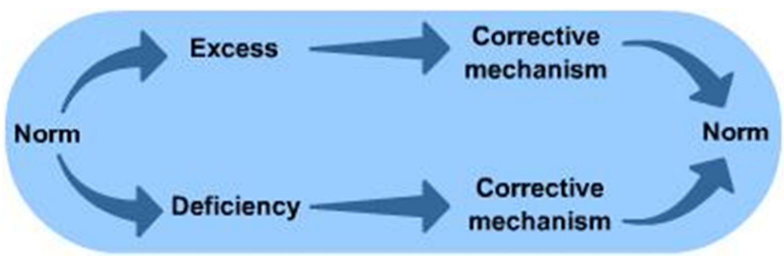
General principles of Homesostasis

Homeostasis is the way the body maintains a stable internal environment. It is important for the body to have a stable environment for cells to function correctly. There are several things that need to be regulated:

1. The body's temperature. If temperature were allowed to rise out of control, protein and therefore enzyme, structure would be affected, perhaps with disastrous results.
2. The amount of water within the body. The levels of water can affect metabolism and osmosis. Again this can have serious consequences.
3. The amount of glucose in the body. This level can also affect osmosis and obviously the rate of respiration as well.
4. The amount of nitrogenous waste in the body. Nitrogenous waste can become toxic in the body. It is important that this level does not get too high.

Negative feedback

To regulate these things the body needs firstly to detect the level and then to respond in an appropriate way. For temperature, water and glucose there is a level called the 'norm' (e.g, normal body temperature is 36.9°C). If the level gets too high this triggers the body to lower it. If the level gets too low this triggers the body to raise it. This is the principle of negative feedback. (Positive feedback is when a high level of something triggers the body to increase it even further).

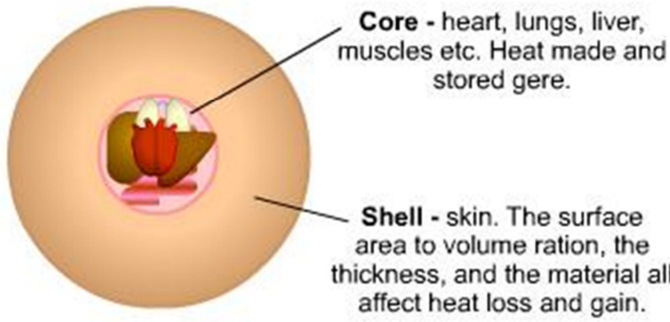


Temperature Control

The vast majority of organisms function between 10-35°C. There are basically two ways to regulate body temperature and we use these to categorise organisms:

1. **Homoiotherms** - These are organisms that that regulate their own body temperature internally. Their internal body temperature is independent of the external temperature. (Don't use the term 'warm-blooded').

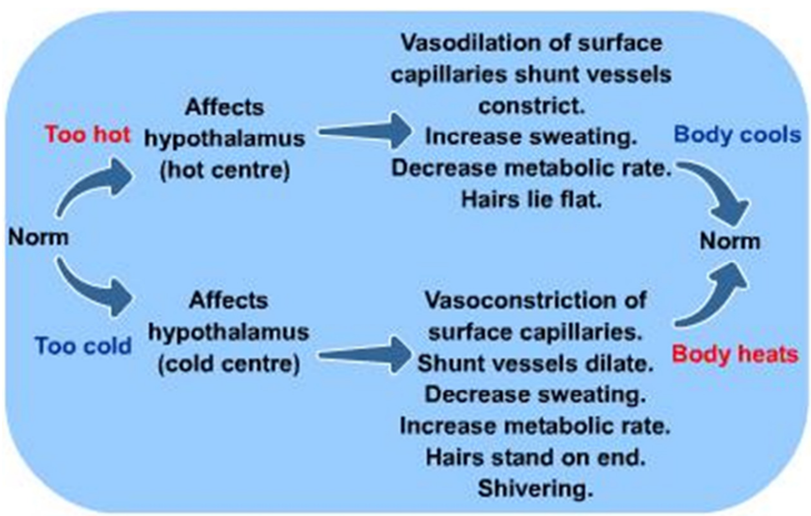
2. **Poikilotherms** - These are organisms that cannot regulate their own body temperature internally. Their internal temperature fluctuates with the external temperature. (Don't use the term 'cold-blooded').



Homoiotherms (for example, you)

In your brain is there is an area called the hypothalamus. The hypothalamus has a thermo-regulatory centre and this detects the temperature of your blood. You also have thermo-receptors in your skin and these detect the temperature outside.

A diagram of the process your body goes through to react to changes in external temperature is shown below:



You can also alter your body temperature behaviorally rather than internally. For instance, you can increase your temperature by doing exercise, or putting on extra layers of clothing. You can decrease your temperature by removing clothes, lying in a cool place, etc.

At extreme internal body temperatures your body has to employ other strategies.

Your **Low Critical Temperature** is about 27° C and at temperatures this low your metabolic rate changes.

At your **Lower Lethal Temperature** (about 25° C) your system will collapse and you will probably die.

***Interesting point*: One woman caught under a frozen waterfall whilst skiing survived after her body temperature had fallen to an amazingly low 13.5° C!** The cold temperature had slowed down her brain so the amount of oxygen in her blood was sufficient to prevent any brain damage. She was revived after her blood was passed through a heart bypass machine, warmed and then returned to her body.

Your **High Critical Temperature** is very high, but if it is reached your metabolic rate cannot decrease to lower it. It increases out of control.

If your **Upper Lethal Temperature** of about 42°C is reached you will die.

Interesting point: Camels could sweat to stay cool in the desert, but they would lose too much water. Instead, unless the temperature is very high (over 40°C), **they stop sweating and allow their extremely tolerant tissues to get very hot**.

Poikilotherms (for example, lizards)

Since these animals cannot control their own body temperature they rely on their behavior to seek out an area at their optimum temperature. In the early morning and evening they are active since it is neither too hot nor too cold. If they need to warm up, they will bask in the sun. At midday they will lie in the shade, and at night they will lie in a crevice or burrow so that their immediate atmosphere is warm.

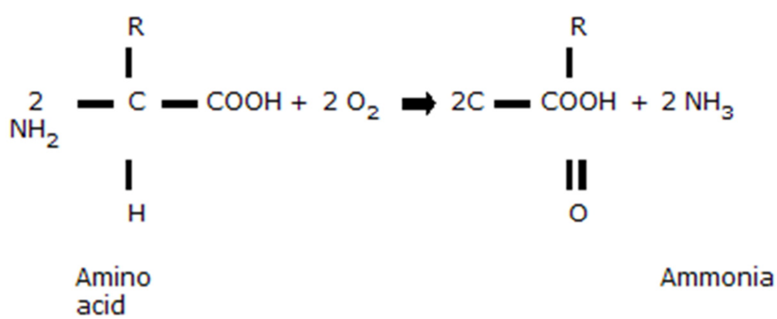
Water Levels and the Kidney

Controlling the level of water is linked to getting rid of nitrogenous waste so we'll deal with them both together. As mentioned before, nitrogenous waste would be toxic if it accumulated so it must be removed from the body. **This is done in number of steps:**

1. Excess proteins (i.e, nitrogenous waste) are broken down into amino acids.
2. These then have the nitrogenous part removed as ammonia (see equation 1 below).
3. Within the liver, the ammonia is converted into urea (see equation 2 below). This process is called deamination.
4. The urea is then transported in the blood to the kidney (where it is extracted and excreted via the bladder).

Deamination

Equation 1:

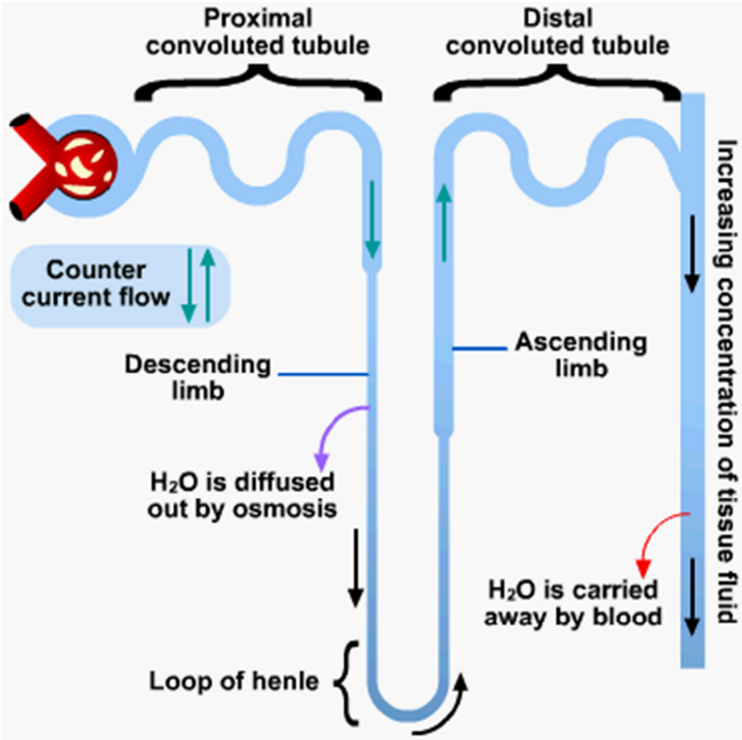


Equation 2:

$$\underset{\text{Ammonia}}{2\,NH_3} + CO_2 \rightarrow \underset{\text{Urea}}{C(NH_2)_2\,O} + H_2O$$

Note: The R group is different for different amino acids.

The kidney



Ultrafiltration

Urea, along with salt, water and glucose, etc., is extracted from the blood in the kidney by a process called *ultrafiltration*. Blood passing the top of the **nephron** is under high pressure, so fluid is forced through the sieve-like capillaries and into the **capsule**. This fluid is called the *filtrate*. It does not contain any blood cells or larger proteins, as they are too big to pass out of the capillaries and into the capsule.

Much of what has been filtered out needs to be returned to the blood - they are too precious to lose - so the next process is called *selective reabsorption*.

Selective re-absorption

When the filtrate reaches the **proximal convoluted tubule**, sodium (Na^+) and chloride (Cl^-) ions, glucose, amino acids and vitamins move back into the blood. Generally they diffuse from the filtrate into the cells lining the proximal convoluted tubule. They are then actively transported out of these cells and into the blood capillaries. Some water follows by **osmosis.** Surprisingly, some unwanted urea also gets reabsorbed here.

Re-absorption of water

The basic idea is to create a strong salt concentration in the next part of the tubule. This will draw water out of the tube by osmosis, and then the water can be taken away by the blood. This conserves water levels in the body.

How the body does it:

It is easier to understand if you start with the **ascending limb** (the second part of the **loop of Henle**).

Na^+ and **Cl^-** are actively pumped out of the filtrate in the tube and into the tissue fluid around it. No water follows, however, as this part of the loop is impermeable to water. This has two consequences.

1. Water flows out of the descending limb into the tissue fluid by osmosis.
2. Na^+ and Cl^-, being at a very high concentration in the tissue fluid, diffuse down the concentration gradient into the **descending limb.**

By the time the filtrate reaches the bottom of the descending limb the fluid in the loop has lost a lot of water and is very concentrated. The fluid surrounding the bottom of the loop - in area of the kidney called the *medulla* - is also very concentrated because of the accumulation of Na^+ and Cl^- ions.

As the fluid then goes up the ascending limb, Na^+ and Cl^- ions are actively pumped out (as was mentioned a few lines ago) so it gets more and more dilute.

Filtrate passing down the descending limb of the loop of Henle is flowing in the opposite direction to fluid in the ascending limb. The fluid is increasingly concentrated as it moves down and increasingly dilute as it moves up. This **countercurrent flow** (or **countercurrent multiplier**) allows concentrated urine to be produced.

This is important because yet more water is drawn out of the tube (at this point called the *collecting duct*) when it passes through the medulla again. This allows you to make concentrated urine. Any filtrate not reabsorbed - most of the urea, some water and some salt - is drained into the bladder.

Obviously the amount of water reabsorbed is controlled by the quantity of water in the blood. The less water in the blood, the more it must be reabsorbed. The hormone **ADH (anti-diuretic hormone)** controls the extent to which water is reabsorbed. If the blood is concentrated, more ADH is released; making the walls of the collecting duct more permeable to water so more is reabsorbed back into the blood. If the blood is less concentrated, less ADH is released so less water is reabsorbed.

Control of ADH

The concentration of the blood (water potential) is monitored by osmoreceptors in the **hypothalamus**. The higher the concentration of the blood the less water there is in the blood.

If the concentration is too high impulses are sent to the **pituitary gland** which then releases more ADH. The water levels will be brought back to normal and the impulses stop.

Interesting points:

Frogs and toads don't have a loop of Henle so these animals are unable to produce concentrated urine.

Desert animals have very long loops of Henle so that they can produce extremely concentrated urine so as to lose as little water as possible.

Most reptiles, birds, insects and land snails excrete uric acid, not urea. This requires more energy, but less water.

If the blood is concentrated the **thirst centre** in the brain is switched on. This makes you thirsty, but it is a useful feeling. You drink and therefore increase the level of water in your blood.

Glucose Levels

Glucose is needed for respiration so if the level falls below this, the normal body activities may not be able to continue. If the level rises too much the normal behaviour of cells is affected and serious problems can arise. The ideal level of blood glucose is about $1mg/cm^3$.

There are natural situations that can affect the level of glucose. For example, eating will increase it and exercise will decrease it. Because of this fluctuation, there are 2 hormones that minimise these fluctuations in glucose levels. Their names are insulin and glucagon and they work antagonistically (against each other). Both are produced in the pancreas; **α cells of the pancreas produce glucagon, β cells of the pancreas produce insulin**.

Glucose is a small, soluble molecule that is carried in the blood plasma. The pancreas detects the level of glucose and the appropriate hormone is released to either increase or reduce the level of glucose.

In the next section you need to be very careful as the words used are very similar and can be confusing.

Try looking at the start of the words to see if it is referring to **Glyco** or **Gluco** and then at the ends of words to see if it is referring to **genesis** (meaning formation) or **lysis** (meaning splitting).

Note**:** **Neogenesis** means new formation.

Action of insulin

Insulin reduces the level of glucose in the blood plasma by:

- Using up the excess glucose (this is done by increasing the rate of respiration).
- Increasing the amount of glucose absorbed into the body cells (particularly the liver) thus taking the glucose out of the blood plasma.
- Turning the glucose into glycogen. This process is called **Glycogenisis** (remember, genesis means formation).

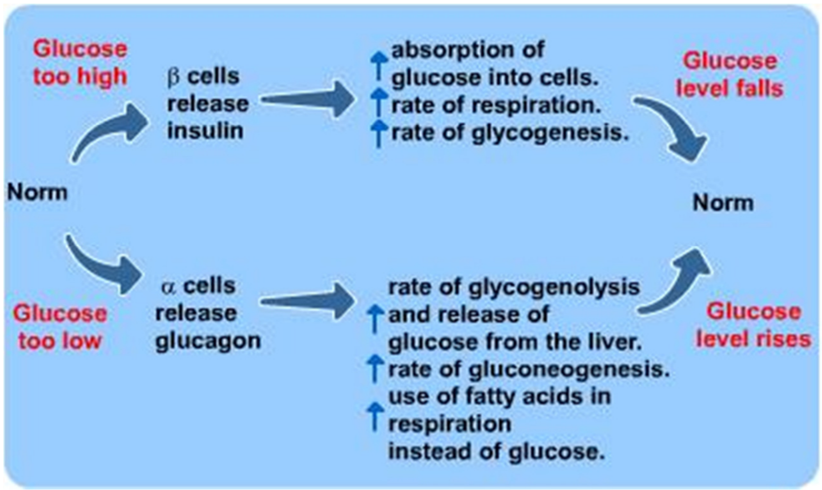
Action of glucagon

Glucagon increases the level of Glucose in the blood plasma by doing roughly the opposite to insulin...

- Slowing the use of glucose (this is done by reducing the rate of respiration).
- Reducing the amount of glucose absorbed into the body cells (particularly the liver).
- Releasing glycogen. Glycogen is stored in the liver and muscles and is easily converted into glucose in a process called **Glycogenolysis** (remember, lysis means splitting).

In addition to this, Glucagon promotes the conversion of fatty acids. into glucose. This process is called **Gluconeogenisis** (remember, neogenesis means new formation).

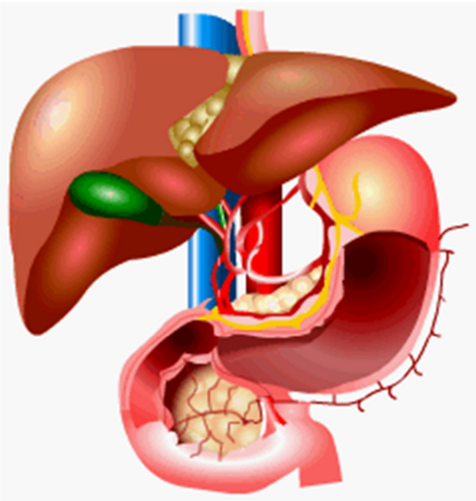
This illustration shows the process your body goes through to react to changes in glucose levels:



The Liver

As well as being involved in the control of blood glucose levels, the liver has other extremely important functions. To be able to fully understand these, the structure of the liver must first be understood.

The structure of the liver



The liver is made up of numerous *lobules* which are packed with virtually identical cells called *hepatocytes*. The liver is supplied with blood flowing in from the hepatic artery (bringing oxygen) and the hepatic portal vein (bringing blood from the gut).

The blood in this vein carries lots of products from digestion for example; glucose, amino acids, lipids, cholesterol, plasma proteins, urea, carbon dioxide.

As the blood flows through the **sinusoids**, the **hepatocytes** take in what they need from it and shed their waste into it.

You should already be familiar with these two liver functions as they have been covered in previous Learn Its:

1. *Carbohydrate metabolism:* gluconeogenesis, glycolysis and glycogenesis all occur in the hepatocytes.
2. *Deamination:* when excess proteins have the NH_2 group removed to make ammonia. This is then converted into urea and released into the blood to be taken to the kidney for excretion.

Other functions include:

★ *Fat metabolism:* if there is not enough carbohydrate for respiration, fats are used. In fact, the preferred respiratory substrate of the heart is fatty acids so the liver is an efficient converter of fats into fatty acids.

★ *Making cholesterol:* rather than being 'bad', the chemical cholesterol is actually essential for your body. It is needed to make:

1. Cell membranes, particularly of neurones,
2. Some hormones e.g. testosterone and oestrogen,
3. Vitamin D,
4. Bile.

Excess cholesterol however is not good. It may precipitate in the gall bladder or bile duct to form gallstones.

This can be very painful and stops the flow of bile to the small intestine. It may also form deposits on the walls of blood vessels.

This **atherosclerosis** narrows the arteries and hardens them and may lead to clots blocking the flow of blood thus killing the cells that are normally supplied by it.

★ *Bile production:* bile salts are made from cholesterol by the hepatocytes and then secreted into the canaliculi to be taken to the bile duct and duodenum or to be stored in the gall bladder.

★ *Detoxification:* hepatocytes break down and chemically change many harmful substances and drugs (e.g, alcohol and antibiotics) as well as some hormones (e.g, testosterone and oestrogen).

★ *Storage of Vitamins:* Vitamin A (for sight), D (needed to make a hormone for the absorption of calcium and phosphate into the blood from food eaten and for their metabolism) and B_{12} (for the formation of red blood cells).

★ *Breakdown of haemoglobin (Hb):* red blood cells are broken down in the spleen and the Hb is released into the plasma. Phagocytic cells of many parts of the body, including the liver take it up. These cells which line the blood vessels in the liver are called *Kuppfer cells.* Having ingested the Hb, they remove the iron from it.

★ The iron is then combined with a plasma protein called *transferrin*. This complex may be taken up by the bone marrow cells for new Hb and red blood cell production or it may be taken up by the hepatocytes for storage. The non-iron part of the Hb is converted into a green-yellow pigment and is released into the bile as an excretory product.

★ *Synthesis of plasma proteins:* e.g, fibrinogen and prothrombin (used in blood clotting), globulins (used in transporting substances that could not otherwise travel in the plasma, e.g, lipids), albumin - keeps the osmotic concentration of the blood high and also used for transport like globulins.