100 mL/4500 mL).

Substance	In plasma	In filtrate	
All inorganic ions	0.9	0.9	
Amino acids	0.5	0.5	
Proteins	8.0	0	
Glucose	0.1	0.1	

Task

1. Calculate the percentage change of ions between the filtrate and the urine.
2. Calculate the total amount of glucose in the patient's whole blood.
3. Explain why inorganic ions in the urine are lower than in the filtrate.

Discuss your findings with the class.

5 section questions

D3. Continuity and change: Organisms / D3.3 Homeostasis

Osmoregulation (HL)

Student view

Overview (/study/ap 422-cid-755105/o

D3.3.9: Role of the loop of Henle (HL) D3.3.10: Osmoregulation by water reabsorption (HL)

D3.3.11: Changes to organ blood supply in response to changes in activity (HL)

Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Outline the functions of the loop of Henle and collecting ducts.
- Explain the effect of ADH on the permeability of the kidney tubules.
- Describe examples of changes in blood supply in response to changes in activity.

As a universal solvent, water plays a central role in metabolism. Water makes up most of a cell's content and body fluids; metabolic reactions occur in the water-based fluid of the cellular environment; and proteins make their functional three-dimensional shape through interaction with water.

The amount of water in the body or the cells is continually changing, since water moves in and out of the body with various processes. Thus, it is important that the body's water content is monitored and regulated.

Since water moves from regions with high water potential to regions with lower water potential (osmosis), cells control movement of water and their solute concentrations. The regulation of osmotic concentration of solutes and water is called osmoregulation.

The loop of Henle

The long U-shaped portion of the nephron tubule after the proximal convoluted tubule is called the loop of Henle. The loop of Henle is divided into two sections covered with capillaries (vasa recta), each with its own unique properties and functions:

- the descending limb
- the ascending limb.

While the Bowman's capsule and convoluted tubules lie in the cortex of the kidney, the loops of Henle lie mainly in the medulla. The osmotic concentration of the cortex is around 300 mOsm/L, which is the same as the osmotic concentration of other body

Student view

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tissues. The osmotic concentration of medulla, on the other hand, changes from 300 mOsm/L (near the cortex) to 1200 mOsm/L (in the core of the medulla). The osmotic gradient from cortex to medulla supports the production of concentrated urine.

The descending and ascending limbs of the loop are adapted to recover mainly the remaining sodium ions and water that were not reabsorbed back in the proximal convoluted tubule (**Figure 1**):

- The descending limb does not reabsorb any sodium. On the walls of the descending limb of the loop, there are many aquaporins where water can move from the filtrate to the blood. Water passively moves from the urine into the surrounding fluid. This occurs because the surrounding fluid has a higher solute concentration than the urine in the loop of Henle. As the urine moves further down the descending limb, more and more water is reabsorbed. About 15% of the water from blood is absorbed back here.
- In the ascending limb of the loop of Henle, solutes such as sodium, chloride and potassium are actively transported out of the urine and into the surrounding fluid. As solutes are transported out of the urine and into the fluid, the concentration of solutes in the urine decreases. The ascending limb of the loop of Henle is **impermeable to water** due to the absence of aquaporins.

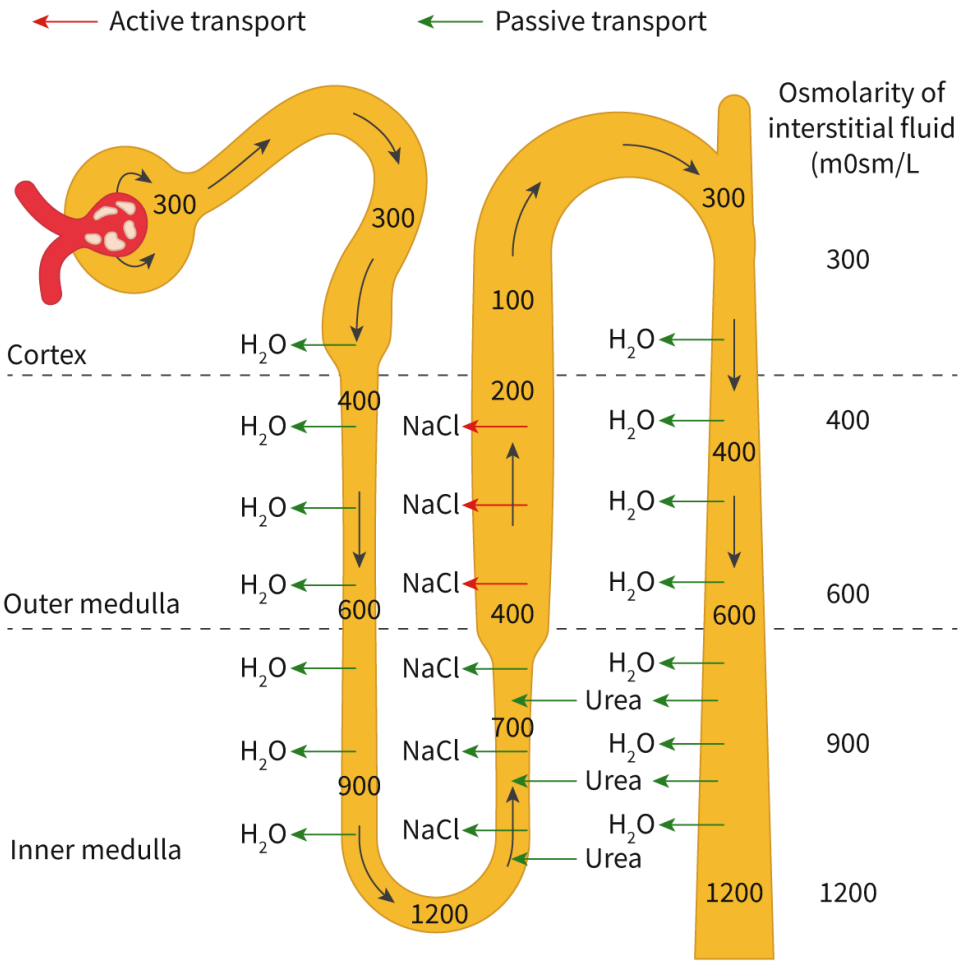

Figure 1. Movement of water and ions in the loop of Henle.

More information for figure 1

Student view

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The collecting duct

The distal convoluted tubule and collecting duct are the final segments of the nephron. The distal convoluted tubule connects the loop of Henle to the collecting duct.

Approximately 80 per cent of filtered water has been reabsorbed before the filtrate enters the distal convoluted tubule. This part of the nephron will reabsorb more water before the filtrate enters the collecting ducts.

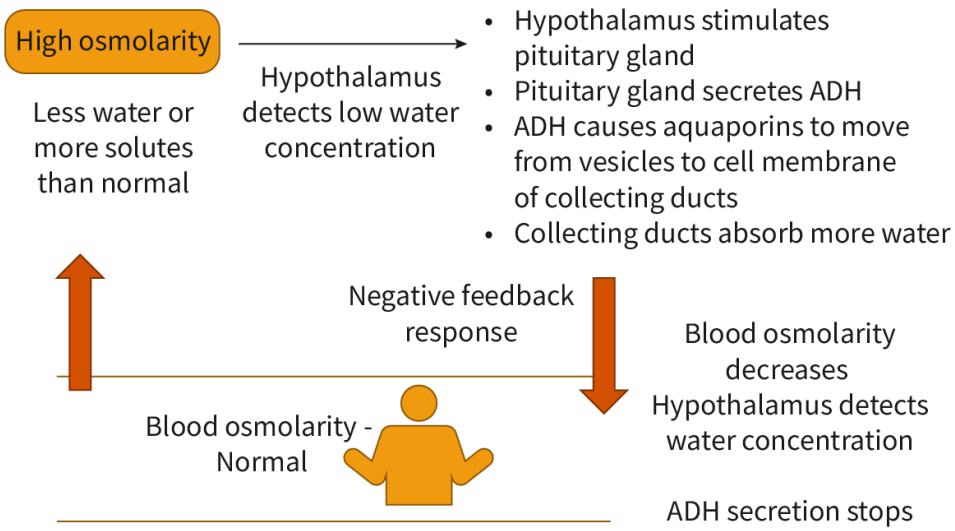
The collecting duct is the last component of the kidney and is responsible for the osmoregulation.

Specialised sensory cells, osmoreceptors, located in the hypothalamus play a crucial role in monitoring and regulating the osmotic balance and water content in the body. Osmoreceptors detect changes in the osmolarity or concentration of solutes in the blood. When the osmolarity increases (indicating dehydration or high sodium levels), osmoreceptors in the hypothalamus are activated to stimulate the release of the hormone antidiuretic hormone (ADH).

ADH is produced in the hypothalamus and stored in the posterior pituitary gland. ADH acts on collecting ducts to increase the number of aquaporins which allows more water reabsorption from the filtrate. In the presence of ADH, aquaporins are mobilised from intracellular vesicles to the cell membrane to allow for more water reabsorption. This is an example of a negative feedback loop.

Most parts of the collecting ducts are normally impermeable to water. The presence of ADH affects the water permeability of collecting ducts as follows:

- In the absence of ADH, water in the filtrate is lost in the urine.
- When ADH is present, aquaporins allow for the reabsorption of this water, and inhibit water loss via urine.



Student view

Overview (/study/ap 422-cid-755105/o

Figure 2. Negative feedback mechanism regulating ADH secretion.

More information for figure 2

Study skills

ADH is produced in the hypothalamus, and stored in the posterior pituitary gland until it is released.

The collecting duct system participates in the regulation of sodium (and some other ions including chloride, potassium, hydrogen ions and bicarbonate) under the control of the hormone aldosterone.

Regulation of blood flow

The blood flow to an organ is regulated in response to changes in activity. When the activity of an organ increases:

- The consumption of oxygen (and other related substances) increases. Thus, the blood must carry more oxygen per unit time.
- The production of carbon dioxide (and other waste) increases. Thus, the blood must carry away more carbon dioxide per unit time.

At the system level, the body responds to changing demand by changing cardiac output (the volume of blood pumped by the heart per minute). The heart rate and stroke volume are increased or decreased to adjust the cardiac output.

Blood vessels contain smooth muscles in their structure. Mainly in arteries or arterioles, muscles contract (vasoconstriction) or dilate (vasodilation) to adjust the volume of blood they carry.

During sleep or rest, since overall activity is reduced:

- The blood supply to major organs including skeletal muscles is relatively low compared to the active state.
- Overall demand for blood flow is low, so heart rate is at normal or below normal levels.
- Blood flow to the muscles is redirected to other essential functions, such as tissue repair, growth and digestion.

During increased activity, the demand for oxygen and nutrients by the organs increases significantly. To meet these demands, the blood supply is greatly enhanced.

Student view

- The blood supply to major organs including lungs and skeletal muscles is relatively high compared to the resting state.
- Overall demand for blood flow is high, so heart rate is above normal levels.
- Blood flow to digestive organs is mainly redirected to skeletal muscles.
- After a heavy exercise, blood flow to the kidneys may increase to support regeneration and regulate the blood values.

The blood flow to the skin can be reduced or increased with thermoregulation.

Blood flow through the capillary beds is regulated depending on the body's needs and is directed by nerve and hormone signals. For example, after a large meal, most of the blood is diverted to the stomach by vasodilation of vessels of the digestive system and vasoconstriction of other vessels. During exercise, blood is diverted to the skeletal muscles through vasodilation while blood to the digestive system would be lessened through vasoconstriction.

Creativity, activity, service

Strand: Service
Learning outcome: Demonstrate the skills and recognise the benefits of working collaboratively

Healthy kidneys filter our blood every minute to remove wastes and extra water to make urine. Chronic kidney disease (CKD) is a progressive condition in which the kidneys do not work. In early stages, the main focus is on managing other health conditions like diabetes and high blood pressure, as well as making healthy changes in diet and exercise.

There is an opportunity to start a CAS project for raising awareness of the importance of our kidneys. Your project may include many activities, such as:

- Visit the World Kidney Day (https://www.worldkidneyday.org) website to learn about this year's theme. You can find some creative ideas from their global activities.
- You can create an exercise and diet programme to guide your community for a healthy lifestyle.
- You can prepare brochures showing the role of kidney, golden rules to protect kidney health or ways to improve your lifestyle.
- You can visit a kidney clinic to learn more or you can invite a doctor to your school.

Try the activity below to research how osmoregulation differs in a desert animal.

Overview (/study/ap 422-cid-755105/o

Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Thinking skills — Applying key ideas and facts in new contexts
- **Time required to complete activity:** 60 minutes
- **Activity type:** Individual activity

Hot deserts are geographic regions characterised by extremely hot temperatures, low rainfall and little or no vegetation. Lack of drinking water is a significant problem for many organisms, especially mammals.

Desert mammals maintain water balance by physiological adaptations that minimise water loss, and by gaining water from several sources.

Using reliable sources, research how osmoregulation through the kidney in desert mammals is different from other mammals. Some examples of desert mammals you can research include the kangaroo rat, camel and desert hedgehog.

Create a presentation that covers the following points:

- Introduction: briefly introduce the concept of osmoregulation and its importance in desert mammals.
- Anatomy: describe the nephron anatomy desert mammals have developed to conserve water.
- Case study: choose one or more specific examples of desert mammals and describe how they have adapted to survive in their particular environment.

Use appropriate visuals, such as diagrams, images and videos, to illustrate the key points of your presentation.

Your presentation can be in any format you choose, such as a PowerPoint, Prezi or video presentation. Be sure to include citations for any sources used in your research.

5 section questions

Student view

D3. Continuity and change: Organisms / D3.3 Homeostasis

Summary and key terms

- Homeostasis is the maintenance of the internal environment of an organism. Body temperature, blood pH, blood glucose concentration and blood osmotic concentration are examples of homeostatic variables in humans. Negative feedback mechanisms keep these variables fluctuating within a preset range.
- Pancreatic hormones, insulin and glucagon, control the blood glucose level. Insensitivity to insulin or insulin deficiency causes prolonged elevated blood glucose, a condition called diabetes.
- The hypothalamus, using information from peripheral thermoreceptors, regulates the body temperature. Thyroxine stimulates cells to increase metabolism and increase heat production in the body. Shivering of muscles, erection of hairs, vasoconstriction and uncoupled respiration in brown fat tissue aims to increase body temperature. In hot environments, when body temperature increases, the body uses sweating, flattening of hair and vasodilation to regulate body temperature.

HL Only

- Metabolic waste must be excreted so that they do not accumulate in the body. Excretion is the process of discharging metabolic wastes from the body. The human excretory system consists of the kidneys, the urinary bladder and associated ducts.
- Each kidney has up to one million functional units called nephrons. A nephron consists of a cup-like Bowman's capsule connected to a long, partially coiled renal tubule.
- The three main regions of the renal tubule are: (i) the proximal convoluted tubule, which processes the glomerular filtrate (the fluid filtered from the blood) from Bowman's capsule; (ii) the loop of Henle, an elongated, hairpin U-shaped portion; and (iii) the distal convoluted tubule, which processes the glomerular filtrate to the collecting duct.
- Osmoregulation is the process of maintaining the relative concentrations of water and solutes within preset limits. The nephron's loop of Henle and collecting ducts support osmoregulation.
- The walls of the descending limb of the loop of Henle are relatively permeable to water but relatively impermeable to sodium and urea. As the glomerular filtrate passes down the loop of Henle, water moves out by osmosis. This process concentrates the filtrate inside the loop of Henle.
- The amount of urine produced depends on the body's need for water. Receptors in the hypothalamus are sensitive to osmotic changes of the blood. They signal the posterior lobe of the pituitary gland to release ADH. ADH makes the collecting ducts more permeable to water so that more water is reabsorbed.

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- During physical activity, the body's demand for oxygen and nutrients increases. This increases blood flow to the muscles. It also means that the body produces more waste, such as urea, and needs to eliminate more waste.

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Student view

Key terms

Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.

1. is maintaining a relatively constant internal environment to balance the changes of metabolic variables.
2. If feedback supports the change of a variable, it is called . If feedback opposes the change, it is called .
3. is a chronic disease that occurs either when the does not produce enough or the body cannot effectively use it. is produced and secreted by the cells in response to decreasing glucose levels.
4. The centre of thermoregulation is the of the brain.
5. The widening of the blood vessels is called and the narrowing is called .
6. Regulation of water and solute concentrations of body fluids is called while removal of waste and excess materials is called .
7. are the main unit that filter blood in kidneys.
8. The first stage of the urine production is of blood in .
9. The long U-shaped portion of the nephron after the proximal convoluted tubule is called the .
10. The ascending limb of the loop of Henle is to water.
11. The presence of hormone affects the water permeability of collecting ducts.

insulin | pancreas | Homeostasis | alpha | antidiuretic | excretion | positive feedback | vasoconstriction | impermeable | loop of Henle | osmoregulation | vasodilation | glomerulus | Diabetes | Glucagon | negative feedback | ultrafiltration | hypothalamus | Nephrons

Check

D3. Continuity and change: Organisms / D3.3 Homeostasis

Checklist

What you should know

After studying this subtopic you should be able to:

- Define the concept of homeostasis in relation to specific examples of variables.
- Explain the role of negative feedback mechanisms in maintaining homeostasis.
- Outline the role of pancreatic hormones in regulating blood glucose.
- Outline the role of negative feedback mechanisms in regulating blood glucose.
- Describe the physiological changes that form the basis of type 1 and type 2 diabetes.
- Describe the roles of thermoreceptors and hypothalamus in regulating body temperature.
- Outline the mechanisms in regulating human body temperature.

Higher level (HL)

- Define osmoregulation and excretion.
- Explain the roles of the glomerulus, Bowman's capsule and proximal convoluted tubule in excretion.
- Outline the functions of the loop of Henle and collecting ducts.
- Explain the effect of ADH on the permeability of the kidney tubules.
- Describe examples of changes in blood supply in response to changes in activity.

D3. Continuity and change: Organisms / D3.3 Homeostasis

Investigation

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Thinking skills – Providing a reasoned argument to support conclusions
- **Tool 1:** Experimental techniques – Measuring variables
- **Inquiry 2:** Collecting and processing data – Collecting data
- **Time required to complete activity:** 30 minutes
- **Activity type:** Pair activity

Your task

In this investigation, you will explore how the human body responds to exercise by monitoring your body temperature and pulse rate.

Materials

- Digital thermometer
- Stopwatch

Procedure

1. Work in pairs and determine the person that will exercise.
2. Before starting the investigation, record your baseline measurements of body temperature using a digital thermometer.
3. Measure your pulse rate in the artery of your wrist.
    - At the wrist, lightly press the index and middle fingers just below the base of the thumb.
    - Count the number of beats in 15 seconds and multiply by four to get beats per minute (bpm).
    - Repeat three times and calculate the mean.
4. Warm up for 3 minutes by walking at a low intensity.
5. Record your body temperature.
6. Record your pulse rate.
7. Run at a slow speed for 3 minutes. Record your temperature and pulse rate.
8. Run at a high speed for 3 minutes. Record your temperature and pulse rate.
9. Repeat each exercise five times and complete a data table like the example shown in **Table 1** for each of the three levels of exercise: walking, running slowly and running fast.

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Table 1. Example data table for recording results.

	Body temperature (°C)	Pulse rate (bpm)
1		
2		
3		
4		
5		
Mean		

Practical skills

- **Tool 1:** Experimental techniques — Measuring variables
- **Inquiry 2:** Collecting and processing data — Collecting data

While recording your data:

- The precision of a tool is plus or minus half of the smallest division on the instrument.
- Find the manufacturer's estimate of precision for electronic instruments.
- When recording data, extend the significant digits to tenths of a degree to match this level of precision.
- Write units of measurement and uncertainty in column headings and notion the rows next to each measurement.
- Make sure calculated numbers such as mean have the same number of decimal places as the original measurements.

Questions

1. Comment on how exercise intensity affects pulse rate and blood flow, and how this relates to thermoregulation.
2. Deduce the body's response to increased internal temperature during exercise.
3. Explain why the measurements are taken five times.

Student view

Reflection

Teacher instructions

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/osmoregulation-hl-id-44810/print/) Assign

The goal of this section is to encourage students to reflect on their learning and conceptual understanding of the subject at the end of this subtopic. It asks them to go back to the guiding questions posed at the start of the subtopic and assess how confident they now are in answering them. What have they learned, and what outstanding questions do they have? Are they able to see the bigger picture and the connections between the different topics?

Students can submit their reflections to you by clicking on 'Submit'. You will then see their answers in the 'Insights' part of the Kognity platform.

Reflection

Now that you've completed this subtopic, let's come back to the guiding question introduced in The big picture (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43551/).

- How are constant internal conditions maintained in humans?
- What are the benefits to organisms of maintaining constant internal conditions?

With these questions in mind, take a moment to reflect on your learning so far and type your reflections into the space provided.

You can use the following questions to guide you:

- What main points have you learned from this subtopic?
- Is anything unclear? What questions do you still have?
- How confident do you feel in answering the guiding questions?
- What connections do you see between this subtopic and other parts of the course?

⚠ Once you submit your response, you won't be able to edit it.

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Submit

Rate subtopic D3.3 Homeostasis

Help us improve the content and user experience.

Student view