

The University of Jordan
Department of Physiology and Biochemistry
Medical students

Introduction to Homeostasis and Control systems

Follow the links:

<https://www.youtube.com/watch?v=LSgEJSIk6W4>

<https://letstalkscience.ca/educational-resources/backgrounders/introduction-homeostasis-and-regulation>

Questions:

What we mean by baroreceptors?

Introduction

- Lecture will cover the basic concepts of physiological functions of various body systems and the importance of maintaining homeostasis for the survival of cells and performing optimal functions.

- General body structures from cells to systems.

- All cells are bathed in a solution called extracellular fluid which represents the internal environment.

All body systems are working to keep constant parameters of internal environment.

- Homeostasis refers to the inclination to prevent alterations of various parameters in a body and uphold a steady and relatively stable internal environment. In another word it refers to keeping constancy of internal environment.

Why it is needed?

There is a need for optimal conditions that are required for the survival of cells.

Typically, homeostasis entails the utilization of negative feedback loops that counterbalance deviations from the desired values, also known as set points. In contrast, positive feedback loops intensify the initial stimuli, thereby steering the system away from its initial state.

Homeostasis, the tendency to uphold a stable internal environment, encompasses more than just temperature regulation. The body also ensures the steady concentration of various ions like Na⁺,

Ca⁺⁺, K⁺, pH levels, and glucose concentration in the blood. Deviations from their constant values can lead to severe illness.

Homeostasis operates at multiple levels, not limited to the entire body's temperature regulation. For instance, the stomach maintains a distinct pH compared to surrounding organs, and individual cells maintain different ion concentrations than the surrounding fluid. Maintaining homeostasis at each level is crucial for the overall functioning of the body.

Maintaining homeostasis: EXAMPLES

Biological systems, such as the human body, are constantly being pushed away from their equilibrium points. When you engage in physical activity, for example, your muscles generate more heat, causing your body temperature to rise. Similarly, consuming a glass of fruit juice leads to an increase in blood glucose levels. The maintenance of homeostasis relies on your body's ability to detect and counteract these changes.

The preservation of homeostasis typically involves negative feedback loops, which work to counter the initial stimulus or cue that triggers them. If your body temperature becomes too high, a negative feedback loop will be activated to bring it back towards the desired set point or target value (normal body temperature).

So, how does this process work? Initially, sensors, primarily receptors located at the nerve terminals in your skin, which their cell body located in the central nervous structures (together forming sensory pathways), detect the elevated temperature and transmit this information to a temperature-regulatory control center in your brain. The control center then processes the data and initiates a response through effectors, such as sweat glands, which work to counteract the stimulus by reducing body temperature.

Question: why keeping constant body temperature is important for systemic functions?

What body systems are involved in controlling body temperature?

Why keeping constant pH is important?

What body systems are involved in controlling pH?

1. A negative feedback loop consists of four fundamental components: a stimulus, a sensor, a control, and an effector.
2. Negative feedback is responsible for regulating body temperature. The stimulus occurs when the body temperature surpasses 37 degrees Celsius, the sensors are nerve endings located in the skin and brain, the control is the temperature regulatory center in the brain, and the effector refers to the sweat glands distributed throughout the body.

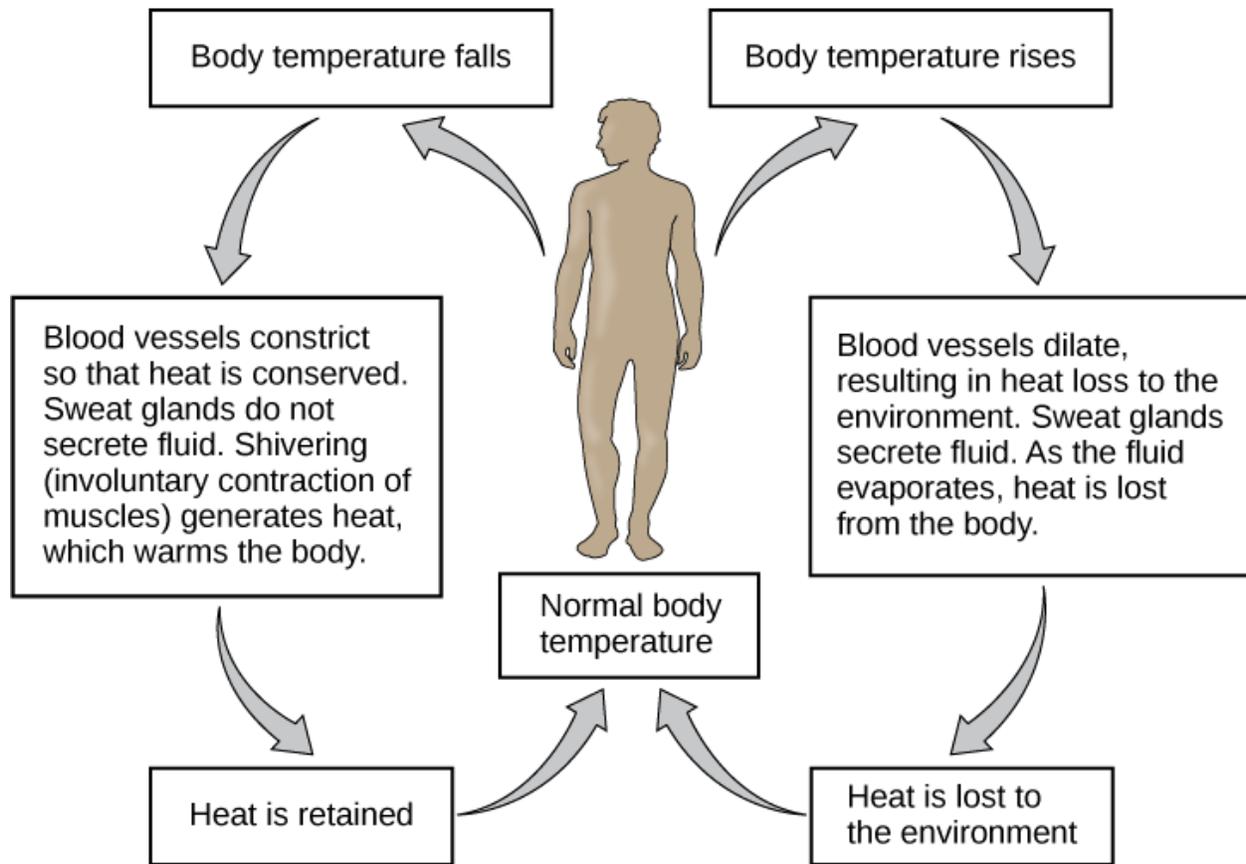


Image credit: [Homeostasis: Figure 4](#) by OpenStax College, Biology, [CC BY 4.0](#)

<https://courses.lumenlearning.com/suny-ap1/chapter/homeostasis-and-feedback-loops/>

Certainly, body temperature does not only exceed its target value, but it can also fall below this value. Typically, homeostatic circuits involve at least two negative feedback loops:

One is activated when a parameter, such as body temperature, surpasses the set point and aims to lower it.

One is activated when the parameter falls below the set point and aims to raise it.

To illustrate this concept further, let's examine the opposing feedback loops that govern body temperature control.

Temperature regulation in homeostatic responses

If there is an increase or a decrease in body temperature, sensors in both the periphery and the brain inform the temperature regulation center of your brain, specifically the hypothalamus region, that your temperature has deviated from its set point.

For example, in the event that you have been engaging in rigorous physical activity, your body temperature may exceed its designated level, necessitating the activation of cooling mechanisms. This involves an increase in blood flow to your skin to expedite heat dissipation into the surrounding environment. Additionally, you may experience sweating, as the evaporation of sweat from your skin aids in cooling you down. Furthermore, heavy breathing can contribute to the loss of heat.

When the body temperature becomes excessively high, the blood vessels expand, sweat glands release fluid, and the body dissipates heat. Consequently, as heat is released into the surroundings, the body temperature gradually reverts back to its normal state.

However, in the event that you find yourself in a chilly environment without adequate clothing, the brain's temperature center will activate mechanisms to warm you up. This includes reducing blood flow to the skin, causing shivering to generate additional heat in the muscles. Additionally, you may experience goose bumps, which raise the hair on your body and create a layer of air near the skin, as well as an increase in the release of heat-producing hormones.

Disruptions to feedback disrupt homeostasis.

Disruptions to the feedback mechanisms can have a significant impact on homeostasis. Homeostasis relies on negative feedback loops, and any interference with these loops can disrupt the balance. This disruption can lead to various diseases, such as diabetes.

Diabetes is a prime example of a disease that arises from a malfunctioning feedback loop involving insulin. When this feedback loop is broken, the body struggles to regulate high blood sugar levels effectively, making it challenging to bring them down to a healthy level.

To understand how diabetes develops, it's essential to grasp the fundamentals of blood sugar regulation. In a healthy individual, insulin and glucagon, two hormones, work together to control blood sugar levels.

Insulin plays a crucial role in reducing glucose concentration in the blood. After a meal, blood glucose levels increase, prompting the pancreas's β cells to secrete insulin. This hormone acts as a signal, prompting cells throughout the body, including fat and muscle cells, to absorb glucose for energy. Additionally, insulin facilitates the conversion of glucose into glycogen, a storage molecule found in the liver. Both processes help remove sugar from the blood, lowering blood sugar levels, reducing insulin secretion, and restoring overall homeostasis.

When blood glucose concentration exceeds the normal range, insulin is released to stimulate body cells to remove excess glucose from the blood. Conversely, if blood glucose concentration falls

below the normal range, glucagon is released to encourage body cells to release glucose into the bloodstream.

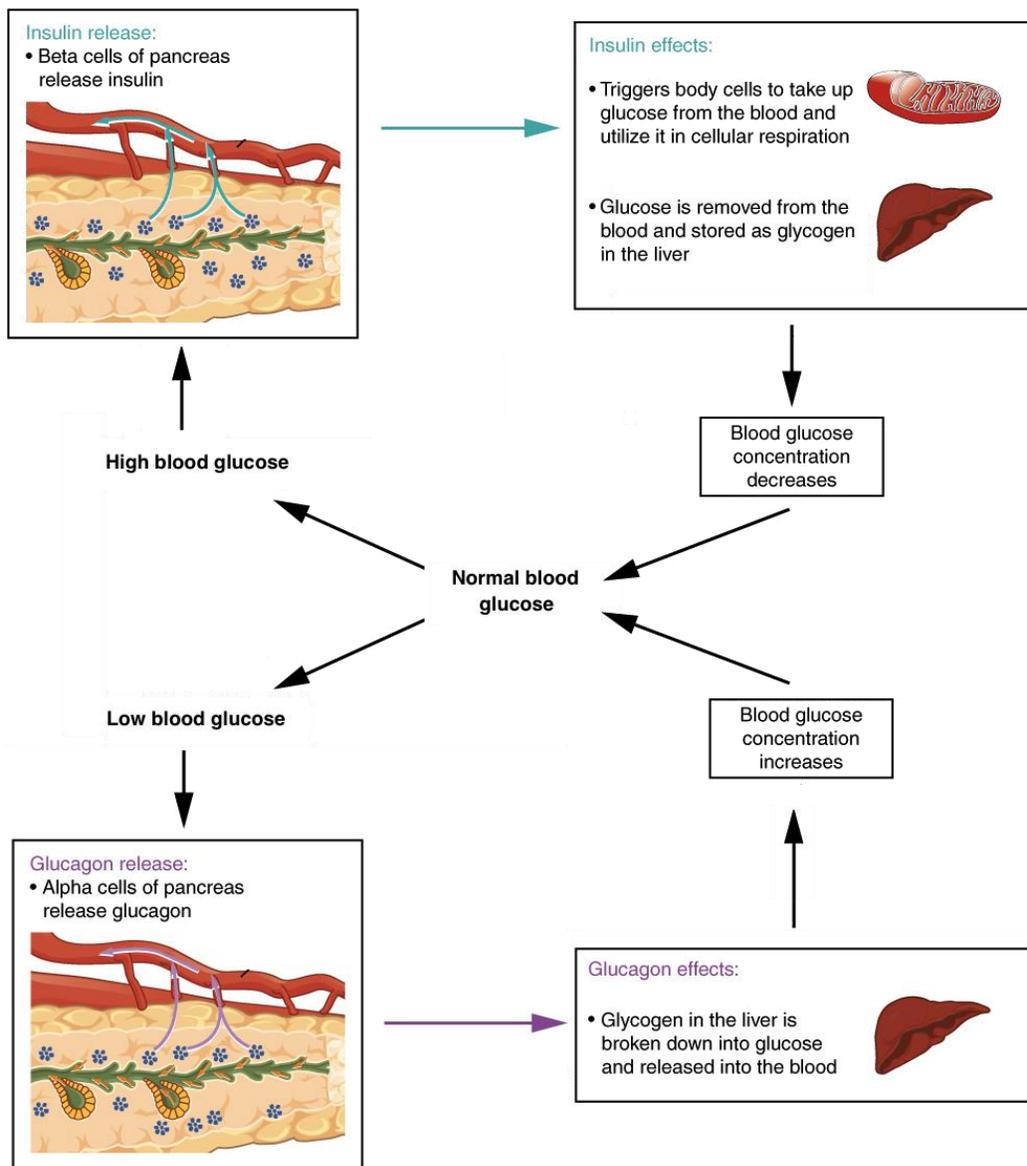


Image credit: modified from [The endocrine pancreas: Figure 2](#) by OpenStax College, Anatomy & Physiology, [CC BY 4.0](#)

Glucagon functions in the opposite manner, as it elevates the concentration of glucose in the bloodstream. In the absence of food intake for an extended period, the decline in blood glucose levels triggers the release of glucagon from the α cells in the pancreas. Glucagon then acts upon the liver, prompting the breakdown of glycogen into glucose, which is subsequently released into the bloodstream. This process effectively raises blood sugar levels, leading to a reduction in glucagon secretion and the restoration of homeostasis within the system.

Diabetes occurs when the pancreas fails to produce sufficient insulin, or when the body's cells become unresponsive to insulin, or both. Consequently, under these circumstances, the cells in the body do not efficiently absorb glucose, resulting in prolonged high blood sugar levels following a meal. This occurs due to two primary reasons:

1. Insufficient glucose uptake by muscle and fat cells, leading to fatigue and potential wasting of muscle and fat tissues.
2. Elevated blood sugar levels causing symptoms such as frequent urination, increased thirst, and even dehydration. Over time, this can give rise to more severe complications.

Positive Feedback

Homeostatic circuits typically involve negative feedback loops, which are characterized by their ability to counteract changes and bring a parameter back towards its set point. However, there are some biological systems that utilize positive feedback loops. Unlike negative feedback loops, positive feedback loops amplify the initial signal and are commonly found in processes that require completion rather than maintaining the original status.

One example of a positive feedback loop is observed during childbirth. When the baby's head presses on the cervix, it activates neurons that send a signal to the brain. This signal triggers the release of **oxytocin** from the pituitary gland. Oxytocin **then increases uterine contractions**, leading to more pressure on the cervix. This, in turn, causes the release of even more oxytocin and stronger contractions. The positive feedback loop continues until the baby is born.

It is important to note that normal childbirth is driven by a positive feedback loop, which results in a change in the body's status rather than a return to homeostasis. The feedback loop in this case is drawn clockwise.

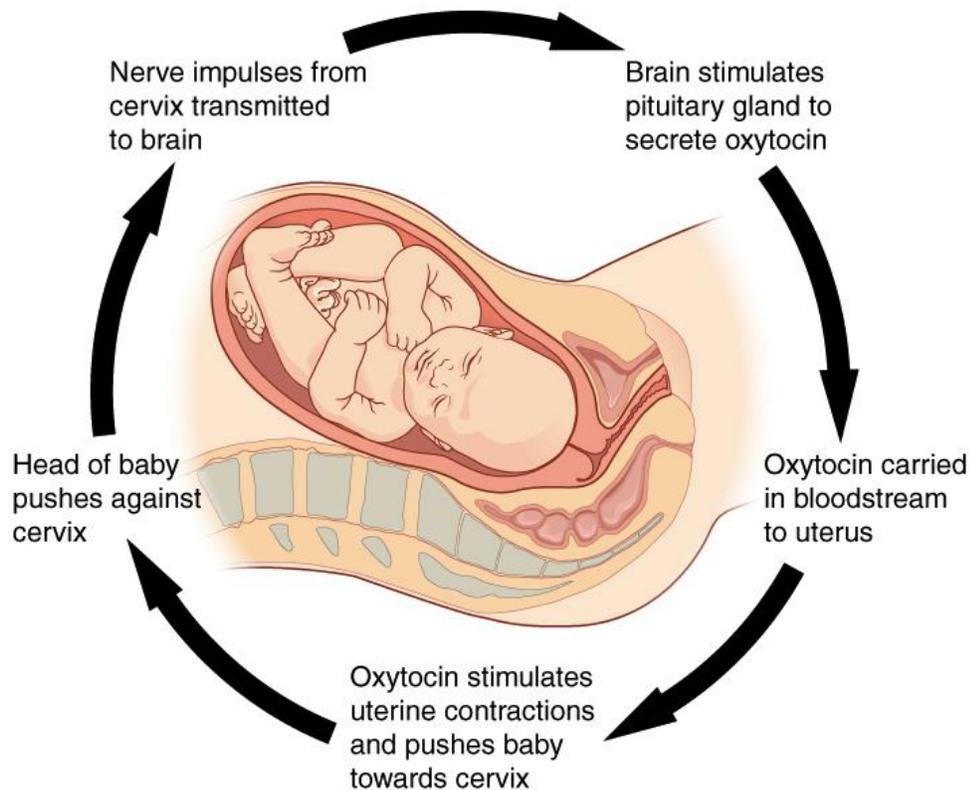


Image credit: [Homeostasis: Figure 2](#) by OpenStax College, Anatomy & Physiology, [CC BY 4.0](#)

1. The transmission of nerve impulses from the cervix to the brain initiates a series of events.
2. Subsequently, the brain triggers the pituitary gland to release oxytocin into the bloodstream.
3. The oxytocin then travels through the bloodstream and reaches the uterus.
4. Once in the uterus, oxytocin stimulates contractions, which in turn push the baby towards the cervix.
5. As the baby's head presses against the cervix, the process continues in a repetitive cycle.

Other examples: increased venous return to the right ventricle → triggers the increase in the force of contraction of cardiac muscle and increase the amount of blood ejected from ventricle.

Summary:

Negative feedbacks serve as the body's mechanism to maintain normalcy or stability,

While, positive feedbacks intensify the specific outcomes or responses and ensure the repetition of a specific function.

Cell and organelles

Useful Links:

Organelles:

<https://www.youtube.com/watch?v=0xe1s65IH0w&t=9s>

Mitochondria

<https://www.youtube.com/watch?v=c4JsEBI9u6I>

electron transport system and oxidative phosphorylation:

<https://www.youtube.com/watch?v=fHoL-vcMENw>

Cell as an active system:

Contains organelles that perform functions to maintain the living of the cell and the survival of the whole body:

Synthesis of its components:

Synthesis of highly energetic compounds

Synthesis of functional compounds that could be secreted --> perform a function in the body by affecting the activity of other cells.

Organelles:

Nucleus:

Contains DNA (arranged structure of deoxyribonucleic acids) which has an importance for genetic control:

*Genes (DNA) are important for protein synthesis. Gene is transcribed, mRNA is formed then translated to synthesize proteins which function as :

enzymes, cellular structure, secretory proteins

all are important for cell functions.

*Genes also are important for cell replication.

Nucleoli: (RNA + Protein)

rRNA that resulted from genes ---> fibrillar RNA (stored in nucleoli) ---> granular RNA (ribosomal subunits) which is transported through the nuclear membrane to the cytoplasm where they assemble to form RIBOSOMES

Nuclear membrane:

Separates the cytoplasm from nuclear content. It is formed of 2 separate membranes: the outer one continuous with the endoplasmic reticulum. The space between the two membrane is also continuous with the compartment inside the endoplasmic reticulum.

Contains pores that allowing only very small molecules to pass to the nucleus.

Cytoplasmic organelles:

Endoplasmic reticulum (ER):

Cytoplasmic membranous bilayer structure that lined a fluid filled space of tubules and flattened sacs.

2 types of ER are found in the cell:

*Rough (granular) ER: to which ribosomes are attached.

Provide site for protein synthesis.

*Smooth (agranular) ER: does NOT contain ribosomes

Synthesis of lipids including the membranous bilayer.

It has specialized function in muscle as a storage organelle (sarcoplasmic reticulum where Ca^{++} is stored).

Golgi apparatus:

Membranous structure of 4 or more stacked layers.

Important for secretion of substances synthesized in the cell.

At this site:

- Finishing of raw materials into their final products.
- Sorting and directing of finished products to their final destination.

It performs a complex activity to finalize the raw materials then sort them according to their destination in the cell. These final products are packed into coated vesicles that bud off from the Golgi apparatus, which then transported to their destination by a mean of vesicular transport system found in the cell. The transported vesicles then fuse with the membranous structure at the destination.

The coat of the vesicles contains recognition markers that recognize the final products of materials in the Golgi apparatus where they can attach and at the outside contains

docking markers that can dock the vesicle with the membrane of appropriate destination where they can fuse.

Lysosomes:

These vesicular organelles are formed by Golgi apparatus. They contain powerful hydrolytic enzymes capable for digesting food particles, cellular debris and foreign bodies that are brought into the interior of the cell by a process called endocytosis. The vesicular membrane protects the cytoplasmic structures from the hydrolytic activity of the enzymes and the low pH of the vesicular content.

At lysosomes, there is also recycling of some functional membranous proteins that are brought to the interior of the cell. Some receptors are internalized when bound to their ligands (known as receptor mediated endocytosis). The lysosomes hydrolyze the ligands and recycle the receptors, which then transported back to the cell membrane.

Peroxisomes:

Smaller vesicles than lysosomes (1/3-1/2 of average size of lysosomes). Houses oxidative enzymes and catalase. These vesicles are important for detoxification of various wastes products or ingested alcohol by combining O₂ with H⁺ from different intracellular chemicals to form Hydrogen peroxide (H₂O₂). The formed H₂O₂ is very powerful oxidant which oxidizes many substances that could be poisonous to the cell.

H₂O₂ is very harmful for the cell structures. The vesicles contain also **catalase** (antioxidant enzyme) which decomposes H₂O₂ into H₂O and O₂).

Mitochondria:

These organelles are important in extracting significant amount of energy from nutrients. The energy then stored into a usable form to energize cellular activities.

This organelle has an oval shape. Composed of 2 membranous structures. A smooth outer membrane and folded inner membrane. The folds of the inner membrane projects toward the centers to form shelves (cristae). The inner membrane separates two compartments inside the mitochondria. The inter-membranous space and matrix.

The matrix consists of concentrated enzymes (citric acid cycle enzymes) which prepare food stuff for final extraction of usable energy.

Production of energy in mitochondria:

The energy resulted from flowing back of H⁺ from the intermembranous space where they are found at high concentration to the matrix through a channel formed by a protein structure known as **ATP-synthetase** will phosphorylate ADP to form the highly energetic compound know as ATP which is a usable form of energy for cellular activities.

The process in which O₂ is consumed by the mitochondria for final production of highly energetic molecules is known as oxidative phosphorylation.

Cytoskeleton:

***Microtubules:** It is the largeset cytoskeletal element. Appears as long hollow, unbranched tubes composed primarily of tubulin (small globular protein).

These structures maintain the asymmetrical shape of cells such as stabilizing asymmetrical axonal extensions in neurons.

Functions:

1. Vesicular transport: with the help of a specific protein particle that can walk along the microtubules known as **kinesin**. This structure can bind to the vesicle and move them along the tubules to different destination in the cell.
2. Movement of cilia and flagella: ensured with the help of an accessory motor protein known as **dynein** that extends between the microtubules within a cilium. The powered activity of dynein will cause a relative sliding of microtubules, which bends cilia.
3. Formation of mitotic spindle: the transient assembly of microtubules into mitotic spindle during cell division will organize and direct the movement of replicated chromosomes away from each others toward the opposite ends of the cell.

***Microfilaments:** composed of actin double helix. In muscle there is also myosin microfilaments involved in muscle contractions.

Functions:

1. Contractile system: such as muscle contraction and amoeboid movements of cells.
2. Mechanical stiffener for specific cellular projections: such as microvilli of the enterocytes.

In addition to these, cytoskeletal structures cells contain: **intermediate filaments** (such as neurofilaments) and **microtrabecular lattice**. In association with other cytoskeletal proteins, these elements strengthen and stabilize plasma and maintain shape, rigidity and spatial geometry of the cells.