Homeostasis

IB Biology - Revision Notes

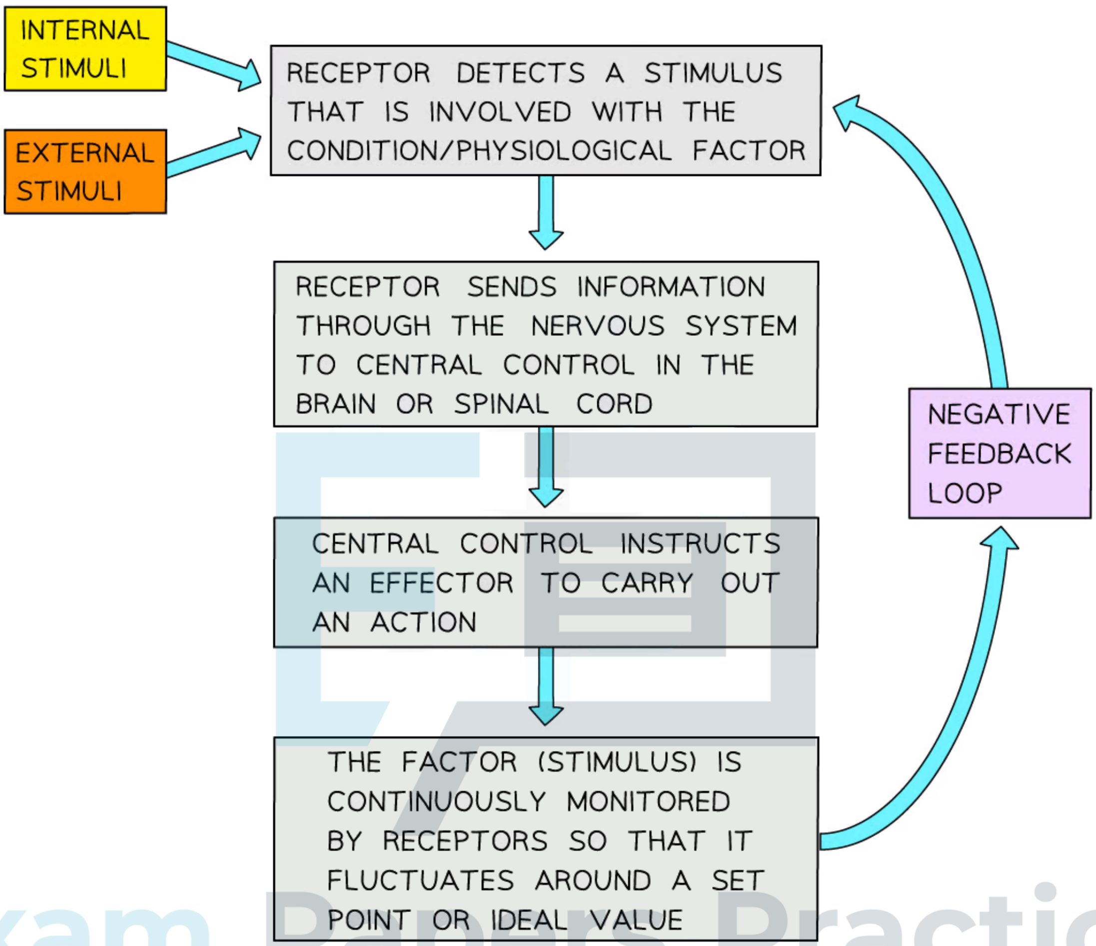
Homeostasis: Maintaining the Internal Environment

Maintaining the Internal Environment

- The process of **maintaining a constant internal environment** is known as **homeostasis**
- Homeostasis ensures that conditions inside the body are kept within **preset limits**
- Homeostasis is **critically important** for organisms as it ensures the maintenance of **optimal conditions** for **enzyme action** and **cell function**
- **Sensory cells** can **detect** information about the **conditions** inside and outside the body; if conditions have changed then the body can respond to keep conditions constant
- Examples of physiological factors that are **controlled** by **homeostasis** in **mammals** include
  - Core body temperature
  - Blood pH
  - Concentration of glucose in the blood
  - Osmotic concentration of the blood

Negative Feedback Loops

- The majority of homeostatic control mechanisms in organisms use **negative feedback loops** to achieve homeostasis
- Negative feedback mechanisms work to **return values to a set point**; they **reverse the effects of any change** within a system
  - Negative feedback loops are essential for **maintaining conditions** within set limits; this is not the case in positive feedback mechanisms which instead **amplify any change**
- Negative feedback control loops involve:
  - A **receptor** – receptor cells **detect change** in a physiological factor
  - A **coordination system** – the brain and nervous system **transfer information** between different parts of the body
  - An **effector** – the muscles and glands bring about a **response**
- Outcome of a negative feedback loop:
  - The factor / stimulus is **continuously monitored**
  - If there is an increase in the factor, the body responds to make the factor decrease
  - If there is a decrease in the factor, the body responds to make the factor increase



Negative feedback loops maintain conditions to a set point

Regulation of Blood Glucose

Diabetes: Type 1 and Type 2

- Diabetes is a condition in which the **homeostatic control of blood glucose has failed** or deteriorated
- The insulin function of diabetic individuals is disrupted which allows the **glucose concentration in the blood to rise**
  - The kidneys are unable to filter out this excess glucose in the blood and so it often appears in the **urine**
  - The increased glucose concentration also causes the kidneys to produce large volumes of urine, making the individual feel thirsty due to **dehydration**
  - Glucose remains in the blood rather than entering the cells, so cellular respiration is reduced, resulting in **fatigue**
  - If the blood glucose concentration reaches a dangerously high level after a meal then **organ damage** can occur
- There are two different types of diabetes: type 1 and type 2

Type 1 diabetes

- Type 1 diabetes is a condition in which the **pancreas fails to produce sufficient insulin** to control blood glucose levels
- It normally begins in childhood due to an **autoimmune response** whereby the body's immune system **attacks the β cells** of the islets of Langerhans in the pancreas
- The damage to the β cells means that **insulin production can no longer take place**, and blood glucose concentration can therefore not be regulated
- Type 1 diabetes is normally treated with regular blood tests, **insulin injections** and a modified **diet**
  - Such a diet may involve a reduction in carbohydrate intake

Type 2 diabetes

- Type 2 diabetes is **more common** than type 1, and usually develops in **older adults**
- In type 2 diabetes the pancreas still produces insulin but the **cell membrane receptors** to which insulin binds have **reduced in number** or **no longer respond**
  - The inability of cells to respond to insulin can be described as **insulin resistance**
- The pancreas will attempt to compensate for this by **secreting more and more insulin**; eventually insulin production will no longer be able to compensate for the reduced cellular response
- There is a **reduced glucose uptake** which leads to uncontrolled **high blood glucose concentration**
- Type 2 diabetes is managed by
  - **Medication** to lower blood glucose
  - A **low carbohydrate diet**

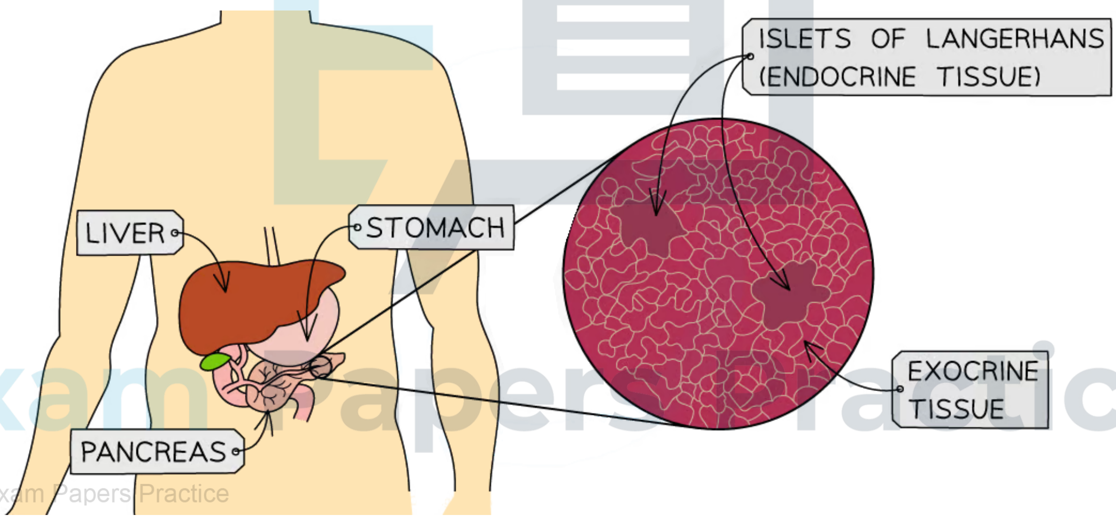
        - Any food that is rapidly digested into sugar will cause a sudden, dangerous spike in blood sugar
    - An **exercise regime** that lowers blood glucose
- **Obesity** is a major risk factor for type 2 diabetes; the over-production of insulin in response to a high-carbohydrate diet triggers the development of insulin resistance

Type 1 and type 2 diabetes table

	Type 1	Type 2
Cause	Inability of pancreas to produce insulin	Cells of the body become resistant to insulin or insufficient insulin produced by pancreas
Treatment	Monitoring blood glucose levels and injecting human insulin throughout the day (particularly after meals consumed)	Maintain a low-carbohydrate diet and regular exercise to reduce need for insulin

Regulation of Blood Glucose

- It is essential that **blood glucose concentration** is kept **within narrow limits**
  - Glucose is essential for **respiration**, so it is important that blood glucose levels do not drop too low
  - Glucose is soluble, so blood glucose concentration **affects the osmotic balance** between the cells and the blood
- The control of blood glucose concentration is a key part of **homeostasis**
- Blood glucose concentration is controlled by two hormones which are secreted into the blood by specialised tissue in the **pancreas**
- This tissue is made up of groups of cells known as the **islets of Langerhans**
  - The islets of Langerhans contain two cell types:
    - **α cells** that secrete the hormone **glucagon**
    - **β cells** that secrete the hormone **insulin**
  - These α and β cells are involved with **monitoring** and **responding to** blood glucose levels



The islets of Langerhans form the endocrine tissue of the pancreas, while the exocrine tissue is involved with the production of digestive enzymes

The effects of insulin

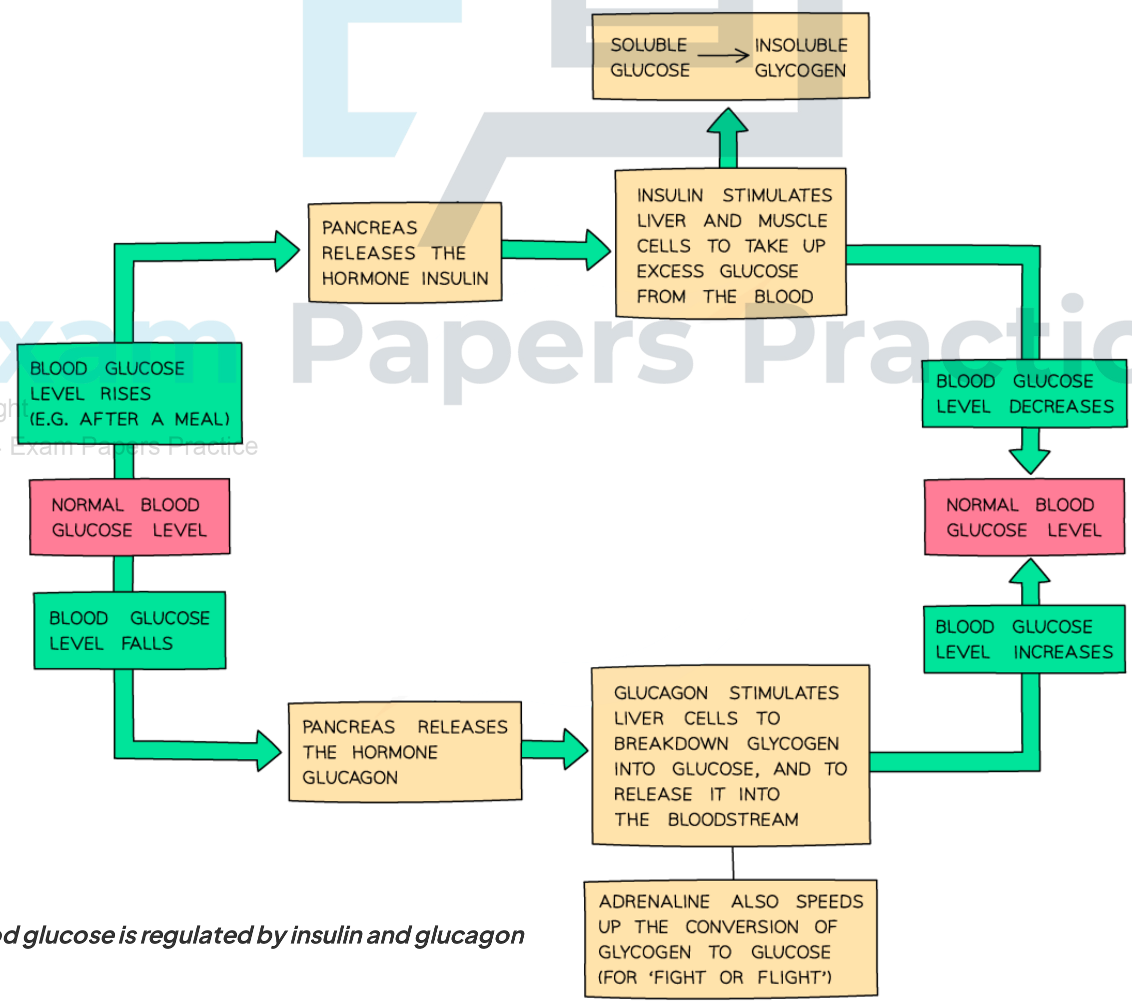
- Blood glucose concentration **increases** after a meal that contains **carbohydrate**
- This increase in blood glucose is detected by the **β cells** in the pancreas, which synthesise and **secrete insulin**
- Insulin is **transported in the blood** to **target cells** all over the body
  - Insulin's main target cells are in the **liver and muscles**
- The effects of insulin include:

  - **Glucose channels in cell surface membranes open**, and glucose moves **out of the blood** and into the body cells by facilitated diffusion
  - Liver and muscle cells **convert excess glucose into glycogen** to be stored; this is **glycogenesis**
  - An **increase in the rate of respiration**, using up glucose
  - Conversion of **glucose to fatty acids**, resulting in fat storage
- Insulin **lowers blood glucose** concentration

The effects of glucagon

- **Glucagon** is synthesised and secreted by **α cells** when **blood glucose falls**
  - Blood glucose could fall after a period of fasting, or after exercise
- Glucagon is transported in the blood to target cells
- The effects of glucagon include:
  - The **activation of enzymes** that enable the hydrolysis of glycogen in liver and muscle cells, **releasing glucose** that enters the blood; this is **glycogenolysis**
  - A **decrease in the rate of respiration**
  - Amino acids are **converted to glucose**; this is **gluconeogenesis**
- Glucagon **increases blood glucose** concentration

Regulation of blood glucose diagram



Blood glucose is regulated by insulin and glucagon

Exam Tip

The terms glucagon and glycogen are very often mixed up by students as they sound similar. Remember:

- Glucagon is the **hormone**
- Glycogen is the **storage polysaccharide** of animal cells

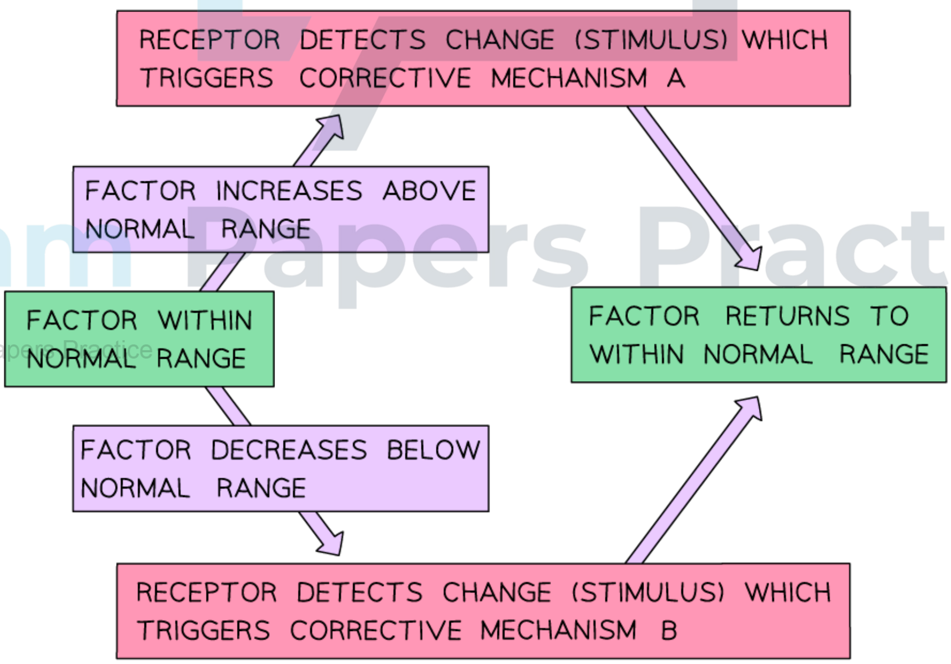
Learn the differences between the spellings and what each one does so you do not get confused in the exam!

Thermoregulation

Thermoregulation as Negative Feedback Control

- **Thermoregulation** is the **control of internal body temperature**
- Thermoregulation is an example of a **negative feedback mechanism**; when body temperature **deviates from pre-set limits**, the responses of the body act to **reverse the change** and bring temperature back to normal
- Negative feedback is brought about by:
  - Using **receptors** to **detect** any deviation from normal levels
    - External body temperature is monitored using **peripheral thermoreceptors** in the skin
    - Internal body temperature is monitored using receptors located inside the **hypothalamus** of the brain
  - Effectors **respond** to any deviation from normal levels
    - **Controlling heat loss** at the skin to the external environment
    - Modifying the generation of heat inside the cells by metabolism

Negative feedback mechanism diagram



Thermoregulation is an example of negative feedback; the 'factor' here is temperature, the 'stimulus' is a change in internal body temperature, and the 'corrective mechanisms' are the action of effectors that *control heat generation and loss*

- Examples of effectors involved with temperature change include:
  - The **hypothalamus**
    - Regulates secretion of a hormone called thyrotropin-releasing hormone
    - Thyrotropin-releasing hormone stimulates the **pituitary gland** to release thyroid-stimulating hormone
    - Thyroid-stimulation hormone stimulates the **thyroid gland** to release **thyroxin**
    - Thyroxin **increases metabolic rate**
      - Altering the level of thyroxin alters **heat generation by cell metabolism**, aiding regulation of body temperature
  - **Muscle tissue**
    - **Shivering** in the muscles raises the metabolic rate of muscle cells, releasing heat energy
  - **Adipose tissue**
    - White adipose tissue stores lipids in a layer beneath the skin and around the internal organs, providing **insulation** that aids temperature regulation
    - Brown adipose tissue can **generate heat energy** before shivering begins in the muscles; this is known as non-shivering thermogenesis

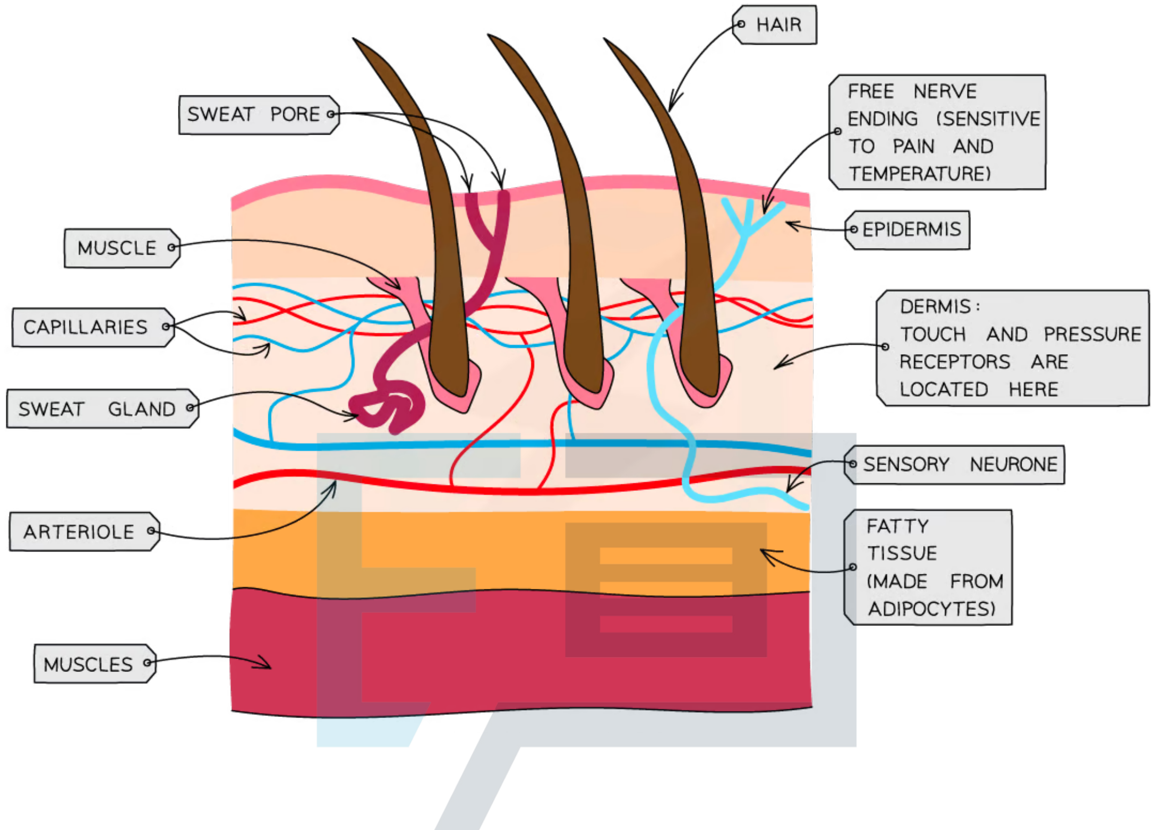
Mechanisms of Thermoregulation

- **Internal body temperature** is a key factor that needs to be controlled in homeostasis
  - A stable core temperature is vital for **enzyme activity**, e.g. human enzymes have evolved to function optimally at a core body temperature of about 37 °C
    - **Lower temperatures** either **prevent** reactions from proceeding or **slow them down**:
      - At lower temperatures molecules have little kinetic energy, so collisions are infrequent and few enzyme-substrate complexes form
    - Temperatures that are **too high** can cause enzymes to **denature**, meaning that they lose their tertiary structure and **enzyme-substrate complexes can no longer form**
- Endotherms are animals that **maintain a constant internal body temperature**, e.g. **mammals** and **birds**
- Mammals and birds can regulate their body temperature using:
  - **Physiological mechanisms**, such as shivering and altered metabolism
  - **Behavioural mechanisms**, such as seeking the shade of an underground burrow, or sunbathing

Thermoregulation in humans

- Endothermic animals detect external temperatures via **peripheral receptors**, e.g. thermoreceptors found in the skin
  - There are receptors for both heat and cold
  - These communicate with the **hypothalamus** to bring about a **physiological response** to changing external temperatures
- Human skin contains a variety of **structures** that are involved in processes that can **increase** or **reduce heat loss** to the environment

Skin structure diagram



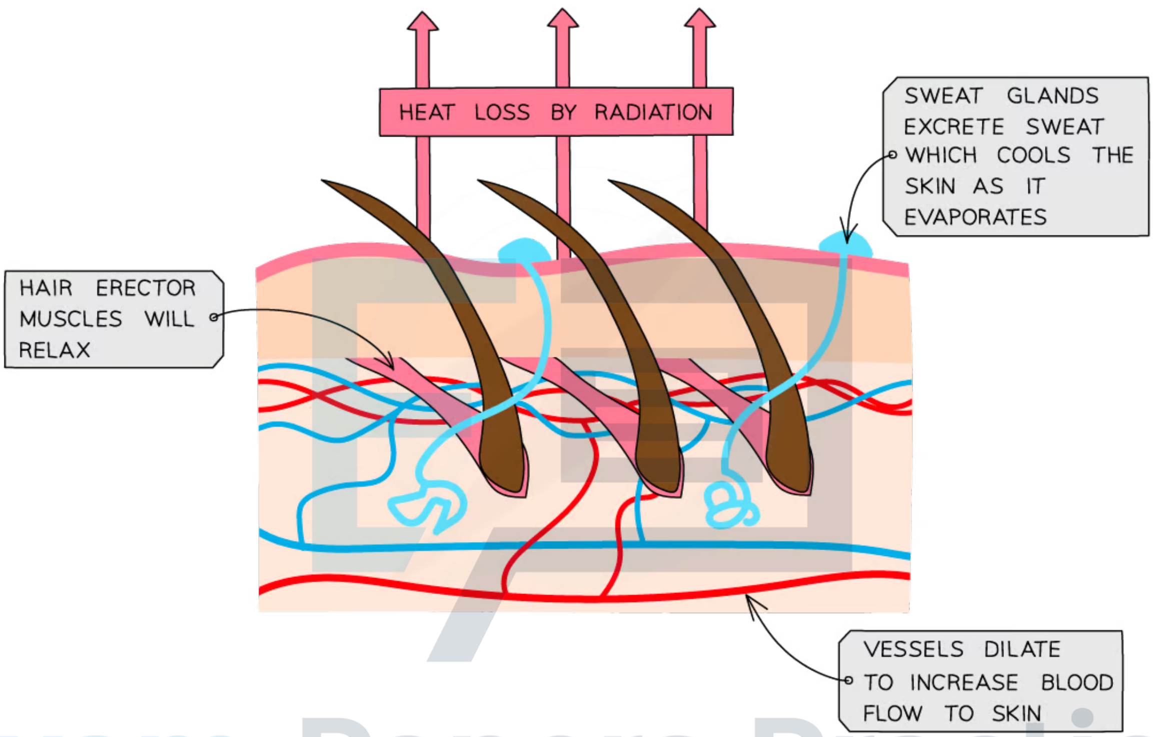
Human skin contains structures that are involved with monitoring and responding to temperature change

Human responses to an increase in temperature

- **Vasodilation**
  - **Arterioles** (small vessels that connect arteries to the skin capillaries) have **muscles in their walls** that can relax or contract to allow more or less blood to flow through them
  - During **vasodilation** these muscles relax, causing the **arterioles near the skin to dilate** and allowing **more blood to flow** through skin capillaries
  - The increased blood flow to the skin means that **more heat is lost** to the environment by **radiation** from the skin surface
- **Sweating**
  - Sweat is secreted by sweat glands
  - This cools the skin by **evaporation** which uses **heat energy** from the body to **convert liquid water into water vapour**
- **Flattening of hairs**
  - The **hair erector muscles** in the skin **relax**, causing **hairs to lie flat**

- This **stops the hairs from forming an insulating layer** of air and **allows air to circulate** over skin, meaning that heat energy lost by radiation can be moved away from the skin surface

Increasing heat loss via the skin diagram



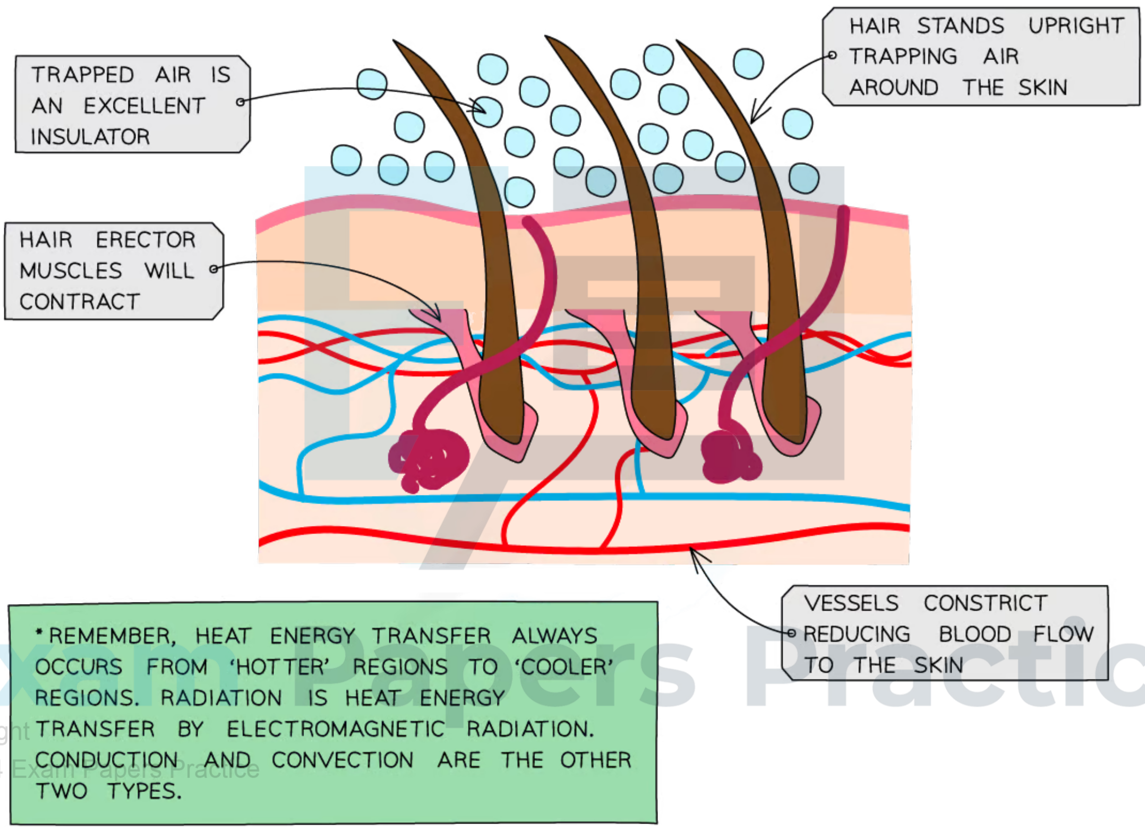
The skin responds to high temperatures with vasodilation, sweating, and relaxation of hair erector muscles

Human responses to a decrease in temperature

- **Vasoconstriction**
  - During vasoconstriction the **muscles in the arteriole walls contract**, causing the arterioles near the skin to **constrict** and allowing **less blood to flow through capillaries**
    - Instead, the blood is diverted through **shunt vessels**, which are deeper in the skin and therefore do not lose heat to the environment
  - The reduction in blood flow to the skin surface means that **less heat energy is lost** by **radiation**
- **Erection of hairs**

- The hair erector muscles in the skin **contract**, causing hairs to stand on end
- This forms an **insulating layer** over the skin's surface by trapping air between the hairs and **stops heat from being lost** by radiation
  - Humans have very little hair on their skin, so this response is less effective than it would have been in their evolutionary ancestors

Reducing heat loss via the skin diagram

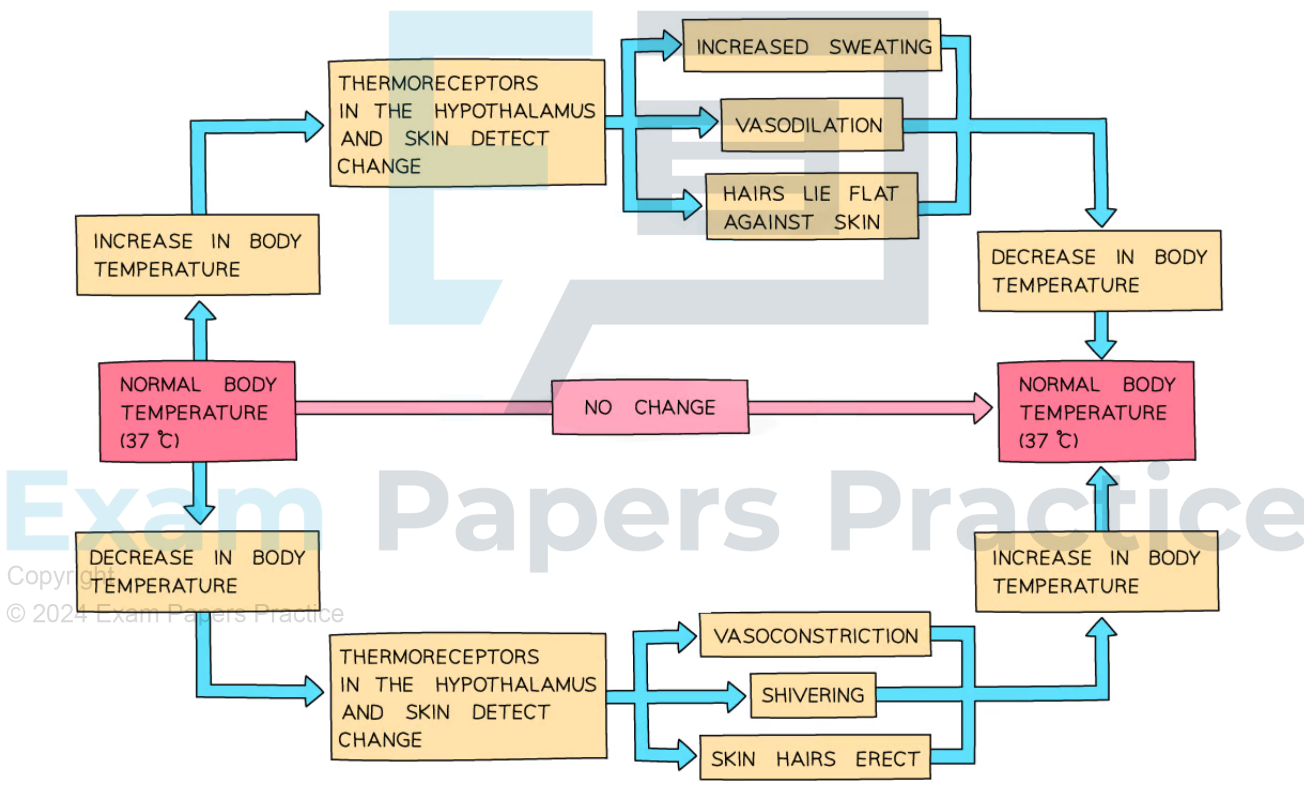


The skin responds to low temperatures by vasoconstriction and the contraction of hair erector muscles

- **Shivering**
  - **Muscles contract and relax** rapidly
  - The metabolic reactions required to power shivering **generate sufficient heat** to warm the blood and raise the core body temperature
- **Uncoupled respiration in brown adipose tissue**

- The reactions of respiration are usually said to be 'coupled' with ATP production, meaning that most of the energy released from carbon compounds is used to generate ATP
- The 'uncoupling' of respiration from ATP production means that **all of the energy released from metabolism is released as heat**, and ATP is not produced
- This can occur in **brown adipose tissue** where **lipids are metabolised** to release heat energy
  - This process occurs mainly in newborn infants, who cannot shiver so rely on this non-shivering thermogenesis
- **Boosting metabolic rate**
  - Most of the metabolic reactions in the body release heat
  - The hormone thyroxine is released from the thyroid gland, and acts to increase the basal metabolic rate (BMR), increasing heat production in the body

Thermoregulation negative feedback diagram



Thermoregulation is an example of negative feedback

Exam Tip

Remember that vasodilation and vasoconstriction are caused by the relaxing and contracting of muscles in the arterioles, **not** the capillaries; capillaries do not have muscles in their walls