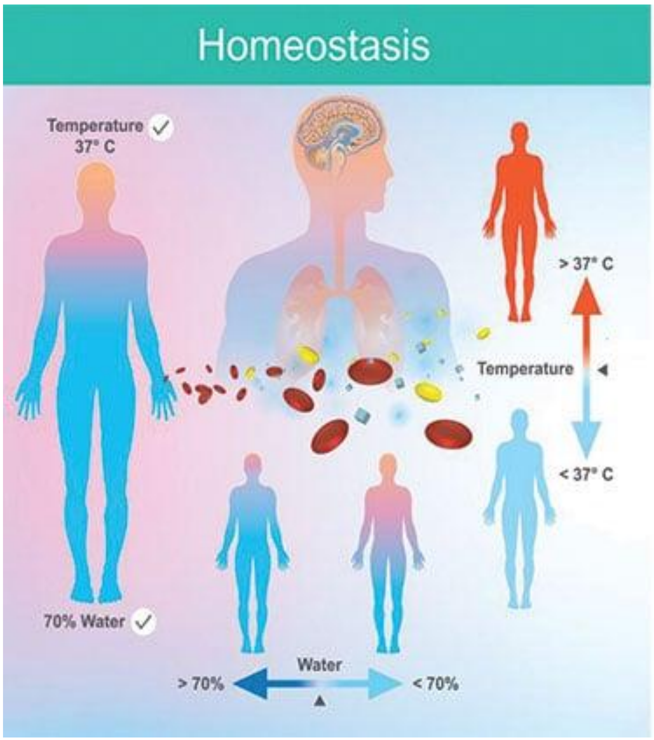
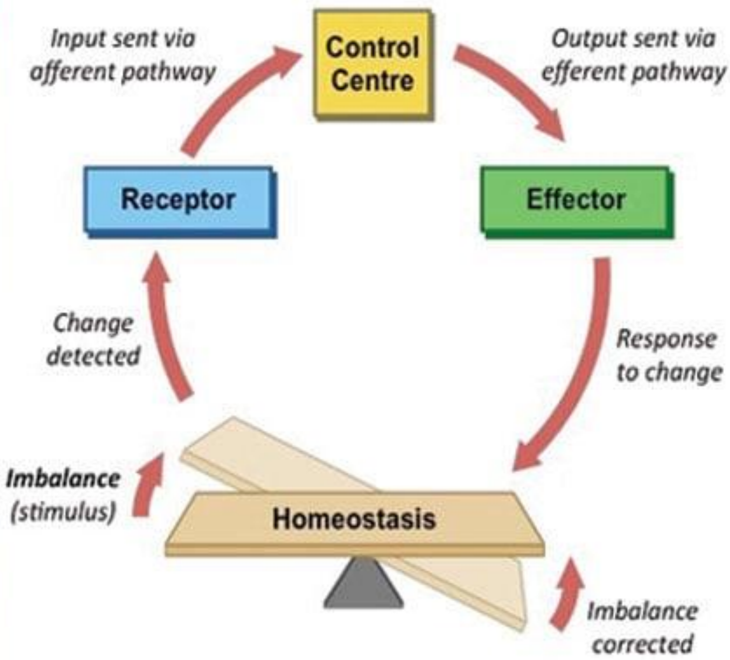
Homeostasis

Homeostasis is the ability of living systems to maintain a steady and uniform internal environment to allow the normal functioning of the systems.

- It is the tendency to achieve equilibrium against various natural and environmental factors.
- Homeostasis results in a dynamic equilibrium, where continuous changes keep on taking place, and yet steady conditions are maintained.
- Homeostasis is mainly involved in managing various internal variables of the living system like body temperature, pH of various fluids, the concentration of different ions, and the body sugar level.
- A number of regulatory mechanisms are employed to resist changes in the body against environmental and bodily factors.
- Homeostasis can be maintained by separate organs or by the entire body at once.





How homeostasis is maintained?

Maintaining homeostasis/Homeostasis Mechanisms

Homeostasis is maintained by a complex system that consists of individual units working in a particular sequence to balance a given variable. All homeostasis mechanisms consist of four separate units, which are:

1. Stimulus

- The stimulus is something that results in changes within the system involving the variable.
- The stimulus represents that the variable has moved away from its normal range, initiating the process of homeostasis.
- One example of this is the increased temperature of the body above 37°C due to various causes. The increased temperature indicates that the temperature of the body has gone higher than its higher range.

2. Sensor/ Receptor

- The sensor or receptor is the sensing unit of homeostasis, where it monitors and responds to the changes in the body.
- The changes in the system are realized by the sensor, which then sends the information to the control unit.
- The nerve cells and receptors like thermoreceptors and mechanoreceptors are examples of sensor/ receptors.

3. Control unit

- Once the information is sent to the control unit, it tallies the changed value to its normal value.
- If the value is different from the normal value, the control center activates the effectors against the stimulus.
- The thermoregulatory unit in the hypothalamus of the brain that controls the temperature of the body is an example of the control unit.

4. Effector

- Effectors can be muscles, organs, glands, or other similar structures that are activated as a result of the signal from the control unit.
- An effector is a target which is acted upon by the control unit to bring the value of variable back to normal.
- The effector essentially counteracts the stimulus to nullify its effect.
- In the case of thermoregulation, the sweat glands are effectors that are acted upon by the thermoregulatory unit to produce sweat so as to bring the value of body temperature back to its normal value.

Feedback Loops

A feedback loop is a biological system that helps to maintain homeostasis where the result of the system either enhances the system (positive feedback) or inhibits the system (negative feedback).

The feedback loop is activated when a change in a system results in an alarm that triggers an output. The output either supports the change or inhibits it.

There are two types of feedback loops that assist the process of homeostasis:

1. Negative feedback loop

- Most homeostatic processes are maintained by negative feedback loops.
- Negative feedback loops result in an output that tends to minimize the effect of the stimulus in order to stabilize the system.
- These loops tend to counteract the stimulus and act against the stimulus that might have triggered the system.
- Negative feedback loops are activated under two conditions;
    - In the first case, the activation is caused when the value of a variable (like body temperature) is above its normal value and thus has to be brought back down.
    - Under the other conditions, the activation is caused when the value of the variable is below the normal value and thus has to be brought back up.
- An example of a negative feedback loop is the production of RBCs by the kidneys when the decreased level of oxygen is sensed in the body.
- Negative feedback loops might occur in nature like in the case of carbon cycle where the cycle is balanced according to the concentration of carbon emission.

2. Positive feedback loop

- Some biological and natural systems might utilize positive feedback loops where the output of the loop tends to increase the effect of the stimulus.
- This loop is generally observed in processes that need to happen quickly and towards completion.
- Thus, positive feedback loops tend to move the process towards completion rather than towards equilibrium.
- An example of a positive feedback loop in the body is the process of childbirth. In this case, as the baby's head pushes the cervix, the neurons in that region are activated. This causes the brain to send signals to produce oxytocin which further increases the uterine contractions putting more pressure on the cervix, facilitating childbirth.
- Positive feedback loops, like negative loops, can be observed in nature during the ripening of the fruits in trees. After the ripening of one fruit, it gives off ethylene gas that when exposed to the nearby fruits, ripens them as well.

Types of Homeostatic Regulation in the body

A number of homeostatic regulation processes, balancing the chemical or physical parameters, take place in the human body. Generally, there are three types of homeostatic regulation in the body, which are:

1. Thermoregulation

- Thermoregulation is the process occurring inside the body that is responsible for maintaining the core temperature of the body.
- Thermoregulation works by the negative feedback loop where once the body temperature is either increased or decreased beyond its normal temperature, it is brought back to normal.
- Different homeostatic processes like sweating, dilation of blood vessels counteract the increased body temperature, whereas processes like contraction of blood vessels, and breakdown of adipose tissue to produce heat prevent the decreased body temperature.
- The process of thermoregulation is maintained by organs like skin and adipose tissue of the integumentary system and the hypothalamus of the brain.

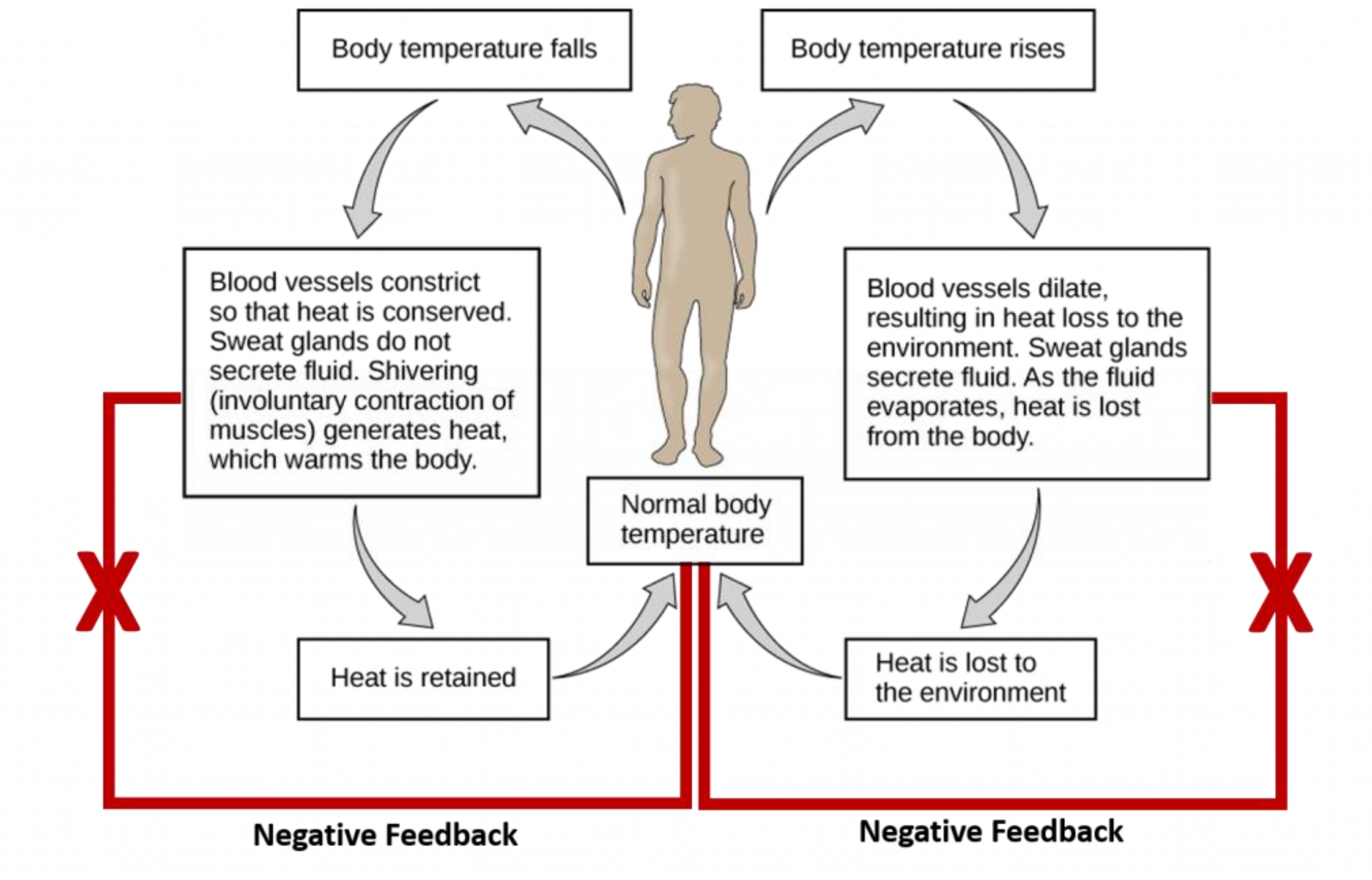


Figure: Homeostatic Regulation of Temperature in Humans. Core body temperature is maintained at a normal setpoint of 37oC. If the core temperature rises above (right hand side) or drops below (left hand side) the setpoint, internal biological responses are initiated to return the core temperature back to the setpoint range. Once this is achieved, negative feedback loops are initiated to down regulate the internal biological responses so that the core temperature doesn't overshoot the required change.

2. Osmoregulation

- Osmoregulation is the process of maintaining a constant osmotic pressure inside the body by balancing the concentration of fluids and salts.
- During this process, excess water or ions or other molecules like urea are removed from the body to maintain the osmotic balance.
- One classic example of this process is the removal of excess water and ions out of the blood in the form of urine to maintain the osmotic pressure of the blood.
- The rennin-angiotensin system and other hormones like antidiuretic hormones act as a messenger for the electrolytic regulation system of the body.

3. Chemical regulation

- Chemical regulation is the process of balancing the concentration of chemicals like glucose and carbon dioxide in the body by producing hormones.
- During this process, the concentration of hormones like insulin increases when the blood sugar level increases in order to bring the level back to normal.
- A similar process is observed in the respiratory system, where the rate of breathing increases as the concentration of carbon dioxide increases.

Examples

Acid-Base Homeostasis

- Acid-Base homeostasis is the process of regulating the pH value of the intracellular and extracellular fluids in the body.
- A pH balance of fluids in the body is crucial for the normal physiology of the body.
- A number of chemical buffers are present in different parts of the body that prevent changes in the pH of solutions.
- Another case of acid-base balance is observed in blood plasma where the excessive carbonic acid is broken down into hydrogen ion and bicarbonate ions.

- If the pH of the blood is low, the hydrogen ions are released into urine causing the pH to rise whereas if the pH of the blood is high, the bicarbonate ions are released into urine causing the pH to drop.

Glucose Homeostasis

- Glucose homeostasis is the process of maintaining a desirable level of glucose in the blood by the opposing and balanced action of insulin and glucagon hormones.
- The level of glucose in the blood is significant to balance the normal functioning of the body.
- When the level of glucose in low in blood as a result of prolonged fasting, the glucagon acts to convert the reserved glycogen into glucose to bring back the balance.
- Similarly, when the level of glucose is high in the blood, the insulin acts to convert glucose into glycogen to bring back the balance.
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Calcium homeostasis

- Calcium homeostasis is the process of balancing the level of calcium in the body.
- The skeletal system plays an essential role in maintaining calcium homeostasis. In addition, parathyroid hormone, vitamin D, and calcitonin also play an essential role.
- When the blood calcium level is low, the parathyroid hormone (PTH) causes osteoclastic activity that causes demineralization of bone to release calcium ions into the blood.
- At the same time, the PTH also increases calcium absorption in the kidneys, balancing the calcium levels in the blood.
- However, when the blood calcium level is high, the thyroid hormone releases calcitonin that inhibits the osteoclastic activity and stimulates the absorption activity of the bones.
- Similarly, the hormone also decreases the absorption of calcium by kidneys, thus maintaining the calcium levels.
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Fluid Homeostasis

- Fluid homeostasis is the process of maintaining the concentration of water and electrolyte in various bodily fluids.
- The principle of this concept is that the amount of water lost by the body must equal the amount of water taken to balance the fluid concentration in the body.

- When the fluid volume decreases, the electrolyte concentration of the fluid increases, this results in the activation of the pituitary gland that releases the antidiuretic hormone, which then stimulates the kidney to retain water.
- However, when the fluid volume increases, the electrolyte concentration of the fluid decreases. In this case, the adrenal cortex of the kidney is stimulated to release aldosterone hormone that directs the nephrons to retain sodium and other electrolytes.

Blood pressure homeostasis

- Blood pressure homeostasis is the process of maintaining blood pressure in the heart and blood vessels.
- When the blood pressure is high, the baroreceptors in the blood vessels are stretched more tightly, causing the parasympathetic nervous system to activate the circulatory system. This creates a decrease in cardiac output and vasodilation of blood vessels, resulting in falling of blood pressure.
- When the blood pressure is low, the stretching of baroreceptors in the blood vessels decreases. This triggers the sympathetic activation of the circulatory system, causing an increase in cardiac output and vasoconstriction. These activities, together, cause blood pressure to rise.

Applications/Importance

- Homeostasis is a necessary process that maintains the internal environment of living beings at optimum levels so that normal physiological processes can take place smoothly.
- As a result of homeostasis, the metabolic reactions are controlled by enzymes.
- Homeostasis allows the body to function even when the environment and other factors change.
- One of the clinical applications of homeostasis is the restoration of the immune system by phagocytic activity during sepsis caused by the therapeutic agent.
- Any failure in homeostatic regulation in any systems within the body affects the normal functioning of the system with some conditions that may even be fatal.

Disease as a Homeostatic Imbalance

What Is Disease?

Disease is any failure of normal physiological function that leads to negative symptoms. While disease is often a result of infection or injury, most diseases involve the disruption of normal homeostasis. Anything that prevents positive or negative feedback system from working correctly could lead to disease if the mechanisms of disruption become strong enough.

Aging is a general example of disease as a result of homeostatic imbalance. As an organism ages, weakening of feedback loops gradually results in an unstable internal environment. This lack of homeostasis increases the risk for illness and is responsible for the physical changes associated with aging. Heart failure is the result of negative feedback mechanisms that become overwhelmed, allowing destructive positive feedback mechanisms to compensate for the failed feedback mechanisms. This leads to high blood pressure and enlargement of the heart, which eventually becomes too stiff to pump blood effectively, resulting in heart failure. Severe heart failure can be fatal.

Diabetes: A Disease of Failed Homeostasis

Diabetes, a metabolic disorder caused by excess blood glucose levels, is a key example of disease caused by failed homeostasis. In ideal circumstances, homeostatic control mechanisms should prevent this imbalance from occurring. However, in some people, the mechanisms do not work efficiently enough, or the amount of blood glucose is too great to be effectively managed. In these cases, medical intervention is necessary to restore homeostasis and prevent permanent organ damage.

Normal Blood Sugar Regulation

The human body maintains constant levels of glucose throughout the day. After a meal, blood glucose levels rise, as glucose is transported from the small intestine into the blood stream. In response to this, the pancreas (the sensor) releases insulin into the bloodstream where it acts as a hormone. As you learned in Chapter 6, hormones are molecules that are made in one part of the body, secreted into the bloodstream and are transported to a distant part of the body, where they mediate an effect or reaction at that secondary target. Insulin is a peptide hormone that is released by the pancreas in response to elevated levels of blood glucose. Insulin binds with high efficiency to receptor proteins on the surface of liver cells, where it turns on signaling within the liver to increase the uptake of glucose from the bloodstream (Figure). Other body cells, such as skeletal muscle, adipose tissue, and brain cells are also activated by insulin. When a molecule has multiple different effects on the body, these multiple effects are called pleiotropic effects. These other cell types will also take up glucose to use as an energy source. This lowers blood glucose levels back to normal levels. The liver can take up more glucose than other tissue types and convert it into a large carbohydrate molecule called glycogen. It is stored as this carbohydrate until glucose is needed when it can then be broken down to released back into the blood stream. Up to 10% of the volume in liver cells is in the form of glycogen.

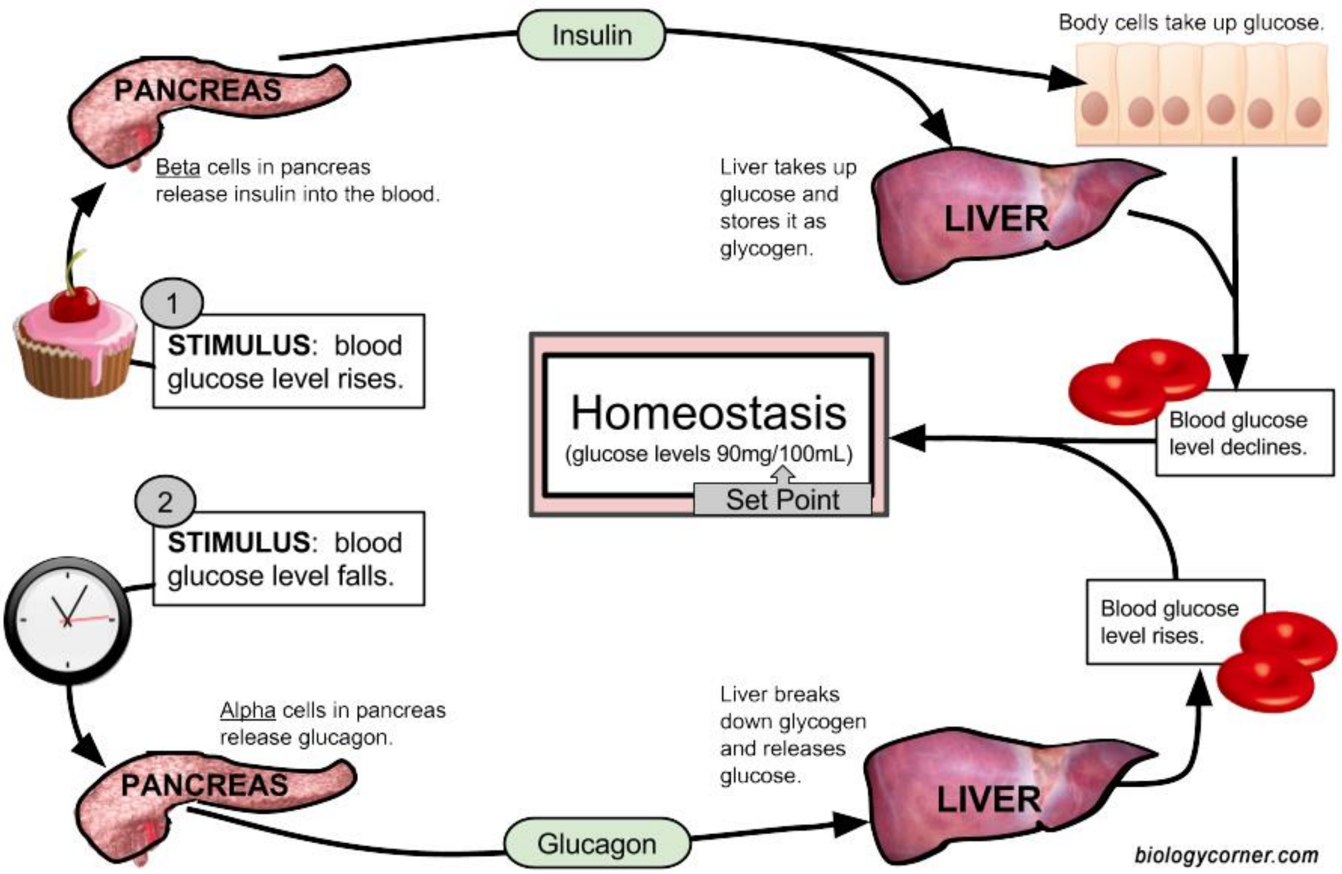
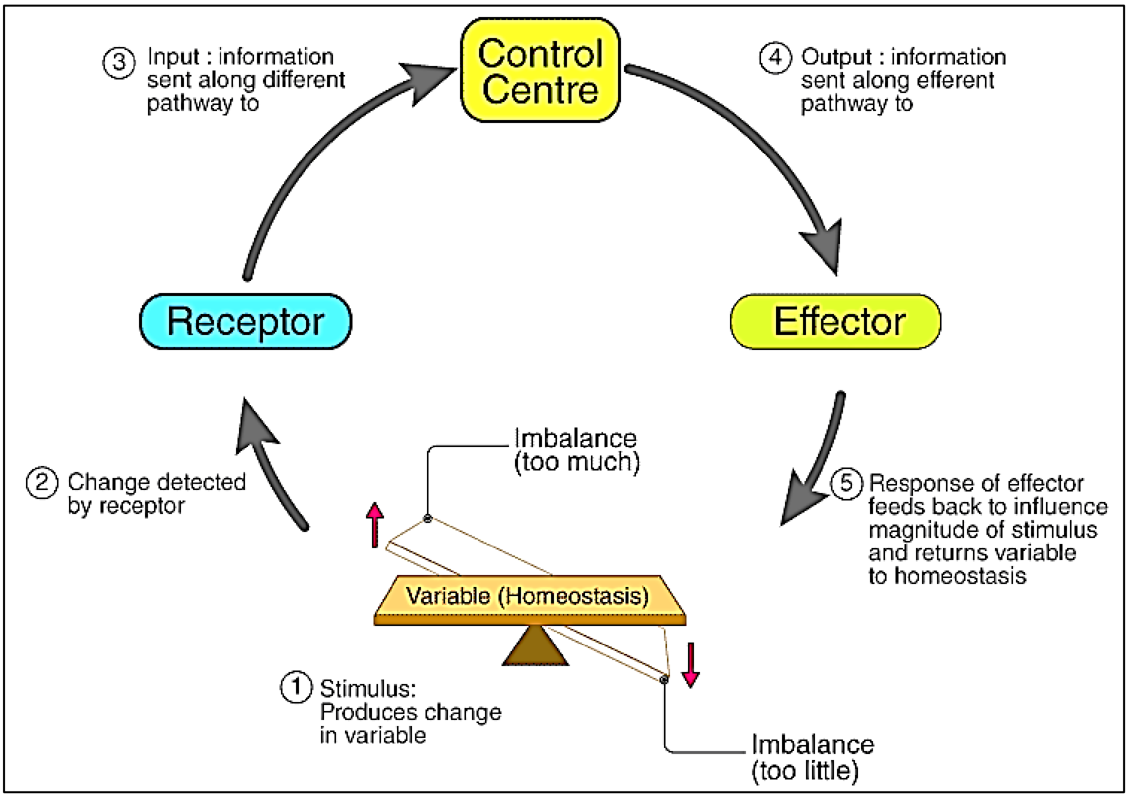


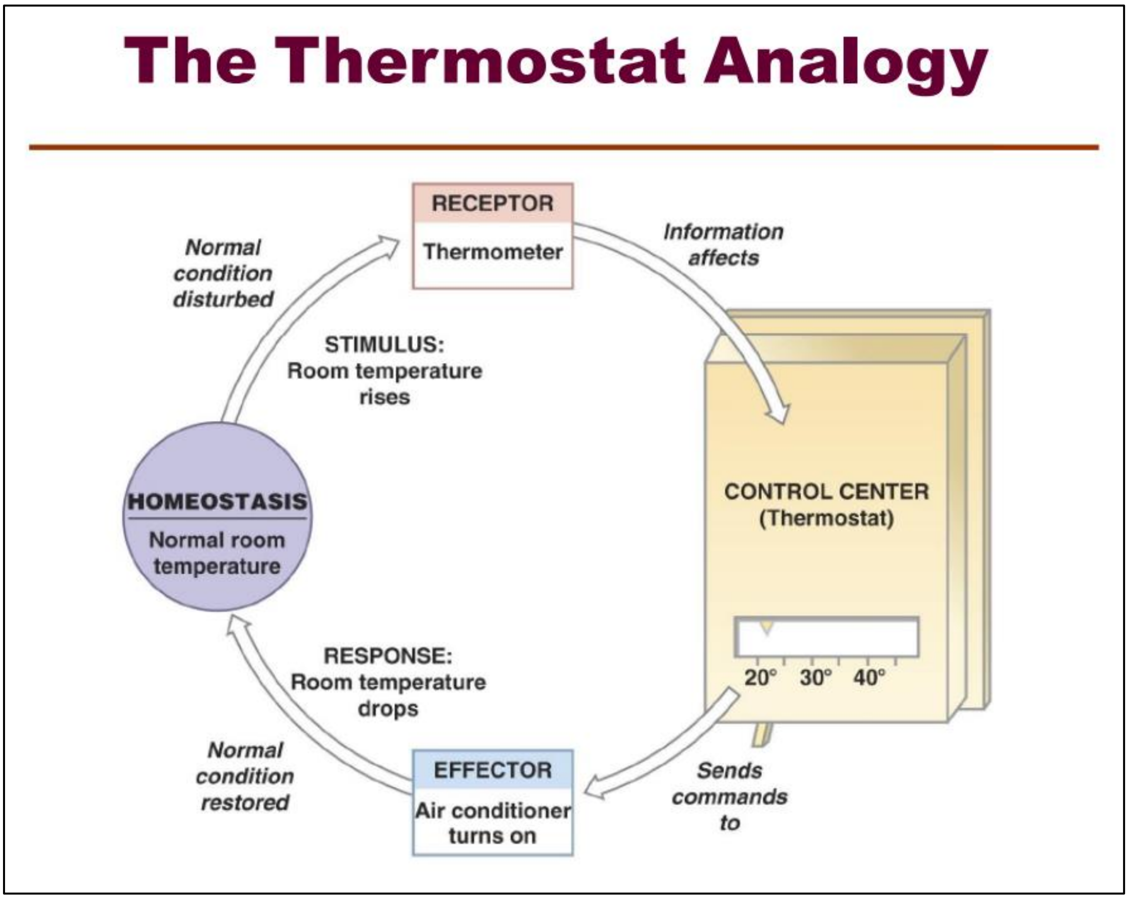
Figure: Glucose Homeostasis. When blood sugar rises due to a meal (Path 1), the pancreas senses the increase in blood glucose levels. In response, it releases the peptide hormone, insulin. Insulin interacts with downstream target cells in the body, including liver and muscle tissue, where it causes the uptake of glucose from the blood stream into the cell. The excess glucose is stored as the carbohydrate, glycogen. This returns blood glucose levels back to normal. If it has been several hours after eating a mean, blood glucose levels will begin to fall (Path 2). This signals liver cells to breakdown glycogen into glucose monomers. The glucose can then be realeased back into the bloodstream.

In between meals or during times of fasting, blood glucose levels begin to drop. This activates the pancreas to secrete a different hormone, called glucagon. Glucagon signaling activates the liver to begin breaking down the glycogen storage molecule into free glucose. The glucose is then released back into the blood stream, increasing blood glucose levels (Figure).

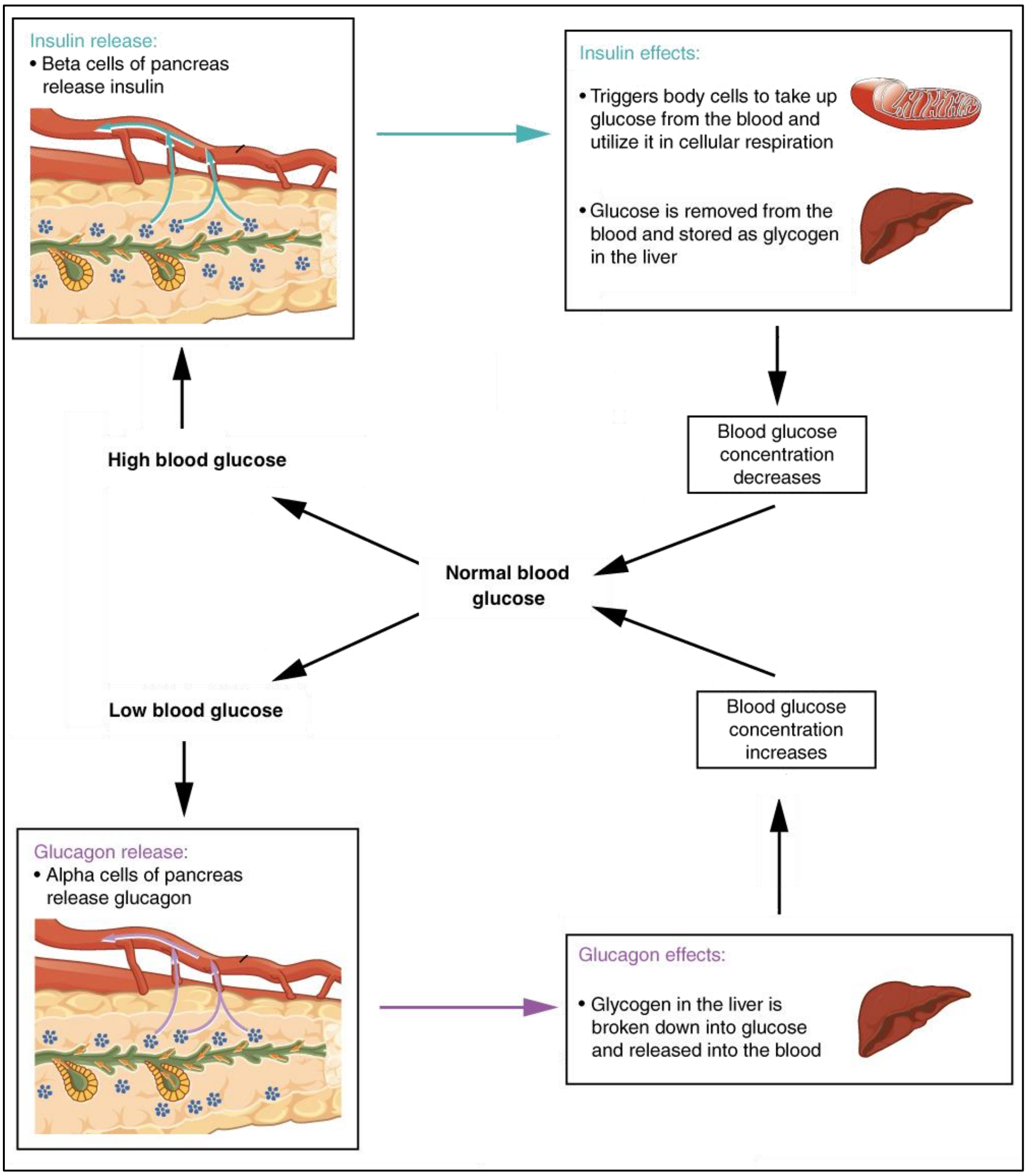
Over the course of a day, blood glucose levels will fluctuate modestly around the homeostatic set point. As meals are eaten, this triggers a rise in blood glucose that is counteracted by the secretion of insulin. In between meals, blood glucose levels fall, and glucagon is released by the pancreas to signal to the liver to release glucose back into the blood stream.

Further Reading……..





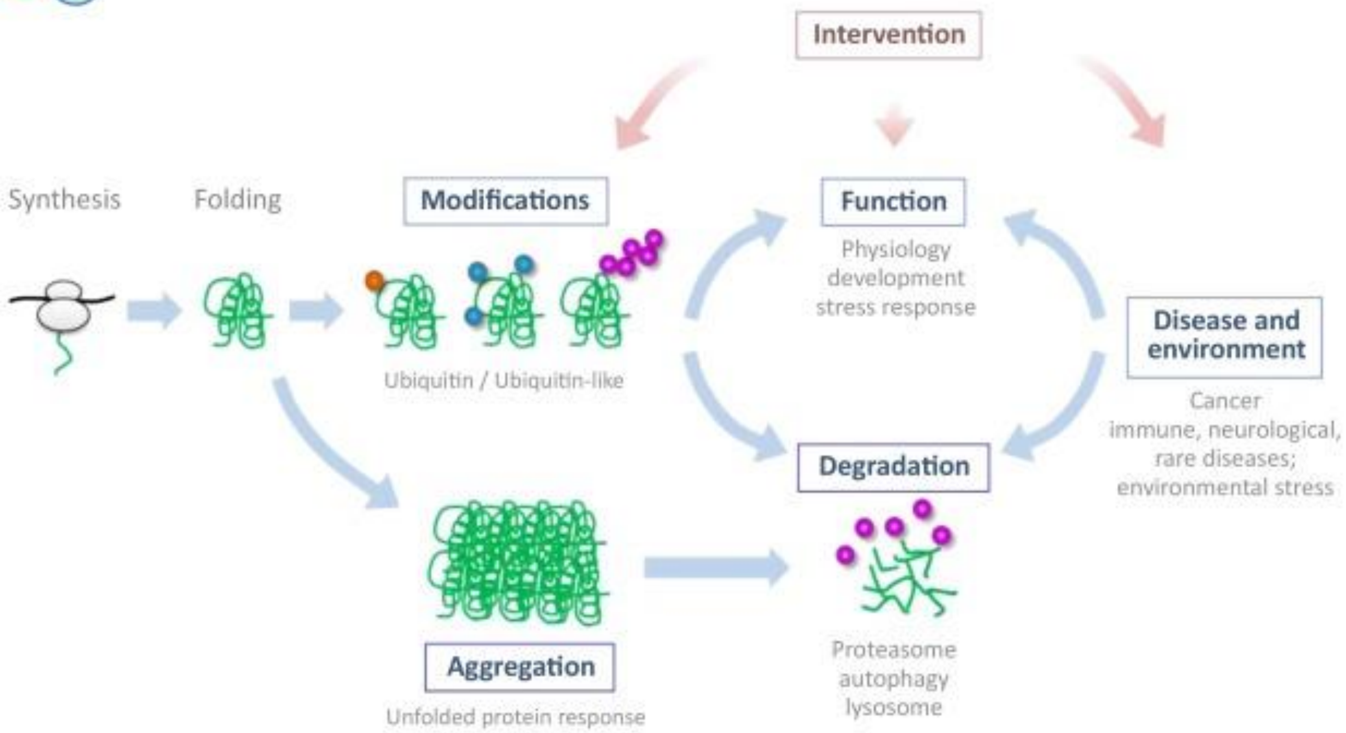
Glucose Homeostasis



Condition	**High Blood Sugar** Toxic	**Low Blood Sugar** Do not meet energy requirements of cell
Receptor	Glucose transporter	Glucose transporter
Control Center	β-cell of the pancreas	α-cell of the pancreas
Effector	Insulin	Glucagon
Result	Glucose uptake by muscle/fat tissue Lowers blood-glucose	Liver breaks down glycogen to create glucose Raises blood-glucose

PROTEOSTASIS

Areas of study



Trends in Biochemical Sciences