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In this section, you will explore the following questions: What is homeostasis? What factors affect homeostasis? What are differences between negative and positive feedback mechanisms used in homeostasis? What are differences between thermoregulation mechanisms in endothermic and ectothermic animals? Animals must be able to maintain homeostasis—the ability to maintain dynamic equilibrium around a set point—while also being able to respond to changing conditions. For example, as an endotherm, your body temperature remains fairly constant around 37◦C or 98.6◦F. If your temperature climbs above the set point, you sweat to cool off; if your temperature drops below the set point, you shiver to warm up. Your blood glucose levels also remain fairly constant because the liver removes glucose from the blood and converts it to glycogen; when the body cells require glucose, glycogen is broken down. (You can probably hypothesize how your liver will respond if you eat a dozen jelly donuts!) The failure to maintain homeostasis can be detrimental and can even cause death. Consequently, negative and/or positive feedback loops regulate homeostasis. Negative feedback mechanisms result in slight fluctuations above and below the set point. For example, if you were to consume a dozen jelly donuts, your blood sugar level would rise, and your pancreas would release insulin, a hormone involved in the conversion of glucose to glycogen, thus returning your blood glucose level to its appropriate set point. By comparison, positive feedback amplifies responses in the same direction, with the variable initiating the response moving the system even further away from the set point. There are fewer examples of positive feedback, but one is the onset of labor in childbirth when uterine contractions increase in strength with the secretion of oxytocin, another hormone. However, the loss of internal equilibrium due to positive feedback can be detrimental; for example, a small area of damaged heart tissue can precipitate a heart attack which, in turn, damages even more cardiac muscle. Information presented and the examples highlighted in the section support concepts outlined in Big Idea 2 of the AP Biology® Curriculum Framework. The AP® Learning Objectives listed in the Curriculum Framework provide a transparent foundation for the AP® Biology course, an inquiry-based laboratory experience, instructional activities, and AP® exam questions. A learning objective merges required content with one or more of the seven Science Practices. Animal organs and organ systems constantly adjust to internal and external changes through a process called homeostasis ("steady state"). These changes might be in the level of glucose or calcium in blood or in external temperatures. Homeostasis means to maintain dynamic equilibrium in the body. It is dynamic because it is constantly adjusting to the changes that the body's systems encounter. It is equilibrium because body functions are kept within specific ranges. Even an animal that is apparently inactive is maintaining this homeostatic equilibrium. The goal of homeostasis is the maintenance of equilibrium around a point or value called a set point. While there are normal fluctuations from the set point, the body's systems will usually attempt to go back to this point. A change in the internal or external environment is called a stimulus and is detected by a receptor; the response of the system is to adjust the deviation parameter toward the set point. For instance, if the body becomes too warm, adjustments are made to cool the animal. If the blood's glucose rises after a meal, adjustments are made to lower the blood glucose level by getting the nutrient into tissues that need it or to store it for later use. When a change occurs in an animal's environment, an adjustment must be made. The receptor senses the change in the environment, then sends a signal to the control center (in most cases, the brain) which in turn generates a response that is signaled to an effector. The effector is a muscle (that contracts or relaxes) or a gland that secretes. Homeostatsis is maintained by negative feedback loops. Positive feedback loops actually push the organism further out of homeostasis, but may be necessary for life to occur. Homeostasis is controlled by the nervous and endocrine system of mammals. Any homeostatic process that changes the direction of the stimulus is a negative feedback loop. It may either increase or decrease the stimulus, but the stimulus is not allowed to continue as it did before the receptor sensed it. In other words, if a level is too high, the body does something to bring it down, and conversely, if a level is too low, the body does something to make it go up. Hence the term negative feedback. An example is animal maintenance of blood glucose levels. When an animal has eaten, blood glucose levels rise. This is sensed by the nervous system. Specialized cells in the pancreas sense this, and the hormone insulin is released by the endocrine system. Insulin causes blood glucose levels to decrease, as would be expected in a negative feedback system, as illustrated in Figure 24.20. However, if an animal has not eaten and blood glucose levels decrease, this is sensed in another group of cells in the pancreas, and the hormone glucagon is released causing glucose levels to increase. This is still a negative feedback loop, but not in the direction expected by the use of the term "negative." Another example of an increase as a result of the feedback loop is the control of blood calcium. If calcium levels decrease, specialized cells in the parathyroid gland sense this and release parathyroid hormone (PTH), causing an increased absorption of calcium through the intestines and kidneys and, possibly, the breakdown of bone in order to liberate calcium. The effects of PTH are to raise blood levels of the element. Negative feedback loops are the predominant mechanism used in homeostasis. Figure 24.20 Blood sugar levels are controlled by a negative feedback loop. (credit: modification of work by Jon Sullivan) A positive feedback loop maintains the direction of the stimulus, possibly accelerating it. Few examples of positive feedback loops exist in animal bodies, but one is found in the cascade of chemical reactions that result in blood clotting, or coagulation. As one clotting factor is activated, it activates the next factor in sequence until a fibrin clot is achieved. The direction is maintained, not changed, so this is positive feedback. Another example of positive feedback is uterine contractions during childbirth, as illustrated in Figure 24.21. The hormone oxytocin, made by the endocrine system, stimulates the contraction of the uterus. This produces pain sensed by the nervous system. Instead of lowering the oxytocin and causing the pain to subside, more oxytocin is produced until the contractions are powerful enough to produce childbirth. Figure 24.21 The birth of a human infant is the result of positive feedback. State whether each of the following processes is regulated by a positive or negative feedback loop. a. A person feels satiated after eating a large meal. b. The blood has plenty of red blood cells. As a result, erythropoietin, a hormone that stimulates the production of new red blood cells, is no longer released from the kidney. a. This is regulated by a positive feedback loop as the stimulus (hunger) has changed direction in response to a signal (fullness). b. This is regulated by a positive feedback loop as the stimulus (red blood cell release) has changed direction in response to a signal (presence of enough red blood cells). a. This is regulated by a negative feedback loop as the stimulus (hunger) has changed direction in response to a signal (fullness). b. This is regulated by a positive feedback loop as the direction of the stimulus has been maintained. a. This is regulated by a positive feedback loop as the stimulus (hunger) has changed direction in response to a signal (fullness). b. This is regulated by a negative feedback loop as the stimulus (red blood cell release) has changed direction in response to a signal (presence of enough red blood cells). a. This is regulated by a negative feedback loop as the stimulus (hunger) changed direction in response to a signal (fullness). b. This is regulated by a negative feedback loop as the stimulus (red blood cell release) changed direction in response to a signal (presence of enough red blood cells). It is possible to adjust a system's set point. When this happens, the feedback loop works to maintain the new setting. An example of this is blood pressure: over time, the normal or set point for blood pressure can increase as a result of continued increases in blood pressure. The body no longer recognizes the elevation as abnormal and no attempt is made to return to the lower set point. The result is the maintenance of an elevated blood pressure that can have harmful effects on the body. Medication can lower blood pressure and lower the set point in the system to a more healthy level. This is called a process of alteration of the set point in a feedback loop. Changes can be made in a group of body organ systems in order to maintain a set point in another system. This is called acclimatization. This occurs, for instance, when an animal migrates to a higher altitude than it is accustomed to. In order to adjust to the lower oxygen levels at the new altitude, the body increases the number of red blood cells circulating in the blood to ensure adequate oxygen delivery to the tissues. Another example of acclimatization is animals that have seasonal changes in their coats: a heavier coat in the winter ensures adequate heat retention, and a light coat in summer assists in keeping body temperature from rising to harmful levels. Feedback mechanisms can be understood in terms of driving a race car along a track: watch a short video lesson on positive and negative feedback loops. Voltage-gated sodium channels occur in the cell membranes of nerve cells. They open in response to sodium entering the cell. This allows more sodium to enter the cell. A scientist claims this is a positive feedback loop. What reasoning can be used to justify this claim? The voltage-gated sodium channels open in response to sodium influx. When a change happens in response to a change in conditions, it makes a positive feedback loop. The voltage-gated sodium channels close when there is enough sodium in the cell. This self regulation means this is an example of a positive feedback loop. The voltage-gated sodium channels open due to sodium and this causes more sodium to go through. The response reinforces the feedback, making this a positive feedback loop. The voltage-gated sodium channels are on the cell membrane. All channels through cell membranes are examples of positive feedback loops. This, this is an examples of a positive feedback loop. Negative feedback loops maintain the levels of some variable near a set point. In diabetes, a rise in blood glucose does not signal the production of insulin, which would normally lower blood glucose back to the set point. The Think About It question is an application of AP® Learning Objective 2.16 and Science Practice 7.2 and Learning Objective 2.17 and Science Practice 5.3 because students are connecting negative feedback to the regulation of homeostasis and then, using blood sugar levels in humans as an example, explaining how a change in a negative feedback mechanism can have a deleterious effect. Body temperature affects body activities. Generally, as body temperature rises, enzyme activity rises as well. For every ten degree centigrade rise in temperature, enzyme activity doubles, up to a point. Body proteins, including enzymes, begin to denature and lose their function with high heat (around 50oC for mammals). Enzyme activity will decrease by half for every ten degree centigrade drop in temperature, to the point of freezing, with a few exceptions. Some fish can withstand freezing solid and return to normal with thawing. Watch this Discovery Channel video on thermoregulation to see illustrations of this process in a variety of animals. How does the loose skin of an elephant help it regulate body temperature? Loose skin is thicker, which allows the excess heat to dissipate quickly through the skin. Loose skin brings more heat and blood to the body surface, facilitating heat loss. Loose skin contains greater skin area, which allows excess heat to dissipate as heat loss occurs through the skin. Loose skin has smaller skin area, which allows excess heat to dissipate as heat loss occurs through the skin. Animals can be divided into two groups: some maintain a constant body temperature in the face of differing environmental temperatures, while others have a body temperature that is the same as their environment and thus varies with the environment. Animals that rely on external temperatures to set their body temperature are ectotherms. This group has been called cold-blooded, but the term may not apply to an animal in the desert with a very warm body temperature. In contrast to ectotherms, poikilotherms are animals with constantly varying internal temperatures. An animal that maintains a constant body temperature in the face of environmental changes is called a homeotherm. Endotherms are animals that rely on internal sources for maintenance of relatively constant body temperature in varying environmental temperatures. These animals are able to maintain a level of metabolic activity at cooler temperature, which an ectotherm cannot due to differing enzyme levels of activity. It is worth mentioning that some ectotherms and poikilotherms have relatively constant body temperatures due to the constant environmental temperatures in their habitats. These animals are so-called ectothermic homeotherms, like some deep sea fish species. Figure 24.22 Heat can be exchanged by four mechanisms: (a) radiation, (b) evaporation, (c) convection, or (d) conduction. (credit b: modification of work by "Kullez"/Flickr; credit c: modification of work by Chad Rosenthal; credit d: modification of work by "stacey.d"/Flickr) Figure 24.23 The body temperature of ectotherms varies with the environment. For that reason, reptiles, such as this American alligator, bask in the sun to warm themselves. If an American alligator has been basking but gets too hot, how might the alligator cool itself? increase vasodilation sweat move into shade increase metabolic rate Animals conserve or dissipate heat in a variety of ways. In certain climates, endothermic animals have some form of insulation, such as fur, fat, feathers, or some combination thereof. Animals with thick fur or feathers create an insulating layer of air between their skin and internal organs. Polar bears and seals live and swim in a subfreezing environment and yet maintain a constant, warm, body temperature. The arctic fox, for example, uses its fluffy tail as extra insulation when it curls up to sleep in cold weather. Mammals have a residual effect from shivering and increased muscle activity: arrector pili muscles cause "goose bumps," causing small hairs to stand up when the individual is cold; this has the intended effect of increasing body temperature. Mammals use layers of fat to achieve the same end. Loss of significant amounts of body fat will compromise an individual's ability to conserve heat. Endotherms use their circulatory systems to help maintain body temperature. Vasodilation brings more blood and heat to the body surface, facilitating radiation and evaporative heat loss, which helps to cool the body. Vasoconstriction reduces blood flow in peripheral blood vessels, forcing blood toward the core and the vital organs found there, and conserving heat. Some animals have adaptations to their circulatory system that enable them to transfer heat from arteries to veins, warming blood returning to the heart. This is called a countercurrent heat exchange; it prevents the cold venous blood from cooling the heart and other internal organs. This adaptation can be shut down in some animals to prevent overheating the internal organs. The countercurrent adaptation is found in many animals, including dolphins, sharks, bony fish, bees, and hummingbirds. In contrast, similar adaptations can help cool endotherms when needed, such as dolphin flukes and elephant ears. Some ectothermic animals use changes in their behavior to help regulate body temperature. For example, a desert ectothermic animal may simply seek cooler areas during the hottest part of the day in the desert to keep from getting too warm. The same animals may climb onto rocks to capture heat during a cold desert night. Some animals seek water to aid evaporation in cooling them, as seen with reptiles. Other ectotherms use group activity such as the activity of bees to warm a hive to survive winter. Many animals, especially mammals, use metabolic waste heat as a heat source. When muscles are contracted, most of the energy from the ATP used in muscle actions is wasted energy that translates into heat. Severe cold elicits a shivering reflex that generates heat for the body. Many species also have a type of adipose tissue called brown fat that specializes in generating heat. The nervous system is important to thermoregulation, as illustrated in Figure 24.22. The processes of homeostasis and temperature control are centered in the hypothalamus of the advanced animal brain. Figure 24.24 The body is able to regulate temperature in response to signals from the nervous system. When bacteria are destroyed by leukocytes, pyrogens are released into the blood. Pyrogens reset the body's thermostat to a higher temperature, resulting in fever. How do pyrogens cause body temperature to rise? Pyrogens circulate to the hypothalamus to reset the body's "thermostat," causing a rise in temperature. Pyrogens circulate to the thalamus to reset the body's "thermostat," causing a rise in temperature. Pyrogens cause an increase in the activity of the animal's enzymes, which results in the temperature rise. Pyrogens entering the blood release some lipid substances, which ultimately cause the rise in temperature. The hypothalamus maintains the set point for body temperature through reflexes that cause vasodilation and sweating when the body is too warm, or vasoconstriction and shivering when the body is too cold. It responds to chemicals from the body. When a bacterium is destroyed by phagocytic leukocytes, chemicals called endogenous pyrogens are released into the blood. These pyrogens circulate to the hypothalamus and reset the thermostat. This allows the body's temperature to increase in what is commonly called a fever. An increase in body temperature causes iron to be conserved, which reduces a nutrient needed by bacteria. An increase in body heat also increases the activity of the animal's enzymes and protective cells while inhibiting the enzymes and activity of the invading microorganisms. Finally, heat itself may also kill the pathogen. A fever that was once thought to be a complication of an infection is now understood to be a normal defense mechanism.