

# 58

## *Maintaining the Internal Environment*

### Concept Outline

#### 58.1 The regulatory systems of the body maintain homeostasis.

**The Need to Maintain Homeostasis.** Regulatory mechanisms maintain homeostasis through negative feedback loops.

**Antagonistic Effectors and Positive Feedback.** Antagonistic effectors cause opposite changes, while positive feedback pushes changes further in the same way.

#### 58.2 The extracellular fluid concentration is constant in most vertebrates.

**Osmolality and Osmotic Balance.** Vertebrates have to cope with the osmotic gain or loss of body water.

**Osmoregulatory Organs.** Invertebrates have a variety of organs to regulate water balance; kidneys are the osmoregulatory organs of most vertebrates.

**Evolution of the Vertebrate Kidney.** Freshwater bony fish produce a dilute urine and marine bony fish produce an isotonic urine. Only birds and mammals can retain so much water that they produce a concentrated urine.

#### 58.3 The functions of the vertebrate kidney are performed by nephrons.

**The Mammalian Kidney.** Each kidney contains nephrons that produce a filtrate which is modified by reabsorption and secretion to produce urine.

**Transport Processes in the Mammalian Nephron.** The nephron tubules of birds and mammals have loops of Henle, which function to draw water out of the tubule and back into the blood.

**Ammonia, Urea, and Uric Acid.** The breakdown of protein and nucleic acids yields nitrogen, which is excreted as ammonia in bony fish, as urea in mammals, and as uric acid in reptiles and birds.

#### 58.4 The kidney is regulated by hormones.

**Hormones Control Homeostatic Functions.** Antidiuretic hormone promotes water retention and the excretion of a highly concentrated urine. Aldosterone stimulates the retention of salt and water, whereas atrial natriuretic hormone promotes the excretion of salt and water.



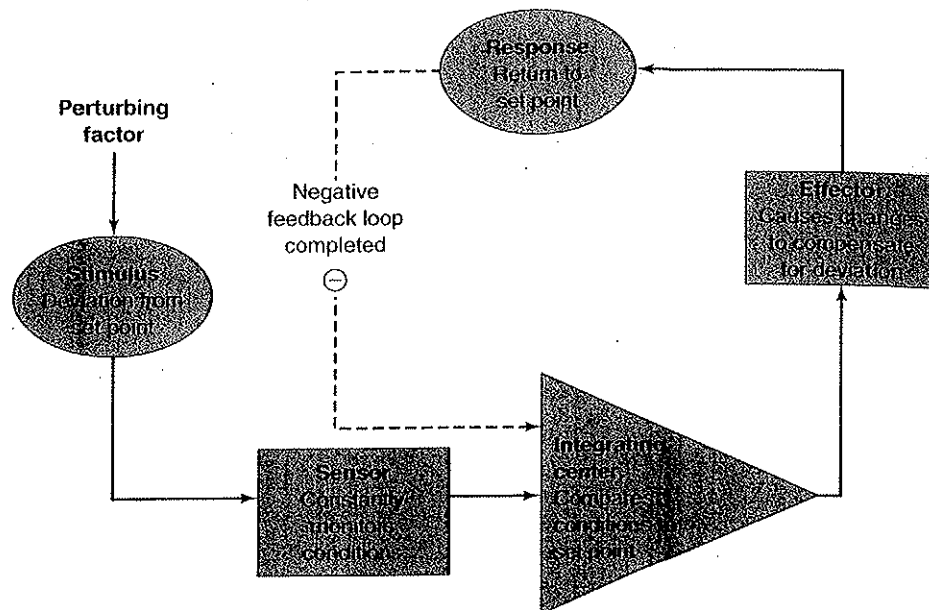
**FIGURE 58.1**  
**Regulating body temperature with water.** One of the ways an elephant can regulate its temperature is to spray water on its body. Water also cycles through the elephant's body in enormous quantities each day and helps to regulate its internal environment.

**T**he first vertebrates evolved in seawater, and the physiology of all vertebrates reflects this origin. Approximately two-thirds of every vertebrate's body is water. If the amount of water in the body of a vertebrate falls much lower than this, the animal will die. In this chapter, we discuss the various mechanisms by which animals avoid gaining or losing too much water. As we shall see, these mechanisms are closely tied to the way animals exploit the varied environments in which they live and to the regulatory systems of the body (figure 58.1).

## The Need to Maintain Homeostasis

As the animal body has evolved, specialization has increased. Each cell is a sophisticated machine, finely tuned to carry out a precise role within the body. Such specialization of cell function is possible only when extracellular conditions are kept within narrow limits. Temperature, pH, the concentrations of glucose and oxygen, and many other factors must be held fairly constant for cells to function efficiently and interact properly with one another.

**Homeostasis** may be defined as the dynamic constancy of the internal environment. The term *dynamic* is used because conditions are never absolutely constant, but fluctuate continuously within narrow limits. Homeostasis is essential for life, and most of the regulatory mechanisms of the vertebrate body that are not devoted to reproduction are concerned with maintaining homeostasis.



**FIGURE 58.2**

A generalized diagram of a negative feedback loop. Negative feedback loops maintain a state of homeostasis, or dynamic constancy of the internal environment, by correcting deviations from a set point.

### Negative Feedback Loops

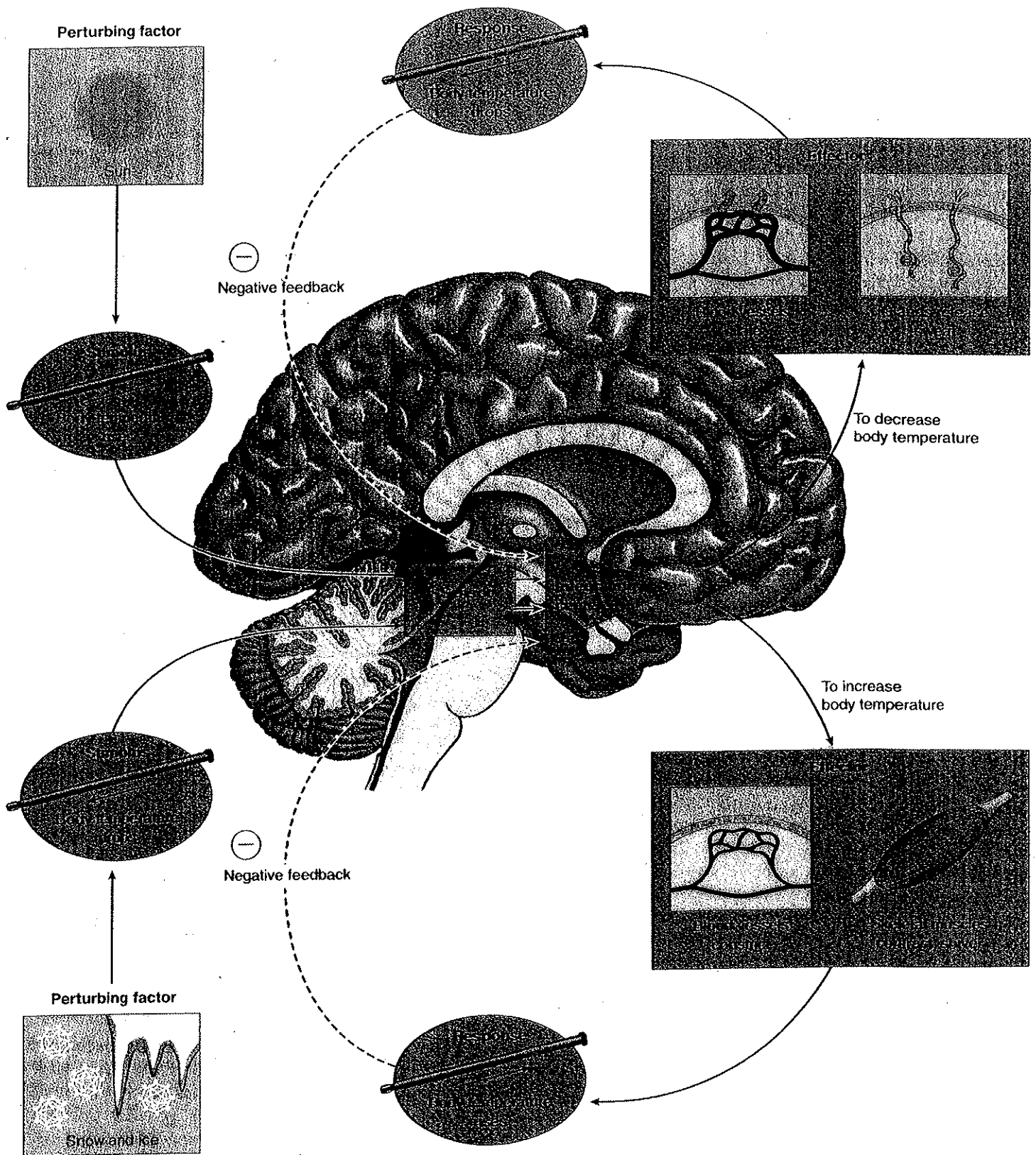
To maintain internal constancy, the vertebrate body must have **sensors** that are able to measure each condition of the internal environment (figure 58.2). These constantly monitor the extracellular conditions and relay this information (usually via nerve signals) to an **integrating center**, which contains the “*set point*” (the proper value for that condition). This set point is analogous to the temperature setting on a house thermostat. In a similar manner, there are set points for body temperature, blood glucose concentration, the tension on a tendon, and so on. The integrating center is often a particular region of the brain or spinal cord, but in some cases it can also be cells of endocrine glands. It receives messages from several sensors, weighing the relative strengths of each sensor input, and then determines whether the value of the condition is deviating from the set point. When a deviation in a condition occurs (the “stimulus”), the integrating center sends a message to increase or decrease the activity of particular **effectors**. Effectors are generally muscles or glands, and can change the value of the condition in question back toward the set point value (the “response”).

To return to the idea of a home thermostat, suppose you set the thermostat at a set point of 70°F. If the temperature of the house rises sufficiently above the set point, the thermostat (equivalent to an integrating center) receives this

input from a temperature sensor, like a thermometer (a sensor) within the wall unit. It compares the actual temperature to its set point. When these are different, it sends a signal to an effector. The effector in this case may be an air conditioner, which acts to reverse the deviation from the set point.

In a human, if the body temperature exceeds the set point of 37°C, sensors in a part of the brain detect this deviation. Acting via an integrating center (also in the brain), these sensors stimulate effectors (including sweat glands) that lower the temperature (figure 58.3). One can think of the effectors as “defending” the set points of the body against deviations. Because the activity of the effectors is influenced by the effects they produce, and because this regulation is in a negative, or reverse, direction, this type of control system is known as a *negative feedback loop*.

The nature of the negative feedback loop becomes clear when we again refer to the analogy of the thermostat and air conditioner. After the air conditioner has been on for some time, the room temperature may fall significantly below the set point of the thermostat. When this occurs, the air conditioner will be turned off. The effector (air conditioner) is turned on by a high temperature; and, when activated, it produces a negative change (lowering of the temperature) that ultimately causes the effector to be turned off. In this way, constancy is maintained.



**FIGURE 58.3** Negative feedback loops keep the body temperature within a normal range. An increase (*top*) or decrease (*bottom*) in body temperature is sensed by the brain. The integrating center in the brain then processes the information and activates effectors, such as surface blood vessels, sweat glands, and skeletal muscles. When the body temperature returns to normal, negative feedback prevents further stimulation of the effectors by the integrating center.

## Regulating Body Temperature

Humans, together with other mammals and with birds, are *endothermic*; they can maintain relatively constant body temperatures independent of the environmental temperature. When the temperature of your blood exceeds 37°C (98.6°F), neurons in a part of the brain called the hypothalamus detect the temperature change. Acting through the control of motor neurons, the hypothalamus responds by promoting the dissipation of heat through sweating, dilation of blood vessels in the skin, and other mechanisms. These responses tend to counteract the rise in body temperature. When body temperature falls, the hypothalamus coordinates a different set of responses, such as shivering and the constriction of blood vessels in the skin, which help to raise body temperature and correct the initial challenge to homeostasis.

Vertebrates other than mammals and birds are *ectothermic*; their body temperatures are more or less dependent on the environmental temperature. However, to the extent that it is possible, many ectothermic vertebrates attempt to maintain some degree of temperature homeostasis. Certain large fish, including tuna, swordfish, and some sharks, for example, can maintain parts of their body at a significantly higher temperature than that of the water. Reptiles attempt to maintain a constant body temperature through behavioral means—by placing themselves in varying locations of sun and shade (see chapter 29). That's why you frequently see lizards basking in the sun. Sick lizards even give themselves a "fever" by seeking warmer locations!

Most invertebrates do not employ feedback regulation to physiologically control their body temperature. Instead, they use behavior to adjust their temperature. Many butterflies, for example, must reach a certain body temperature before they can fly. In the cool of the morning they orient so as to maximize their absorption of sunlight. Moths and many other insects use a shivering reflex to warm their thoracic flight muscles (figure 58.4).

## Regulating Blood Glucose

When you digest a carbohydrate-containing meal, you absorb glucose into your blood. This causes a temporary rise in the blood glucose concentration, which is brought back down in a few hours. What counteracts the rise in blood glucose following a meal?

Glucose levels within the blood are constantly monitored by a sensor, the islets of Langerhans in the pancreas. When levels increase, the islets secrete the hormone *insulin*, which stimulates the uptake of blood glucose into muscles, liver, and adipose tissue. The islets are, in this case, the sensor and the integrating center. The muscles, liver, and adipose cells are the effectors, taking up glucose to control the levels. The muscles and liver can convert the glucose into the polysaccharide glycogen; adipose cells can convert glucose into fat. These actions lower the blood glucose (figure 58.5) and help to store energy in forms that the body can use later.

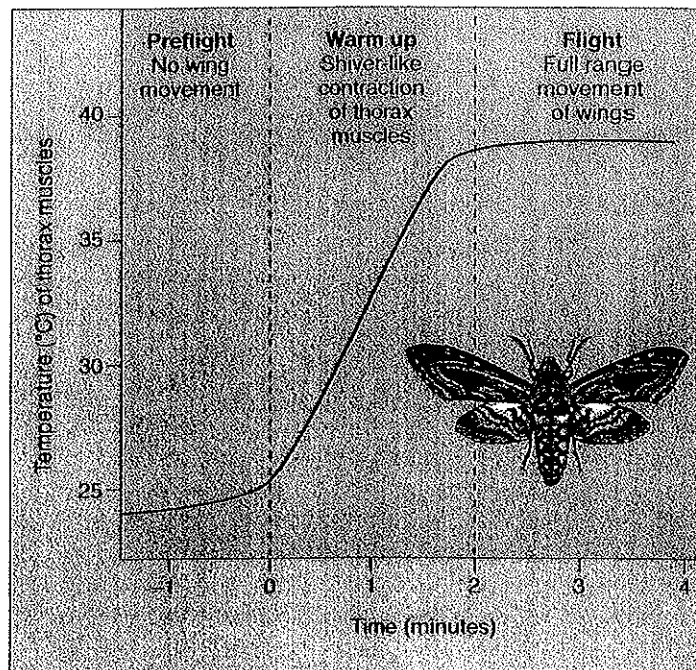


FIGURE 58.4

**Thermoregulation in insects.** Some insects, such as the sphinx moth, contract their thoracic muscles to warm up for flight.

Source: Data from B. Heinrich, *Science*, American Association for the Advancement of Science.

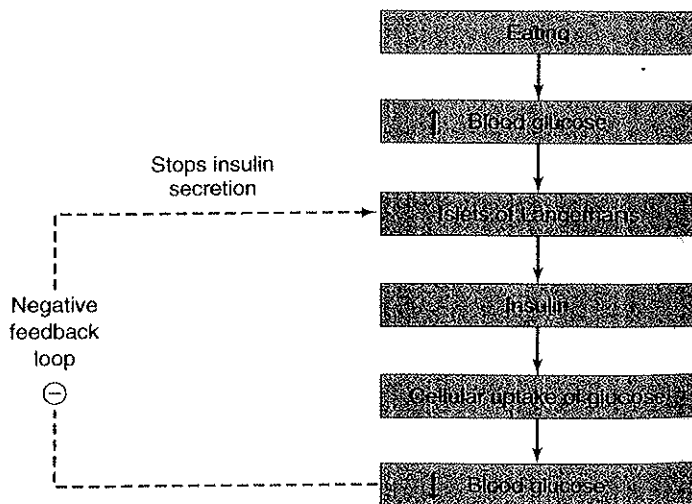


FIGURE 58.5

**The negative feedback control of blood glucose.** The rise in blood glucose concentration following a meal stimulates the secretion of insulin from the islets of Langerhans in the pancreas. Insulin is a hormone that promotes the entry of glucose in skeletal muscle and other tissue, thereby lowering the blood glucose and compensating for the initial rise.

Negative feedback mechanisms correct deviations from a set point for different internal variables. In this way, body temperature and blood glucose, for example, are kept within a normal range.