

Homeostasis Is Maintained by Negative Feedback Loops

Suppose you have a room thermostat that you set at 70° F—this is the **set point**. If the room gets sufficiently cooler than this, a **sensor** will detect that deviation from the set point. The sensor will indirectly activate a heater, which has the effect of correcting this deviation from the set point. The heater thus serves as an **effector** in this mechanism for defending the set point. If you had a fancier room thermostat that controlled an air conditioner as well as a heater, the sensor might send its information to an **integrating center**, which in turn controls both effectors—the heater and the air conditioner. In that case, the air conditioner would turn off and the heater would turn on to correct a fall in room temperature from the set point. The opposite would occur if the room got significantly hotter than the set point.

The relationship just described, where a sensor is activated by a deviation from a set point and an effector responds to oppose that deviation, is called a **negative feedback loop**. “Negative” describes the action of effectors to oppose the deviation. “Loop” describes the circular nature of the cause-and-effect sequence; the effector “feeds back” on the initial deviation (the stimulus, which is the first step in the sequence) to oppose it and help maintain homeostasis. In this textbook, the last step in a negative feedback loop will be shown by a dashed arrow with a negative sign to indicate the opposing action of the effectors on the initial stimulus (fig. 1.1, *top*). The deviated measurement and its negative feedback correction can be charted over time as shown in figure 1.1, *bottom*. It’s important to also realize that a deviation in the opposite direction must also be corrected by a negative feedback loop in order to maintain homeostasis (fig. 1.2).

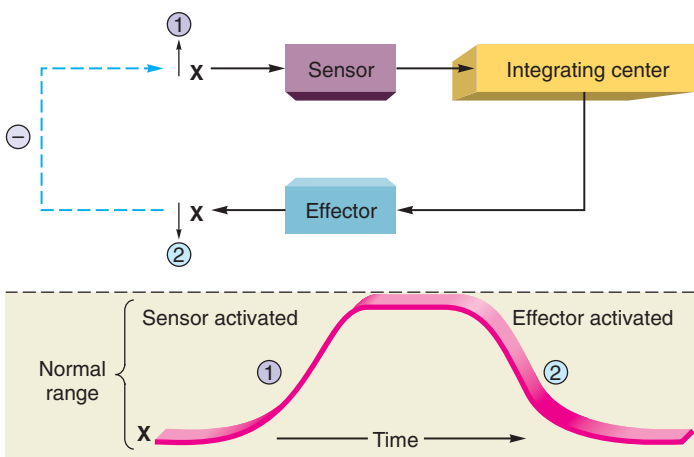


FIGURE 1.1 A rise in some factor of the internal environment ($\uparrow X$) is detected by a sensor. This information is relayed to an integrating center, which causes an effector to produce a change in the opposite direction ($\downarrow X$). The initial deviation is thus reversed, completing a negative feedback loop (shown by the dashed arrow and negative sign). The numbers indicate the sequence of changes.

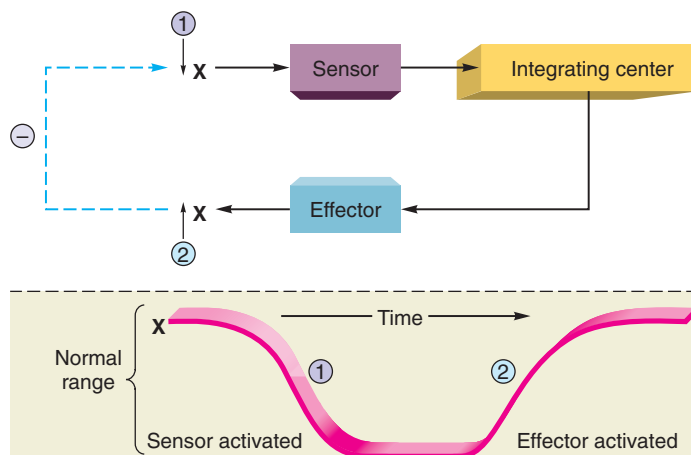


FIGURE 1.2 A fall in some factor of the internal environment ($\downarrow X$) is detected by a sensor. Compare this negative feedback loop with that shown in fig. 1.1.

Our physiological mechanisms maintain homeostasis by operating through negative feedback loops. In our body, the integrating center is often (but not always) a particular area of the brain. Sensors are cells (often neurons or gland cells) that respond to specific stimuli, and effectors are usually muscles and glands. For example, in order to maintain homeostasis of body temperature, we have neurons that act as temperature sensors in our brain. The integrating center is also located there. In response to a fall in deep body temperature, effectors (such as shivering skeletal muscles) act to raise the body temperature back to the set point. In response to a rise in body temperature above the set point, effectors (including sweat glands) are activated to cool the body temperature back to the set point. In this way, a normal body temperature is maintained by opposing negative feedback loops (fig. 1.3). Notice that in figure 1.3 there is a normal range; constancy is dynamic and relative, not absolute.

Shivering skeletal muscles and sweat glands are **antagonistic effectors**. Both act through negative feedback loops, but they

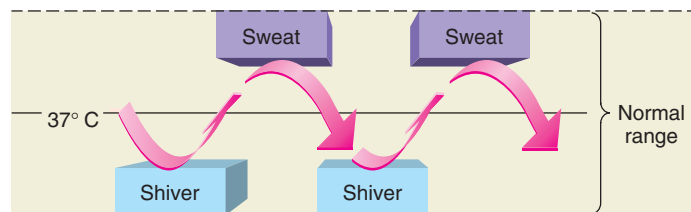


FIGURE 1.3 How body temperature is maintained within the normal range. The body temperature normally has a set point of 37° C. This is maintained, in part, by two antagonistic mechanisms—shivering and sweating. Shivering is induced when the body temperature falls too low, and it gradually subsides as the temperature rises. Sweating occurs when the body temperature is too high, and it diminishes as the temperature falls. Most aspects of the internal environment are regulated by the antagonistic actions of different effector mechanisms.

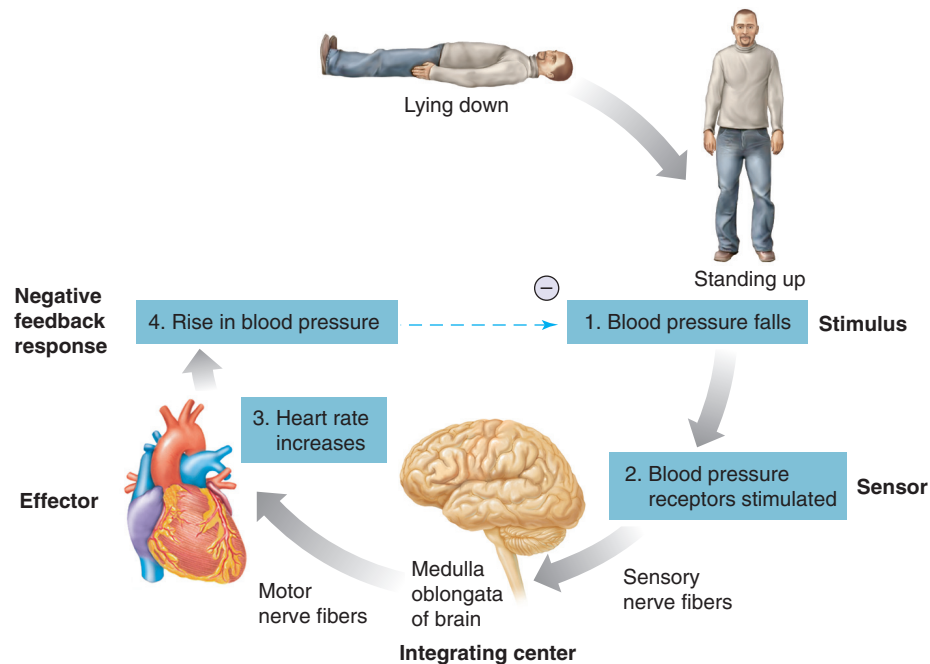


FIGURE 1.4 Negative feedback control of blood pressure. This negative feedback loop helps correct a fall in blood pressure by stimulating an increased heart rate. In this negative feedback loop, sensory and motor nerve fibers convey information between the sensor, integrating center, and effector.

have opposing effects. Thus, their negative feedback loops are activated by opposite stimuli: we shiver in response to a fall in body temperature and sweat in response to a rise in body temperature. Antagonistic effectors afford better, tighter control than would be possible if we had only one type of effector. For example, constant body temperature would not be very well maintained if we shivered when it was cold and simply didn't shiver when it was hot. Most aspects of the internal environment are maintained in a state of homeostasis by numerous antagonistic negative feedback loops.

Neural and Endocrine Regulation of Homeostasis

Let's follow a typical negative feedback loop involving neural control. Suppose that there is a fall in blood pressure—for example, because a person who was lying down stands up quickly. The fall in blood pressure below the set point is the stimulus that activates the sensors, which are blood pressure receptors (baroreceptors). These stimulate sensory neurons that convey this information to an integrating center in the brain (in the medulla oblongata). This integrating center then causes motor (autonomic) neurons that slow the heart rate (parasympathetic neurons) to become less active, while neurons that cause a faster heart rate (sympathetic neurons) become more active. As a result, the heart, which is the effector in this story, increases its rate of beat. This helps raise the blood pressure back to the set point, thereby completing the negative feedback loop (fig. 1.4).

Now let's look at a negative feedback loop that involves a hormone. Suppose that a person eats a candy bar, raising the blood glucose (sugar) concentration higher than the set point. The change is detected by sensors, which are cells sensitive to the blood glucose concentration. This story may be confusing because it's so simple: the sensor cells are also the integrating center and the effector. They are the cells located in clusters (called islets) within the pancreas that secrete the hormone insulin when the blood glucose concentration rises. Insulin then stimulates certain tissues (primarily skeletal muscles, liver, and adipose tissue) to take glucose out of the blood. This lowers the blood glucose concentration, completing the negative feedback loop (fig. 1.5). Conversely, when a person fasts and the blood glucose concentration starts to fall, insulin secretion is decreased.

It's not important at this time for you to learn the negative feedback loops depicted in figures 1.4 and 1.5, as they will be presented again more completely later in this book. These negative feedback loops are shown here only to illustrate how negative feedback loops operate to maintain homeostasis. Although a negative feedback loop may involve many steps and the cooperation of different organs and systems, these examples show that the effects are easy to understand. If you know the direction of the initial change from the set point (the stimulus, or first step, of the negative feedback loop), then you know that the effectors must cause a change in the opposite direction in order to maintain homeostasis.

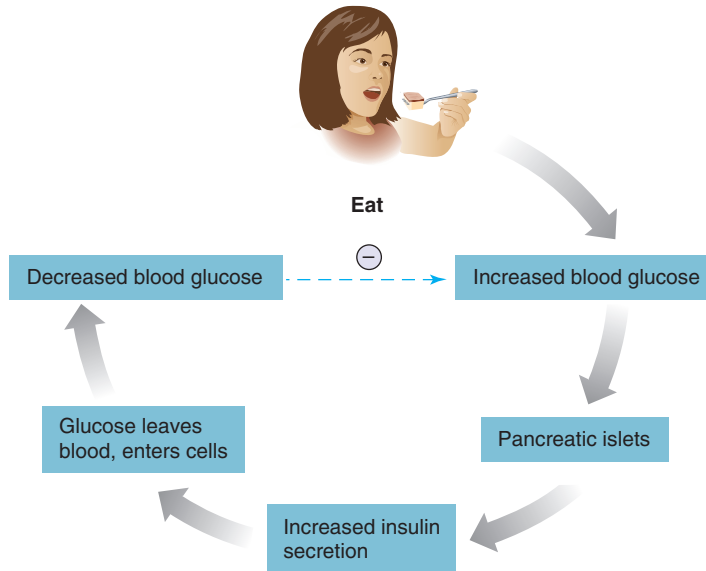


FIGURE 1.5 Negative feedback control of blood glucose. When someone eats carbohydrates (sugars or starch), the blood glucose concentration rises. This stimulates the secretion of the hormone insulin from the pancreatic islets (also called the islets of Langerhans). Insulin stimulates blood glucose to enter cells (primarily of skeletal muscles), so that the elevated blood glucose is brought back down to the level it was at before the carbohydrates were eaten.

CLINICAL INVESTIGATION CLUES

Remember that Laura ate a low-carbohydrate, low-calorie diet.

- How might the diet affect her blood glucose concentration?
- How would this influence her level of insulin secretion?
- Given that high insulin promotes fat storage, and low insulin promotes fat breakdown, what might account for her weight loss?



from the damaged vessel. Because the clot prevents blood loss, it helps maintain homeostasis of blood volume.

Other examples of positive feedback operate in the reproductive system. For example, a positive feedback effect of hormones operating between the ovary and the pituitary gland culminate in the explosive event of ovulation (extrusion of an egg cell from the ovary). Another positive feedback mechanism operates between the uterus and the pituitary of a pregnant woman, culminating in the forceful contractions of the uterus during labor and delivery. These examples help the ovary and uterus do their jobs, which is not to maintain homeostasis but to reproduce.

Positive Feedback Amplifies Changes

Constancy requires that a change be compensated by an opposing (negative) change. Thus, homeostasis can be maintained only by negative feedback mechanisms. **Positive feedback** mechanisms operate to amplify changes. In response to a small change in a particular direction, a positive feedback loop would cause the change to become greater and greater, like an avalanche.

There are a few cases where positive feedback loops operate in the body. For example, damage to a blood vessel initiates a change in the blood that starts a positive feedback cascade, where one clotting factor activates another. This positive feedback mechanism produces a blood clot, which helps stem the loss of blood

CHECK POINT

1. What is the definition of homeostasis, and what is the significance of homeostasis in physiology and medicine?
2. Describe the components of a negative feedback loop. Use an example to show how a negative feedback loop helps maintain homeostasis.
3. What is a positive feedback loop? Can positive feedback loops act to maintain homeostasis? Explain, and give an example of a positive feedback loop acting in the body.