The Earth System

The global interconnectedness of air, water, rocks, and life has become a focus of modern scientific investigation. As a result, a new approach to the study of Earth has taken hold. The traditional way to study Earth has been to focus on separate units—a population of animals, the atmosphere, a lake, a single mountain range, soil in some region—in isolation from other units. In the new, holistic approach, Earth is studied as a whole and is viewed as a system of many separate but interacting parts. Nothing on Earth is isolated; research reveals numerous interactions among all of the parts.

EARTH SYSTEM SCIENCE

Earth system science is the science that studies the whole planet as a system of innumerable interacting parts and focuses on the changes within and among those parts. Examples of these parts are the ocean, the atmosphere, continents, lakes and rivers, soils, plants, and animals; each can be studied separately, but each is dependent on and interconnected with the others.

FIGURE 1.1 Earth's interacting parts
Earth system science is the study of the whole planet as a system of many interacting parts, with a particular focus on the changes within and among those parts, including the impacts of human activities.

SYSTEMS

The system concept allows scientists to break down a large, complex problem into smaller, more easily studied pieces. A system is any portion of the universe that can be isolated from the rest of the universe for the purpose of observing and measuring changes. By saying that a system is any portion of the universe, we mean that the system can be whatever the observer defines it to be. That is why a system is only a concept; you choose its limits for the convenience of your study. It can be large or small, simple or complex.

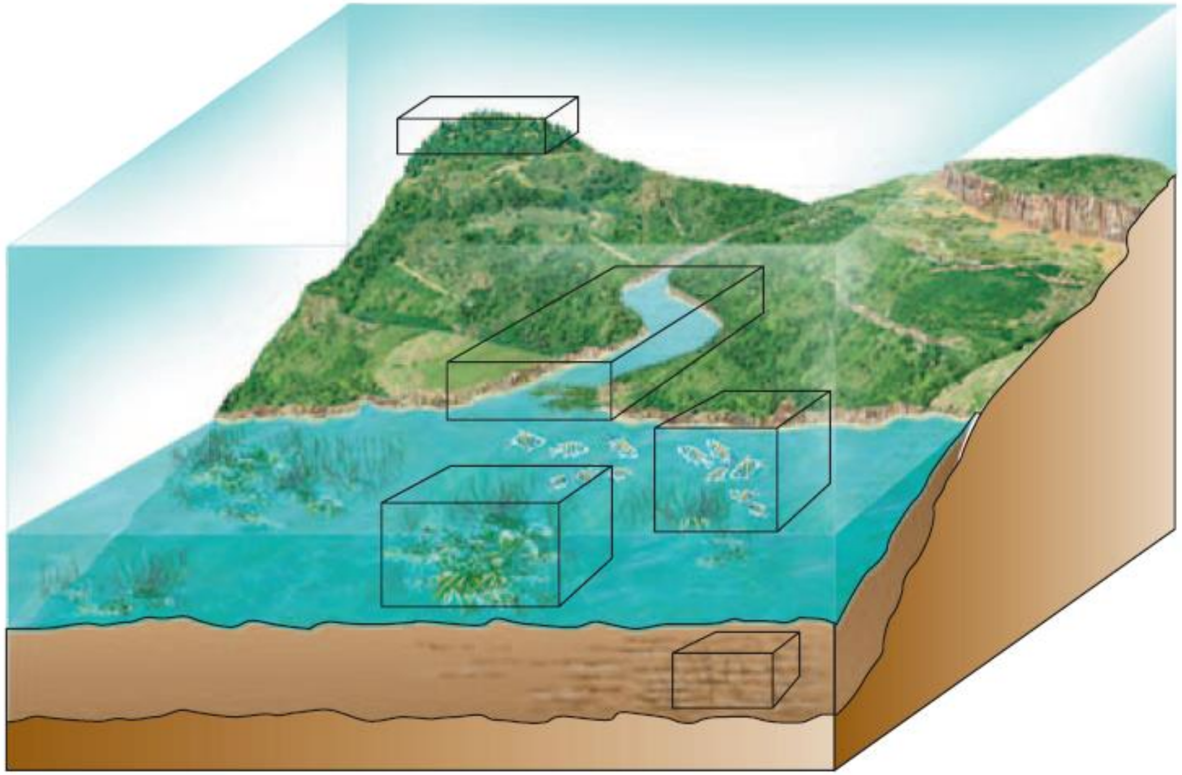


FIGURE 1.4 **A simple system**
The mountain–river–lake landscape shown here is an example of a system. Some of its component subsystems are outlined by boxes.

THE BASICS TYPES OF SYSTEMS

ISOLATED SYSTEM in which the boundary prevents the system from exchanging either matter or energy with its surroundings.

CLOSED SYSTEM in which the boundary permits the exchange of energy, but not matter, with the surroundings.

OPEN SYSTEM, is one that can exchange both energy and matter across its boundary.

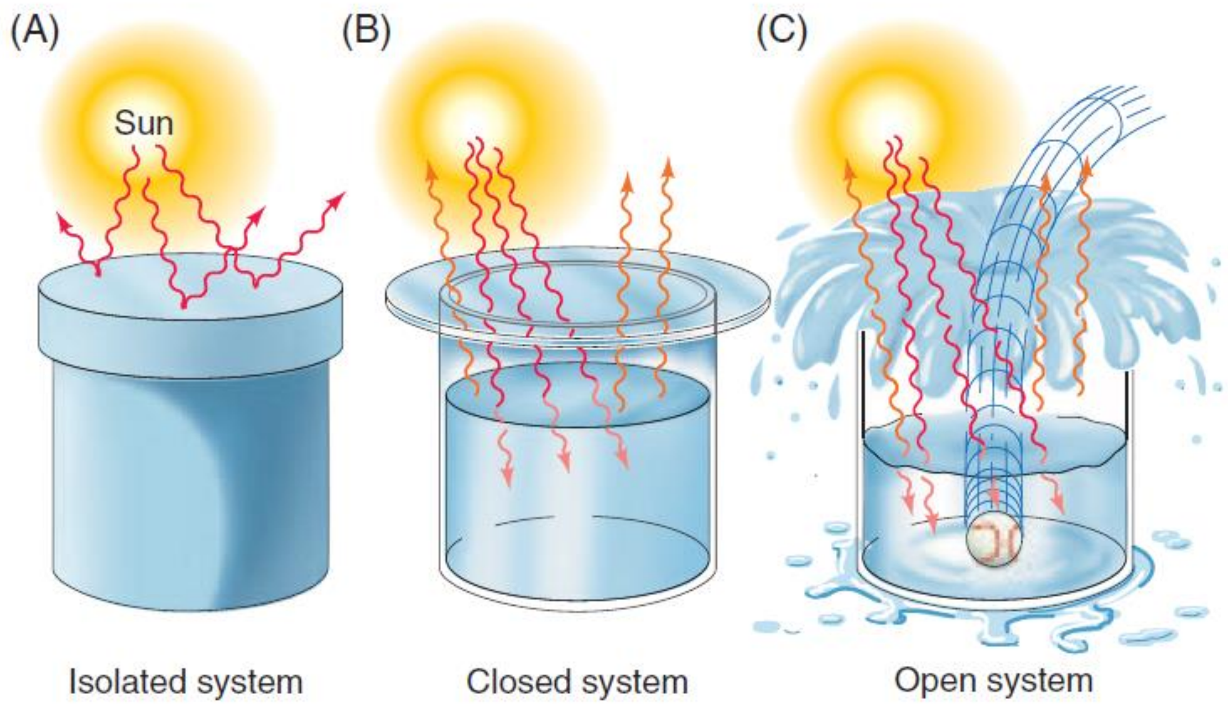


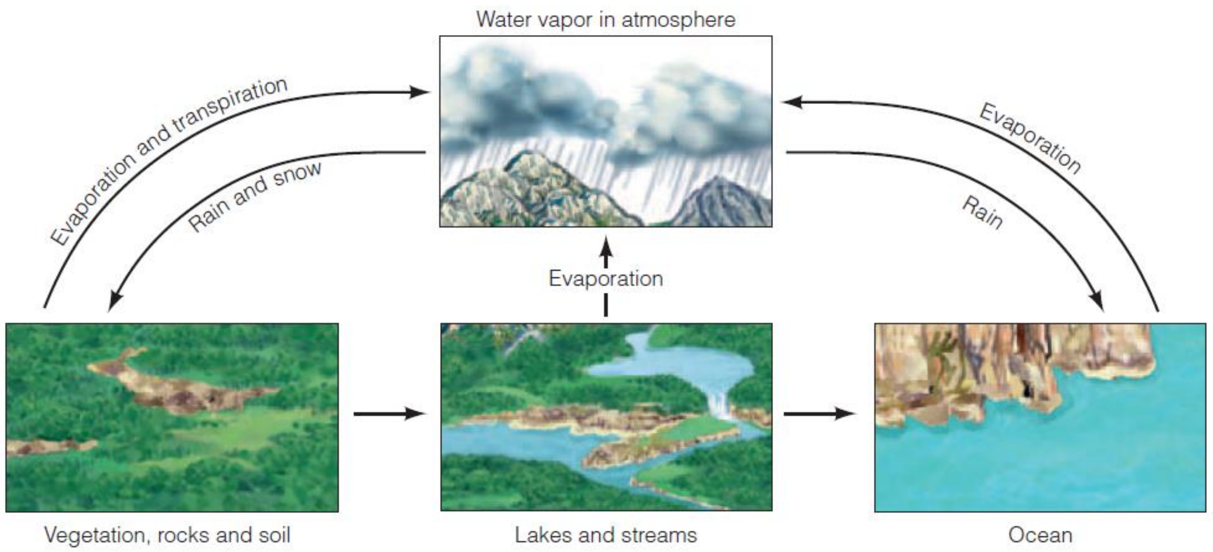
FIGURE B1.1 Systems
The three basic types of systems are: (A) An isolated system. (B) A closed system. (C) An open system.

Fluxes, Reservoirs, and Residence Times

The amount of matter (or energy) that is transferred from any one of reservoirs to another, and the rate at which it is transferred, is called a flux.

These storage places are called reservoirs.

When the flux of matter into a reservoir matches the flux out of that reservoir, we say that the reservoir is at steady state.



Fluxes, Reservoirs, and Residence Times

If the flux of some substance into a reservoir is greater than the flux of that substance out of the reservoir, then we refer to the reservoir as a sink. On the other hand, if more of a substance is coming *from* a reservoir than is flowing *into* it, the reservoir is called a source.

The average length of time water spends in any of these reservoirs is called its residence time.

The residence time of any material in any particular reservoir is determined by the interaction of many factors, including the physical, chemical, and biologic properties of the material itself, the properties of the reservoir, and any external forces or processes acting on either the material or the reservoir.

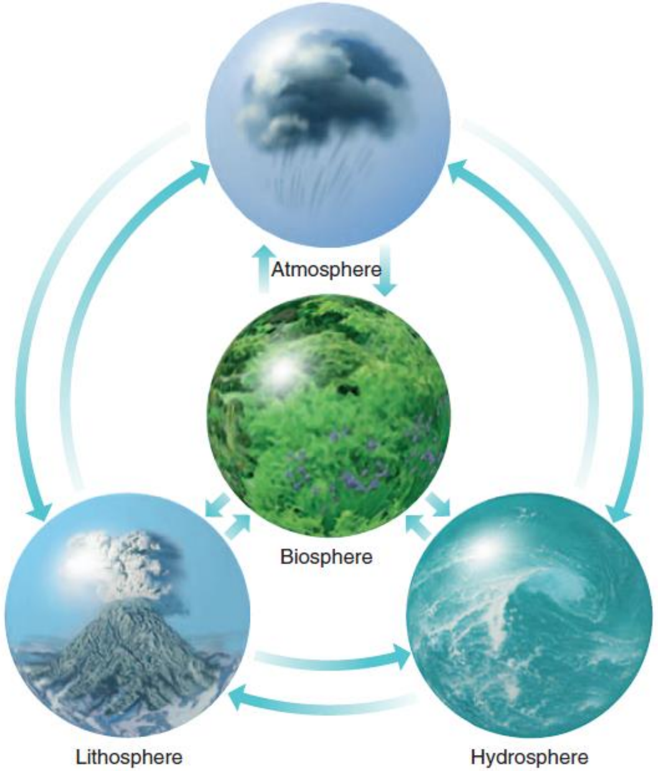
EARTH AS A SYSTEM

- Planet Earth is a dynamic body with many separate but interacting parts or *spheres*. The hydrosphere, atmosphere, biosphere, and geosphere and all of their components can be studied separately. However, the parts are not isolated. Each is related in some way to the others to produce a complex and continuously interacting whole that we call the *Earth system*.

Living in a Closed System

The Earth system comprises four vast reservoirs, with constant flows of energy and matter among them. The four great reservoirs are the atmosphere, the hydrosphere, the biosphere, and the geosphere. Each of these complex reservoirs functions as a subsystem on its own.

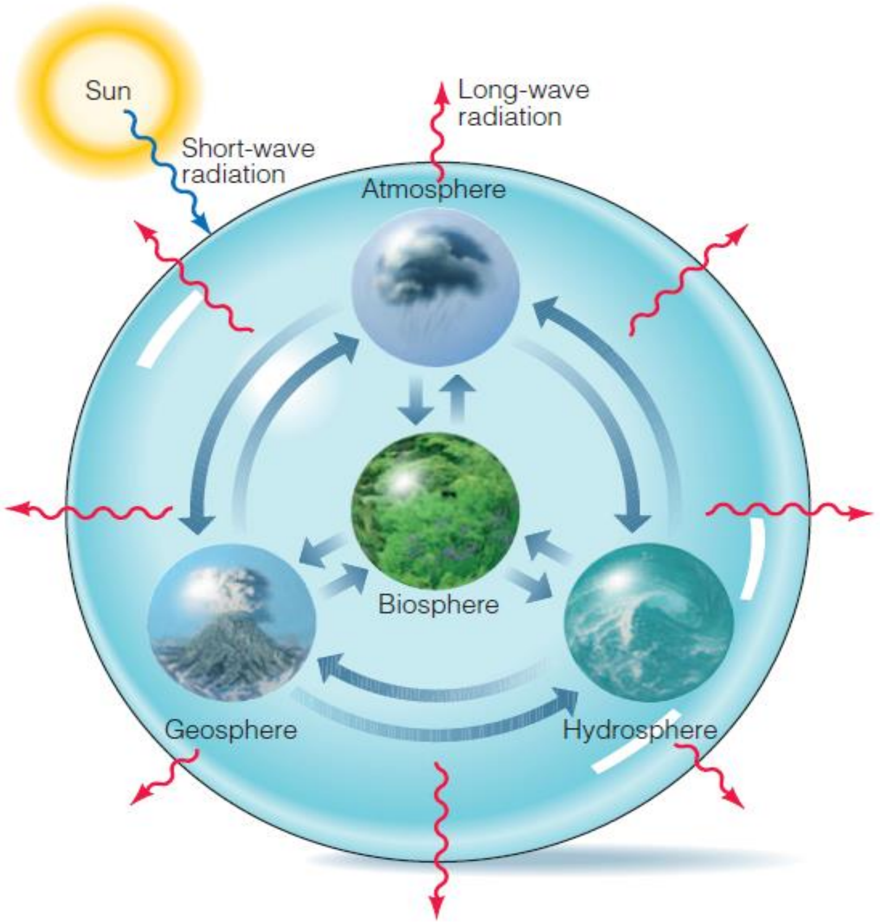
FIGURE 1.6 Earth's interacting parts
This is a diagrammatic representation—essentially a simple box model—of Earth as a system of interacting parts. Each character represents one of the four major reservoirs (or subsystems), and each arrow represents a flow of materials or energy.



EARTH AS A CLOSED SYSTEM

The Earth system comprises four vast reservoirs, with constant flows of energy and matter among them. The four great reservoirs are the atmosphere, the hydrosphere, the biosphere, and the geosphere. Each of these complex reservoirs functions as a subsystem on its own. As a whole, Earth is a closed system—or at least very close to being a closed system. Energy reaches Earth in abundance in the form of solar radiation. Energy also leaves the system in the form of longer-wavelength infrared radiation. Matter, on the other hand, is largely confined within the system. It is not quite correct to say that no matter crosses the boundaries of the Earth system; we lose a small but steady stream of hydrogen atoms from the upper part of the atmosphere, and we gain some incoming material in the form of meteorites. However, the amount of matter that enters or leaves the Earth system is so minuscule compared with the mass of the system as a whole that for all practical purposes Earth is a closed system.

FIGURE 1.7 Earth as a closed system
Earth essentially operates as a closed system. Energy reaches Earth from an external source and eventually returns to space as long-wavelength radiation, but the matter within the system is basically fixed. The subsystems within Earth are open systems, freely exchanging matter and energy.



EARTH AS A CLOSED SYSTEM

The fact that Earth is a closed system has two important implications for those of us who occupy its surface.

First, because *the amount of matter in a closed system is fixed and finite*, the mineral resources on this planet are all we have and—for the foreseeable future—all we will ever have.

Second, *if changes are made in one part of a closed system, the results of those changes eventually will affect other parts of the system*.

Earth is a closed system, but all of its innumerable smaller parts are interconnected; they are open systems, and both matter and energy can be transferred between them. The atmosphere, hydrosphere, biosphere, and geosphere are all open systems, and so is every smaller subsystem within them. When something disturbs one of them, the others also change.

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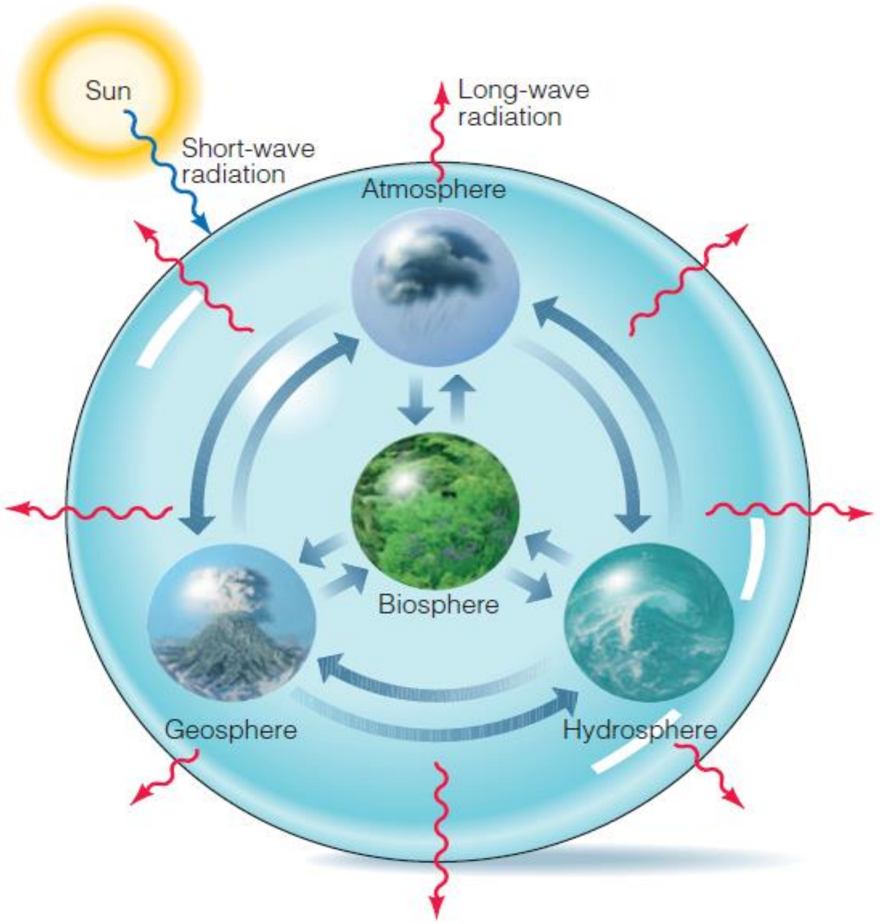


EARTH SYSTEM RESERVOIRS

A convenient way to think about Earth as a system of interdependent parts is to consider it as four vast reservoirs of material with flows of matter and energy between them. Each of these major systems can be further subdivided into smaller, more manageable study units. For example, we can divide the hydrosphere into the ocean, glacier ice, streams, and groundwater.

The study of Earth's four major reservoirs and the interactions among them forms the foundation of Earth system science.

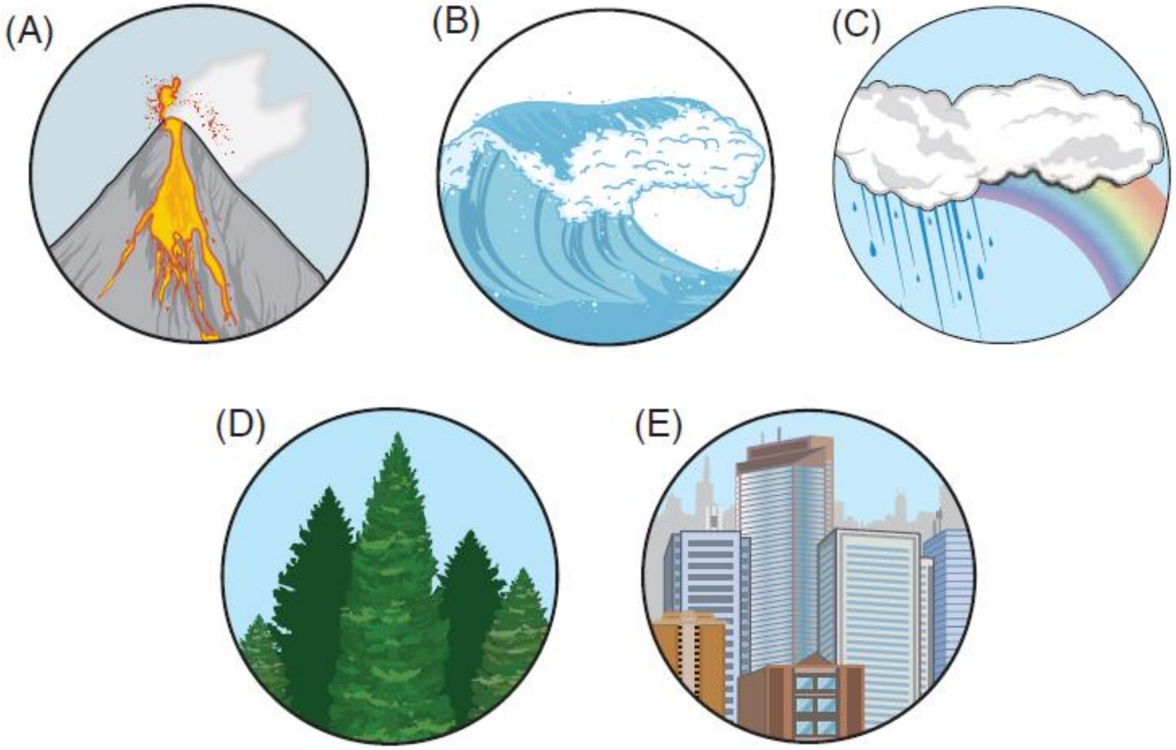


FIGURE 1.9 Earth's subsystems
The major subsystems of the Earth system are: (A) geosphere, (B) hydrosphere, (C) atmosphere, (D) biosphere, and (E) anthroposphere.

DYNAMIC INTERACTIONS AMONG RESERVOIRS

The causes and effects of disturbances in a complex closed system are very difficult to predict.

When pesticides are used in the cotton fields of India, the chemicals can find their way to the waters of the Ganges River and thence to the sea, where some may be ingested by fish and stored in their body tissues. The fish, in turn, may be caught and eaten. In this way, pesticides can end up in the breast milk of mothers halfway around the world from the place where they were applied. Such processes can take a long time to happen, and that is why they have been all too easy to overlook in the past.

DYNAMIC INTERACTIONS AMONG RESERVOIRS: FEEDBACKS

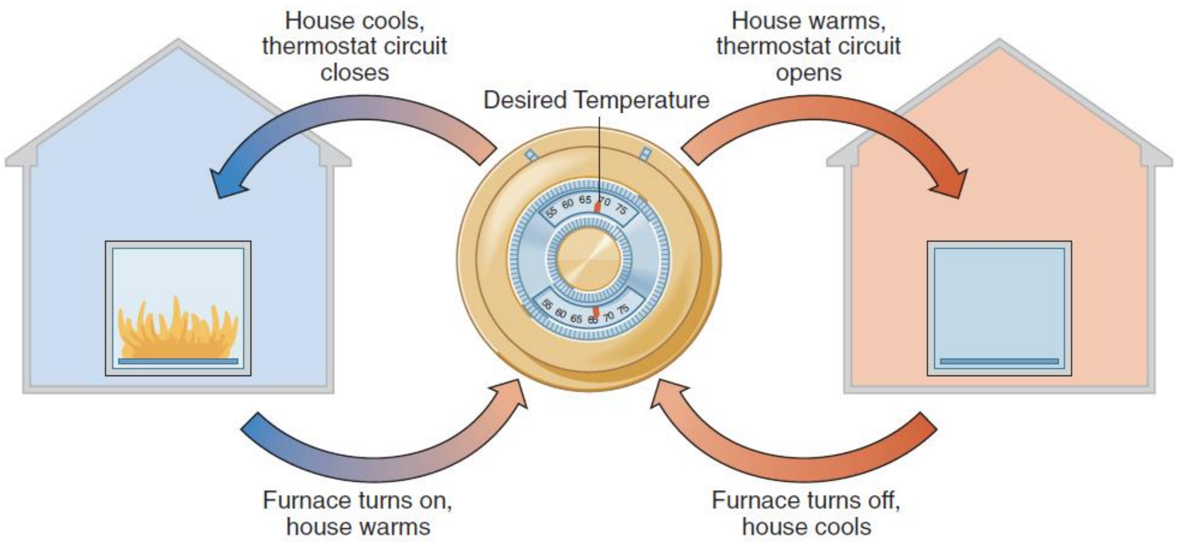
Because energy flows freely into and out of systems, all closed and open systems respond to inputs and, as a result, have outputs. A special kind of system response, called feedback, occurs when the output of the system also serves as an input and leads to changes in the state of the system.

Negative feedback

Positive feedback

Negative Feedback

The household central heating system is an example of negative feedback, in which the system's response is in the opposite direction from the initial input. In this case, cooling is the initial change; the response to this disturbance on the part of the furnace is to initiate warming, returning the system (the house) to its original temperature. Negative feedback is generally desirable because it is stabilizing and usually leads to a system that remains in a constant condition.



Positive Feedback

Positive feedback, on the other hand, an increase in output leads to a further increase in the output.

Positive feedback, sometimes called a “vicious circle,” is destabilizing; instead of returning the system to equilibrium, a positive feedback amplifies the original disturbance.

A fire starting in a forest provides an environmental example of positive feedback. The wood may be slightly damp at the beginning and not burn well, but once a small fire starts, wood near the flame dries out and begins to burn. This, in turn, dries out more wood, leading to a larger fire. Serious problems can occur when our interactions with the natural environment lead to positive feedbacks.