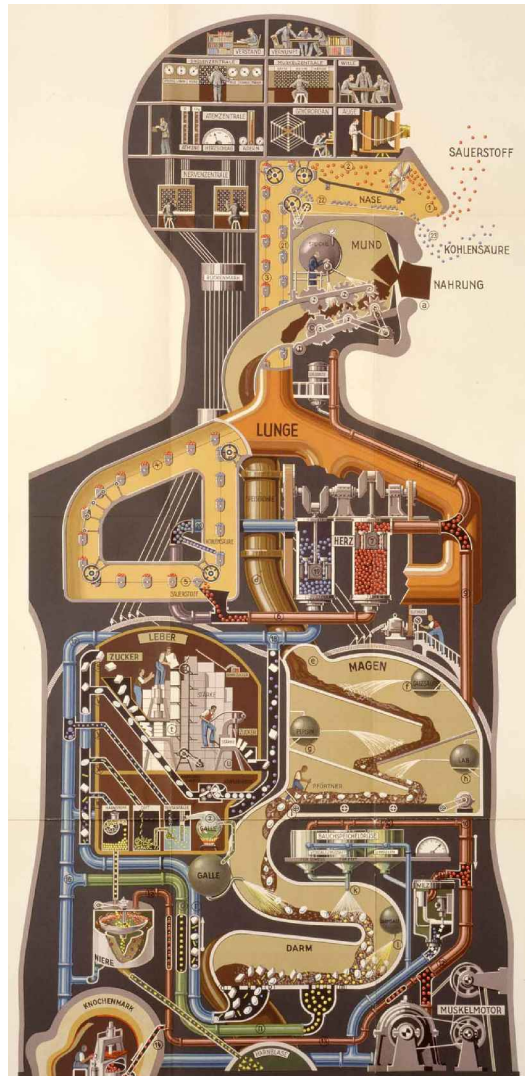


# HUMAN PHYSIOLOGY

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*Cover: Der Mensch als Industriepalast (Man as Industrial Palace)* by Fritz Kahn.

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## Introduction

**Human physiology** is the study of the functioning of the normal body, and is responsible for describing *how* various systems of the human body work. Explanations often begin at a macroscopic level and proceed to a molecular level. In 1926, Fritz Kahn portrayed the body as a complex chemical plant, as seen in the painting on the right. This textbook provides an introductory explanation of the workings of the human body, with an effort to draw connections between the body systems and explain their interdependencies. A framework for the book is homeostasis and *how* the body maintains balance within each system. This is intended as a first introduction to physiology for a college-level course. As such, some material is deliberately left out (but references will be provided within chapters for students wishing to learn more).

# 1 HOMEOSTASIS

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## Overview

The human body consists of trillions of cells all working together for the maintenance of the entire organism. While cells may perform very different functions, all the cells are quite similar in their metabolic requirements. Maintaining a constant internal environment with all that the cells need to survive (oxygen, glucose, mineral ions, waste removal, and so forth) is necessary for the well-being of individual cells and the well-being of the entire body. The varied processes by which the body regulates its internal environment are collectively referred to as homeostasis.

## What is Homeostasis?

**Homeostasis** in a general sense refers to stability, balance or equilibrium. Maintaining a stable internal environment requires constant monitoring and adjustments as conditions change. This adjusting of physiological systems within the body is called homeostatic regulation.

Homeostatic regulation involves three parts or mechanisms: 1) the *receptor*, 2) the *control center* and 3) the *effector*.

The *receptor* receives information that something in the environment is changing. The *control center* or *integration center* receives and processes information from the *receptor*. And lastly, the *effector* responds to the commands of the *control center* by either opposing or enhancing the stimulus.

A metaphor to help us understand this process is the operation of a thermostat. The thermostat monitors and controls room temperature. The thermostat is set at a certain temperature that is considered ideal, the *set point*. The function of the thermostat is to keep the temperature in the room within a few degrees of the *set point*. If the room is colder than the *set point*, the thermostat receives information from the thermometer (the *receptor*) that it is too cold. The *effectors* within the thermostat then will turn on the heat to warm up the room. When the room temperature reaches the *set point*, the *receptor* receives the information, and the thermostat "tells" the heater to turn off. This also works when it is too hot in the room. The thermostat receives the information and turns on the air conditioner. When the *set point* temperature is reached, the thermostat turns off the air conditioner.

Our bodies control body temperature in a similar way. The brain is the control center, the receptor is our body's temperature sensors, and the effector is our blood vessels and sweat glands in our skin. When we feel heat, the temperature sensors in our skin send the message to our brain. Our brain then sends the message to the sweat glands to increase sweating and increase blood flow to our skin. When we feel cold, the opposite happens. Our brain sends a message to our sweat glands to decrease sweating, decrease blood flow, and begin shivering. This is an ongoing process that continually works to restore and maintain homeostasis.

Because the internal and external environment of the body are constantly changing and adjustments must be made continuously to stay at or near the set point, homeostasis can be thought of as a *dynamic equilibrium*.

## Positive and Negative Feedback

When a change of variable occurs, there are two main types of feedback to which the system reacts:

- **Negative feedback:** a reaction in which the system responds in such a way as to reverse the direction of change. Since this tends to keep things constant, it allows the maintenance of homeostasis. For instance, when the concentration of carbon dioxide in the human body increases, the lungs are signaled to increase their activity and expel more carbon dioxide. Thermoregulation is another example of negative feedback. When body temperature rises (or falls), receptors in the skin and the hypothalamus sense a change, triggering a command from the brain. This command, in turn, effects the correct response, in this case a decrease in body temperature.
- **Home Heating System Vs. Negative Feedback:** When you are home, you set your thermostat to a desired temperature. Let's say today you set it at 70 degrees. The thermometer in the thermostat waits to sense a temperature change either too high above or too far below the 70 degree set point. When this change happens the thermometer will send a message to the "Control Center", or thermostat, which in turn will then send a message to the furnace to either shut off if the temperature is too high or kick back on if the temperature is too low. In the home-heating example the air temperature is the "NEGATIVE FEEDBACK." When the Control Center receives negative feedback it triggers a chain reaction in order to maintain room temperature.
- **Positive feedback:** a response is to amplify the change in the variable. This has a destabilizing effect, so does not result in homeostasis. Positive feedback is less common in naturally occurring systems than negative feedback, but it has its applications. For example, in nerves, a threshold electric potential triggers the generation of a much larger action potential. Blood clotting and events in childbirth are other types of positive feedback.

'\***Harmful Positive Feedback**' Although Positive Feedback is needed within Homeostasis it also can be harmful at times. When you have a high fever it causes a metabolic change that can push the fever higher and higher. In rare occurrences the the body temperature reaches 113 degrees the cellular proteins stop working and the metabolism stops, resulting in death.

**Summary:** Sustainable systems require combinations of both kinds of feedback. Generally with the recognition of divergence from the homeostatic condition, positive feedbacks are called into play, whereas once the homeostatic condition is approached, negative feedback is used for "fine tuning" responses. This creates a situation of "metastability," in which homeostatic conditions are maintained within fixed limits, but once these limits are exceeded, the system can shift wildly to a wholly new (and possibly less desirable) situation of homeostasis.

### *Homeostatic systems have several properties*

- They are ultra-stable, meaning the system is capable of testing which way its variables should be adjusted.
- Their whole organization (internal, structural, and functional) contributes to the

maintenance of balance.

- Physiology is largely a study of processes related to homeostasis. Some of the functions you will learn about in this book are not specifically about homeostasis (e.g. how muscles contract), but in order for all bodily processes to function there must be a suitable internal environment. Homeostasis is, therefore, a fitting framework for the introductory study of physiology.

### Where did the term "Homeostasis" come from?

The concept of homeostasis was first articulated by the French scientist Claude Bernard (1813-1878) in his studies of the maintenance of stability in the "milieu interior." He said, "All the vital mechanisms, varied as they are, have only one object, that of preserving constant the conditions of life in the internal environment" (from *Leçons sur les Phénomènes de la Vie Commune aux Animaux et aux Végétaux*, 1879). The term itself was coined by American physiologist Walter Cannon, author of *The Wisdom of the Body* (1932). The word comes from the Greek *homoios* (same, like, resembling) and *stasis* (to stand, posture).

### Cruise Control on a car as a simple metaphor for homeostasis

When a car is put on cruise control it has a set speed limit that it will travel. At times this speed may vary by a few miles per hour but in general the system will maintain the set speed. If the car starts to go up a hill, the systems will automatically increase the amount of fuel given to maintain the set speed. If the car starts to come down a hill, the car will automatically decrease the amount of fuel given in order to maintain the set speed. It is the same with homeostasis- the body has a set limit on each environment. If one of these limits increases or decreases, the body will sense and automatically try to fix the problem in order to maintain the pre-set limits This is a simple metaphor of how the body operates--constant monitoring of levels, and automatic small adjustments when those levels fall below (or rise above) a set point.

## Pathways That Alter Homeostasis

A variety of homeostatic mechanisms maintain the internal environment within tolerable limits. Either homeostasis is maintained through a series of control mechanisms, or the body suffers various illnesses or disease. When the cells in your body begin to malfunction, the homeostatic balance becomes disrupted. Eventually this leads to disease or cell malfunction. Disease and cellular malfunction can be caused in two basic ways: either, *deficiency* (cells not getting all they need) or *toxicity* (cells being poisoned by things they do not need). When homeostasis is interrupted in your cells, there are *pathways* to correct or worsen the problem. In addition to the internal control mechanisms, there are external influences based primarily on lifestyle choices and environmental exposures that influence our body's ability to maintain cellular health.

- **Nutrition:** If your diet is lacking in a specific vitamin or mineral your cells will function poorly, possibly resulting in a disease condition. For example, a menstruating woman with inadequate dietary intake of iron will become anemic. Lack of hemoglobin, a molecule that requires iron, will result in reduced oxygen-carrying capacity. In mild cases symptoms may be

vague (e.g. fatigue), but if the anemia is severe the body will try to compensate by increasing cardiac output, leading to palpitations and sweatiness, and possibly to heart failure.

- **Toxins:** Any substance that interferes with cellular function, causing cellular malfunction. This is done through a variety of ways; chemical, plant, insecticides, and or bites. A commonly seen example of this is drug overdoses. When a person takes too much of a drug their vital signs begin to waver; either increasing or decreasing, these vital signs can cause problems including coma, brain damage and even death.

- **Psychological:** Your physical health and mental health are inseparable. Our thoughts and emotions cause chemical changes to take place either for better as with meditation, or worse as with stress.

- **Physical:** Physical maintenance is essential for our cells and bodies. Adequate rest, sunlight, and exercise are examples of physical mechanisms for influencing homeostasis. Lack of sleep is related to a number of ailments such as irregular cardiac rhythms, fatigue, anxiety and headaches.

- **Genetic/Reproductive:** Inheriting strengths and weaknesses can be part of our genetic makeup. Genes are sometimes turned off or on due to external factors which we can have some control over, but at other times little can be done to correct or improve genetic diseases. Beginning at the cellular level a variety of diseases come from mutated genes. For example, cancer can be genetically inherited or can be caused due to a mutation from an external source such as radiation or genes altered in a fetus when the mother uses drugs.

- **Medical:** Because of genetic differences some bodies need help in gaining or maintaining homeostasis. Through modern medicine our bodies can be given different aids -from anti-bodies to help fight infections or chemotherapy to kill harmful cancer cells. Traditional and alternative medical practices have many benefits, but the potential for harmful effects is also present. Whether by nosocomial infections, or wrong dosage of medication, homeostasis can be altered by that which is trying to fix it. Trial and error with medications can cause potential harmful reactions and possibly death if not caught soon enough.

The factors listed above all have their effects at the cellular level, whether harmful or beneficial. Inadequate beneficial pathways (deficiency) will almost always result in a harmful waiver in homeostasis. Too much toxicity also causes homeostatic imbalance, resulting in cellular malfunction. By removing negative health influences, and providing adequate positive health influences, your body is better able to self-regulate and self-repair, thus maintaining homeostasis.

## Homeostasis Throughout the Body

Each body system contributes to the homeostasis of other systems and of the entire organism. No system of the body works in isolation, and the well-being of the person depends upon the well-being of all the interacting body systems. A disruption within one system generally has consequences for several additional body systems. Here are some brief explanations of how various body systems contribute to the maintenance of homeostasis:

## Nervous System

The nervous system, along with the endocrine system, serves as the primary control center of the body working below the level of consciousness. For example, the hypothalamus of the brain is where the body's "thermostat" is found. The hypothalamus also stimulates the pituitary gland to release various hormones that control metabolism and development of the body. The sympathetic and parasympathetic divisions of the nervous system alternatively stimulate or inhibit various bodily responses (such as heart rate, breathing rate, etc) to help maintain proper levels. It also controls contractions like the arrector pili muscles (involved in thermoregulation) and skeletal muscles, which in addition to moving the body, also cause bone thickening and maintenance, which affects bone composition. The nervous system also regulates various systems such as respiratory (controls pace and depth of breathing), cardiovascular system (controls heart rate and blood pressure), endocrine organs (causes secretion of ADH and oxytocin), the digestive system (regulates the digestive tract movement and secretion), and the urinary system (it helps adjust renal blood pressure and also controls voiding the bladder). The nervous system is also involved in our sexual behaviors and functions.

## Endocrine System

The endocrine system consists of glands which secrete hormones into the bloodstream. Each hormone has an effect on one or more target tissues. In this way the endocrine system regulates the metabolism and development of most body cells and body systems. To be more specific, the Endocrine system has sex hormones that can activate sebaceous glands, development of mammary glands, alter dermal blood flow and release lipids from adipocytes and MSH can stimulate melanocytes on our skin. Our bone growth is regulated by several hormones, and the endocrine system helps with the mobilization of calcitonin and calcium. In the muscular system hormones adjust muscle metabolism, energy production, and growth. In the nervous system hormones affect neural metabolism, regulate fluid/electrolyte balance and help with reproductive hormones that influence CNS development and behaviors. In the Cardiovascular system we need hormones that regulate the production of RBC's, elevate and lower blood pressure. Hormones also have anti-inflammatory affects as well as stimulates the lymphatic system. In summary, the endocrine system has a regulatory effect on basically every other body system.

## Integumentary System

The integumentary system is involved in protecting the body from invading microbes (mainly by forming a thick impenetrable layer), regulating body temperature through sweating and vasodilation, or shivering and piloerection (goose bumps), and regulating ion balances in the blood. Stimulation of mast cells also produce changes in blood flow and capillary permeability which can effect the blood flow in the body and how it is regulated. It also helps synthesize vitamin D which interacts with calcium and phosphorus absorption needed for bone growth and maintenance for example if we ever broke a bone and it needs repair. Hair on the skin guards entrance into the nasal cavity or other orifices preventing invaders of getting further into our bodies. Our skin also helps maintain balance by excretion of water and other solutes (i.e.) the keratinized epidermis limits fluid loss through skin. Thus saying it provides mechanical protection against environmental hazards. We need to remember that our skin is integumentary, it is our first line of defense and to keep it balanced takes work.



## Skeletal System

The skeletal system serves as an important mineral reserve. For example, if blood levels of calcium or magnesium are low and the minerals are not available in the diet, they will be taken from the bones. On the other hand the skeletal system provides Calcium needed for all muscle contractions. Lymphocytes and other cells relating to the immune response are produced and stored in the bone marrow. The skeletal system aids in protection of the nervous system, endocrine organs, chest and pelvic regions - all of these are vital organs.

## Muscular System

The muscular system is largely responsible for maintaining body temperature through heat production. It also contributes to blood glucose balance by storing energy as glycogen. Indirectly it contributes to the well-being of the organism by simply allowing a person to move about (to find and consume food, find shelter from weather extremes, etc.) by having our skin intact to muscles help us with our facial expressions. In the nervous system it helps monitor body position. Muscles provide us with protecting our endocrine glands and digestive organs. They also control contractions during sex producing sensations, and controls muscles that allow you to hold your urine when you are thousands of miles away from the nearest bathroom or without toilet paper. Muscles also aid in moving blood through veins, protect deep blood vessels and help the lymphatic system move lymph.

## Cardiovascular System

The cardiovascular system, in addition to needing to maintain itself within certain levels, plays a role in maintenance of other body systems by transporting hormones (heart secretes ANP and BNP) and nutrients (oxygen, EPO to bones, etc.), taking away waste products, and providing all living body cells with a fresh supply of oxygen and removing carbon dioxide. Homeostasis is disturbed if the cardiovascular or lymphatic systems are not functioning correctly. Our skin, bones, muscles, nervous system, endocrine, lymphatic system, lungs, digestive tract, urinary system and reproductive use the cardiovascular system as its "road" or "highway" as far as distribution of things that go on in our body. There are many risk factors for an unhealthy cardiovascular system. Some diseases associated are typically labeled "uncontrollable" or "controllable." The main uncontrollable risk factors are age, gender, and a family history of heart disease, especially at an early age.

## Lymphatic System

The lymphatic system has three principal roles. First is the maintenance of blood and tissue volume. Excess fluid that leaves the capillaries when under pressure would build up and cause edema. Secondly, the lymphatic system absorbs fatty acids and triglycerides from fat digestion so that these components of digestion do not enter directly into the blood stream. Third, the lymphatic system is involved in defending the body against invading microbes, and the immune response. This system assists in maintenance such as bone repair after injuries and muscle repair after an injury. Another defense is maintaining the acid pH of urine to fight infections in the urinary system. The tonsils are our bodies helpers to defend us against infections and toxins absorbed from the digestive tract. The tonsils also protect against infections entering into our lungs.

## Respiratory System

The respiratory system works in conjunction with the cardiovascular system to provide oxygen to cells within every body system for cellular metabolism. The respiratory system also removes carbon dioxide. Since CO<sub>2</sub> is mainly transported in the plasma as bicarbonate ions, which act as a chemical buffer, the respiratory system also helps maintain proper blood pH levels a fact that is very important for homeostasis. As a result of hyperventilation, CO<sub>2</sub> is decreased in blood levels. This causes the pH of body fluids to increase. If acid levels rise above 7.45, the result is respiratory alkalosis. On the other hand, too much CO<sub>2</sub> causes pH to fall below 7.35 which results in respiratory acidosis. The respiratory system also helps the lymphatic system by trapping pathogens and protecting deeper tissues within. Note that when you have increased thoracic space it can provide abdominal pressure through the contraction of respiratory muscles. This can assist in defecation. Remember the lungs are the gateway for our breath of life.

## Digestive System

Without a regular supply of energy and nutrients from the digestive system all body systems would soon suffer. The digestive system absorbs organic substances, vitamins, ions, and water that are needed all over the body. In the skin the digestive tract provides lipids for storage in the subcutaneous layer. Note that food undergoes three types of processes in the body: digestion, absorption, and elimination. If one of these is not working, you will have problems that will be extremely noticeable. Mechanics of digestion can be chemical digestion, movements, ingestion absorption, and elimination. In order to maintain a healthy and efficient digestive system we have to remember the components involved. If these are disturbed, digestive health may be compromised.

## Urinary System

Toxic nitrogenous wastes accumulate as proteins and nucleic acids are broken down and used for other purposes. The urinary system rids the body of these wastes. The urinary system is also directly involved in maintaining proper blood volume (and indirectly blood pressure) and ion concentration within the blood. One other contribution is that the kidneys produce a hormone (erythropoietin) that stimulates red blood cell production. The kidneys also play an important role in maintaining the correct water content to of the body and the correct salt composition of extracellular fluid. External changes that lead to excess fluid loss trigger feedback mechanisms than they act to maintain the body's fluid content by inhibiting fluid loss.

## Reproductive System

The Reproductive System is unique in that it does little to contribute to the homeostasis of the organism. Rather than being tied to the maintenance of the organism, the reproductive system relates to the maintenance of the species. Having said that, the sex hormones do have an effect on other body systems, and an imbalance can lead to various disorders (e.g. a woman whose ovaries are removed early in life is at much higher risk of osteoporosis).

## Case Study

### Heat stroke and Heat exhaustion

If you have ever tried to do some sort of heavy manual labor on a hot day or competed in a physical competition you may have experienced dizziness and weakness. In some cases when it is severe enough you may have even gone as far as to collapsing and loss of consciousness. This is known as heat exhaustion. Heat exhaust happens when your body is trying to get rid of excessive heat and keep its temperature at a optimal place. When the body is trying to get rid of a lot of heat you will start to sweat in large amounts which will lead to a significant reduction of blood volume. The body also diverts the blood to the skin from other areas of the body. With both of these changes the body produces a reduction in blood pressure which will reduce the blood flow to the brain and give you the symptoms described above. heat stroke is a far more serious condition. This happens when the body's temperature rises out of control due to the failure of the thermoregulating system. If the body is unable to reduce its temperature due to outside or physical influences the brain will start to malfunction. Delirium and loss of consciences set in. The center of the brain controlling the sweat glands will stop functioning halting the production of sweat. This causes the body's temperature to rise even faster. furthermore with the increase of the body's temperature the metabolic process will speed up causing even more heat in the body. If left untreated this will result in death. One of the easiest ways to spot heat stroke is the skin. If it is flushed due to the increase of blood flow but dry because the sweat glands have stopped secreting the individual will need medical attention fast.

### Other Examples

- Thermoregulation
  - The skeletal muscles can shiver to produce heat if the body temperature is too low.
- Non-shivering thermogenesis involves the decomposition of fat to produce heat.
- Sweating cools the body with the use of evaporation.
- Chemical regulation
  - The pancreas produces insulin and glucagon to control blood-sugar concentration.
- The lungs take in oxygen and give off carbon dioxide, which regulates pH in the blood.
- The kidneys remove urea, and adjust the concentrations of water and a wide variety of ions.

Main examples of homeostasis in mammals are as follows:

- The regulation of the amounts of water and minerals in the body. This is known as osmoregulation. This happens primarily in the kidneys.
  - The removal of metabolic waste. This is known as excretion. This is done by the excretory organs such as the kidneys and lungs.
  - The regulation of body temperature. This is mainly done by the skin.
  - The regulation of blood glucose level. This is mainly done by the liver and the insulin and glucagon secreted by the pancreas in the body.

Most of these organs are controlled by hormones secreted from the pituitary gland, which in turn is directed by the hypothalamus.

## Review Questions

1. Meaning of Homeostasis:

- A) contributor and provider
- B) expand
- C) same or constant
- D) receiver

2. What is the normal pH value for body fluid?

- A) 7.15-7.25
- B) 7.35-7.45
- C) 7.55- 7.65
- D) 7.00-7.35
- E) 6.5-7.5

3. An example of the urinary system working with the respiratory system to regulate blood pH would be

- A) When you hold your breath the kidneys will remove CO<sub>2</sub> from your blood
- B) If you exercise a lot your urine will become more acidic
- C) If you have smoke and develop emphysema the kidneys will remove fewer bicarbonate ions from circulation
- D) If you hyperventilate the kidneys will counteract the alkalinity by adding hydrogen ions into the blood stream
- E) None of the above-the urinary system never works with the respiratory system

4. The urge to breathe comes in direct response to:

- A) How long it has been since you last took a breath
- B) The oxygen concentration of your surrounding environment
- C) The buildup of nitrogen within your blood stream
- D) The pH of your blood
- E) The buildup of blood pressure that occurs when you don't breathe

5. In response to a bacterial infection my body's thermostat is raised. I start to shiver and produce more body heat. When my body temperature reaches 101 degrees, I stop shivering and my body temperature stops going up. This is an example of:

- A) Negative feedback
- B) A malfunctioning control system
- C) Positive feedback
- D) A negative impact

6. Which of the follow is an example of a positive feedback?

- A) Shivering to warm up in a cold winter storm
- B) A cruise control set on your car applies more gas when going up a hill
- C) You sweat on a hot summer's day and the blood vessels in your skin vasodilate

D) You get cut and platelets form a clot. This in turn activates the fibrin clotting system and more blood forms clots

7. Where is the body's "thermostat" found?

- A) Within the nervous system, in the Hypothalamus
- B) Within the integumentary system, in the skin
- C) Within the brain, in the corpus callosum
- D) Within the Urinary system, in the kidneys

## Glossary

**Control Center or Integration Center:** receives and processes information from the receptor

**Effector:** responds to the commands of the control center by either opposing or enhancing the stimulus

**Homeostasis:** refers to stability, balance or equilibrium

**Negative Feedback:** a reaction in which the system responds in such a way as to reverse the direction of change

**Positive Feedback:** a response is to amplify the change in the variable

**Receptor:** receives information that something in the environment is changing

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