

CHAPTER 7.2:

MECHANISMS OF HEAT TRANSFER

A. LEARNING OBJECTIVES: MECHANISMS OF HEAT TRANSFER

By the end of this section, students will be able to:

- Explain some phenomena that involve conductive, convective, and radiative heat transfer
- Solve problems on the relationships between heat transfer, time, and rate of heat transfer
- Solve problems using the formulas for conduction and radiation
- Explain the importance of the regulation of body temperature in humans and how the human body regulates temperature
- Explain the physics behind different thermometers to measure the temperature of the human body, such as mercury thermometers, digital thermometers, and radiation thermometers

B. MECHANISMS OF HEAT TRANSFER

There are three mechanisms by which heat is transferred between objects.

1. **Conduction** is heat transfer through stationary matter by physical contact. (The matter is stationary on a macroscopic scale—we know there is thermal motion of the atoms and molecules at any temperature above absolute zero.) Heat transferred between the electric burner of a stove and the bottom of a pan is transferred by conduction.
2. **Convection** is the heat transfer by the macroscopic movement of a fluid. This type of transfer takes place in a forced-air furnace and in weather systems.
3. **Radiation** is the transfer of heat that occurs when microwaves, infrared radiation, visible light, or another form of radiation is emitted or absorbed. An example is the warming of the Earth by the Sun.

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](#).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

Conduction

The molecules in two bodies at different temperatures have different average kinetic energies. Collisions occurring at the contact surface tend to transfer energy from high-temperature regions to low-temperature regions. In Figure 1, a molecule in the lower temperature region (right side) has low energy before collision, but its energy increases after colliding with the contact surface. In contrast, a molecule in the higher temperature region (left side) has high energy before collision, but its energy decreases after colliding with the contact surface.

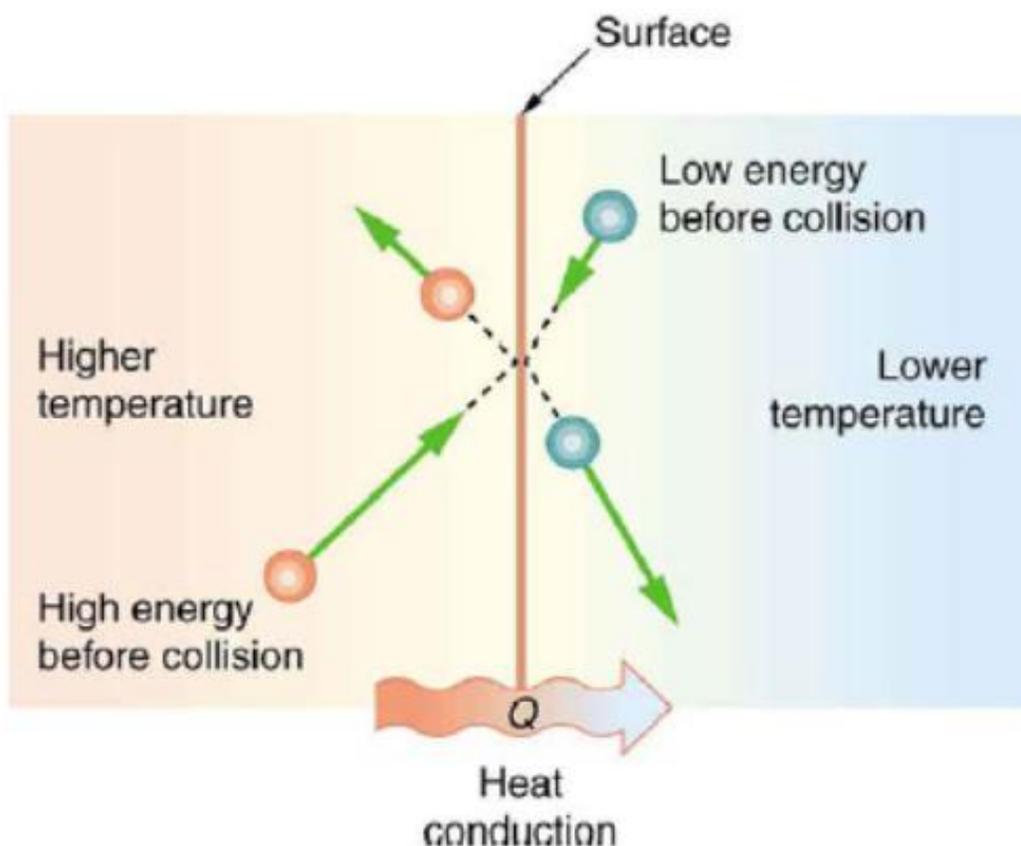


Figure 1: Conduction of heat

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

The heat transferred between two objects, as shown in Figure 2, depends on:

1. the temperature difference between the two objects at temperatures, T_1 and T_2 , respectively.

$$\Delta T = T_2 - T_1, \text{ where } T_2 > T_1.$$

2. The cross-sectional area A of the objects on contact, and
3. The thickness of the material through which heat transfers, d .

The **rate of conductive heat transfer** through a slab of material, P , such as the one in Figure 2, is given by

$$P = \frac{\Delta Q}{\Delta t} = \frac{kA(T_2 - T_1)}{d}$$

Where $\frac{\Delta Q}{\Delta t}$ is the rate of heat transfer in Watts or kilocalories per second,

k is the **thermal conductivity** of the material, A and d are its surface area and thickness, respectively, as shown in Figure 2, and $(T_2 - T_1)$ is the temperature difference across the slab.

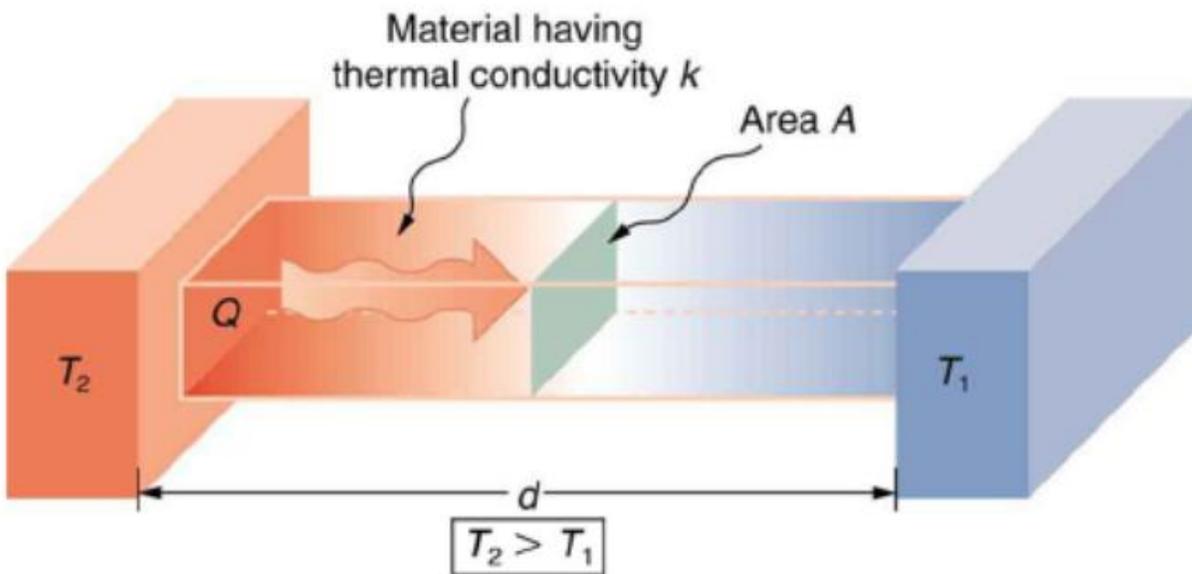


Figure 2: Heat conduction occurs through any material, represented here by a rectangular bar, whether window glass or walrus blubber. The temperature of the material is T_2 on the left and T_1 on the right, where T_2 is greater than T_1 . The rate of heat transfer by conduction is directly proportional to the surface area A , the temperature difference $T_2 - T_1$, and the substance's conductivity k . The rate of heat transfer is inversely proportional to the thickness d .

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

Worked Example: Calculating Heat Transfer Through Conduction

A polystyrene foam icebox has a total area of 0.950 m^2 and walls with an average thickness of 2.50 cm . The box contains ice, water, and canned beverages at 0°C . The inside of the box is kept cold by melting ice. How much ice melts in one day if the icebox is kept in the trunk of a car at 35.0°C ?

Strategy

This question involves both heat for a phase change (melting of ice) and the transfer of heat by conduction. To find the amount of ice melted, we must find the net heat transferred. This value can be obtained by calculating the rate of heat transfer by conduction and multiplying by time.

Solution

First, we identify the knowns.

$$k = 0.010 \frac{\text{W}}{\text{m}} \text{ } ^\circ\text{C} \text{ for polystyrene foam}$$

$$A = 0.950 \text{ m}^2$$

$$d = 2.50 \text{ cm} = 0.0250 \text{ m}$$

$$T_c = 0^\circ\text{C}$$

$$T_h = 35.0^\circ\text{C}$$

$$t = 1 \text{ day} = 24 \text{ hours} = 86\,400 \text{ s.}$$

Then we identify the unknowns. We need to solve for the mass of the ice, m . We also need to solve for the net heat transferred to melt the ice, Q . The rate of heat transfer by conduction is given by

$$P = \frac{\Delta Q}{\Delta t} = \frac{kA(T_h - T_c)}{d}$$

The heat used to melt the ice is $Q = mL_f$. We insert the known values:

$$P = \frac{\left(0.010 \frac{\text{W}}{\text{m}} \text{ } ^\circ\text{C}\right) (0.950 \text{ m}^2) (35.0^\circ\text{C} - 0^\circ\text{C})}{0.0250 \text{ m}} = 13.3 \text{ W}$$

Multiplying the rate of heat transfer by the time we obtain

$$Q = Pt = (13.3 \text{ W})(86\,400 \text{ s}) = 1.15 \times 10^6 \text{ J}$$

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](#).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

We set this equal to the heat transferred to melt the ice, $Q = mL_f$, and solve for the mass m :

$$m = \frac{Q}{L_f} = \frac{1.15 \times 10^6 \text{ J}}{334 \times 10^3 \text{ J/kg}} = 3.44 \text{ kg}$$

Significance

The result of 3.44 kg, or about 7.6 lb, seems about right, based on experience. You might expect to use about a 4 kg (7–10 lb) bag of ice per day. A little extra ice is required if you add any warm food or beverages.

Polystyrene foam is a very poor conductor and thus a good insulator. Other good insulators include fiberglass, wool, and goose down feathers. Like polystyrene foam, these all contain many small pockets of air, taking advantage of air's poor thermal conductivity.

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](#).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

Convection

In convection, hot air rises because density decreases as temperature increases. The house in Figure 3 is kept warm in this manner, as is the pot of water on the stove in Figure 3. Ocean currents and large-scale atmospheric circulation transfer energy from one part of the globe to another. Both are examples of natural convection.

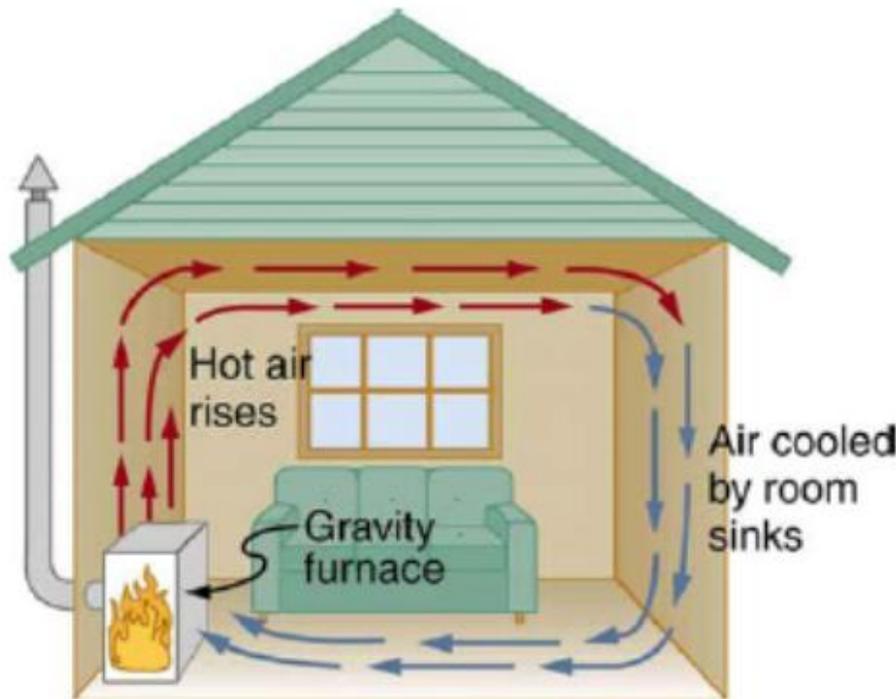


Figure 3: Air heated by the so-called gravity furnace expands and rises, forming a convective loop that transfers energy to other parts of the room. As the air is cooled at the ceiling and outside walls, it contracts, eventually becoming denser than room air and sinking to the floor. A properly designed heating system using natural convection, like this one, can be quite efficient in uniformly heating a home.

Worked Example: Calculating the Flow of Mass During Convection

The average person produces heat at the rate of about 120 W when at rest. At what rate must water evaporate from the body to get rid of all this energy? (For simplicity, we assume this evaporation occurs when a person is sitting in the shade and surrounding temperatures are the same as skin temperature, eliminating heat transfer by other methods.)

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

Strategy

Energy is needed for this phase change ($Q = mL_v$). Thus, the energy lost per unit time is

$$\frac{Q}{t} = \frac{mL_v}{t} = 120 \text{ W} = 120 \text{ J/s}$$

We divide both sides of the equation by L_v to find that the mass evaporated per unit time is

$$\frac{m}{t} = \frac{120 \text{ J/s}}{L_v}$$

Solution

Insert the value of the latent heat, $L_v = 2430 \text{ kJ/kg} = 2430 \text{ J/g}$. This yields:

$$\frac{m}{t} = \frac{120 \text{ J/s}}{2430 \text{ J/g}} = 0.0494 \text{ g/s} = 2.96 \text{ g/min}$$

Significance

Evaporating about 3 g/min seems reasonable. This would be about 180 g (about 7 oz.) per hour. If the air is very dry, the sweat may evaporate without even being noticed. A significant amount of evaporation also takes place in the lungs and breathing passages.

Self-Assess

Question: List the three methods of heat transfer. For two objects in contact, what does the rate at which heat is transferred depend on?

Answer: The three methods in which heat can be transferred are

1. Conduction
2. Convection and
3. Radiation

Heat transferred between two objects depends on the temperature difference between the two objects, $\Delta T = T_2 - T_1$, where $T_2 > T_1$, the cross-sectional area A of the objects in contact, and the thickness of the material through which heat transfers, d .

The **rate of conductive heat transfer** through a slab of material is given by

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](#).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

$$Q/t = [kA(T_2 - T_1)]/d$$

where Q/t is the rate of heat transfer in watts or kilocalories per second, k is the **thermal conductivity** of the material, A and d are its surface area and thickness of the slab, respectively.

C. RADIATION

Radiation is a way for an object to lose or gain heat by emitting or absorbing **electromagnetic waves**. **No medium** is required for electromagnetic waves to propagate. Different names are used for electromagnetic waves of different wavelengths, such as radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays.

Most of the heat transfer from the fire in Figure 4 to the observers is through infrared radiation. The visible light, although dramatic, transfers relatively little thermal energy. Convection transfers energy away from the observers as hot air rises, while conduction is negligibly slow here. Skin is very sensitive to infrared radiation, so that you can sense the presence of a fire without looking at it directly. (credit: Daniel X. O’Neil)



Figure 4: Heat Transfer from fire.

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

All objects absorb and emit electromagnetic radiation. Figure 5 shows what happens when radiation is incident on a transparent (a) and an opaque object (b).

When radiation is incident on a transparent object, part of it is reflected and part of it enters the object. Within the object, some of the radiation is absorbed, and the rest is transmitted through the object. In an opaque object, part of the incident radiation is reflected, and the rest is absorbed by the object.

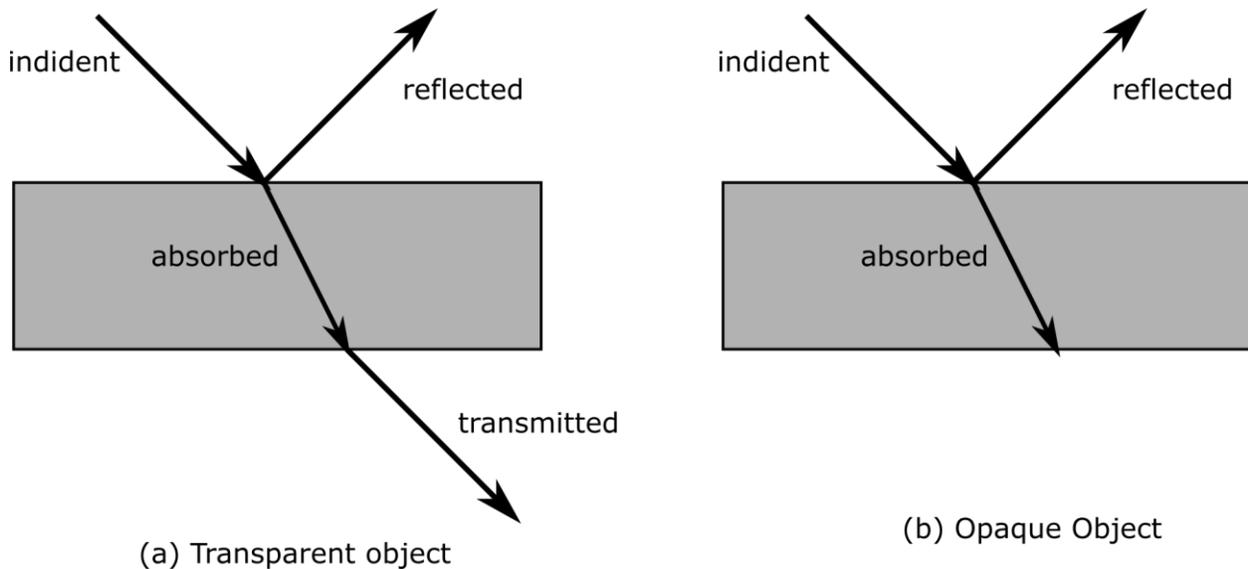


Figure 5: (a) Radiation incident on a transparent object; and (b) radiation incident on an opaque object

The absorbed radiation is emitted back to the surroundings, as seen in Figure 6. The absorption and emission depend on the wavelength of the radiation and are determined by the material properties of the objects. The absorption and emission can be different for different wavelengths or colors of the radiation.

Black absorbs heat more effectively, and white absorbs heat least effectively (see Figure 6). People living in hot climates generally avoid wearing black clothing. An ideal absorber absorbs all the energy incident on it. An ideal radiator emits all the energy incident on it.

A perfect blackbody absorbs **all the radiation** incident on it.

The reverse is also true – black radiates heat most effectively while white radiates heat least effectively. Thus, on a clear summer night, the asphalt will be colder than the gray sidewalk, because black radiates the energy more rapidly than gray.

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

An **ideal radiator** is the same color as an **ideal absorber** and captures all the radiation that falls on it. In contrast, white is a poor absorber and is also a poor radiator.

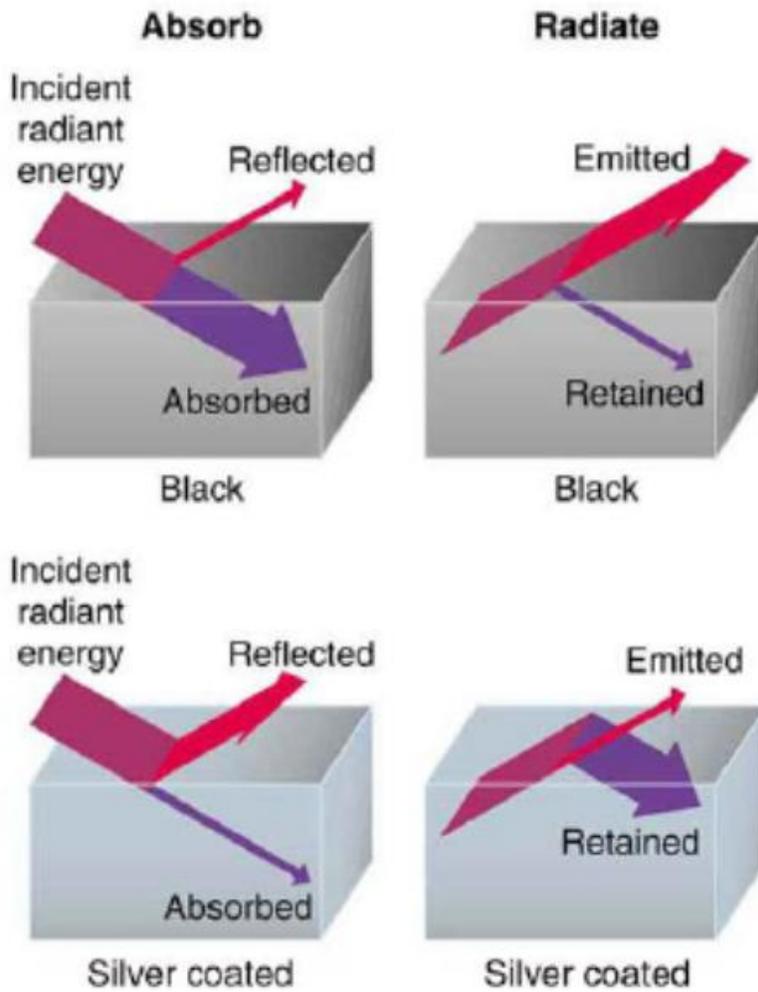


Figure 6: A black object is a good absorber and a good radiator, while a white (or silver) object is a poor absorber and a poor radiator.

Radiation of a Black Body

In this section, we study what wavelengths or frequencies are emitted by an ideal black body and the intensities of these frequencies relative to each other.

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

The energy of electromagnetic radiation depends on the frequency (color) and varies over a wide range: a smaller wavelength (or higher frequency) corresponds to a higher energy. Because more heat is radiated at higher temperatures, a temperature change is accompanied by a color change.

Take, for example, an electrical element on a stove, which glows from red to orange, while the higher-temperature steel in a blast furnace glows from yellow to white. The radiation you feel is mostly infrared, which corresponds to a lower temperature than that of the electrical element and the steel.

An ideal black body emits radiation over a range of wavelengths as represented by the x-axis of the plot in Figure 7(a). The intensity $I(\lambda, T)$, defined as the **energy radiated per unit time (power) per unit area of the object per unit wavelength, at each wavelength**, is represented on the y-axis.

$$I(\lambda, T) = \frac{\text{Energy}}{\text{Time} \times \text{Area} \times \Delta\lambda} = \frac{\text{Power}}{\text{Area} \times \Delta\lambda}$$

Recall that power equals energy emitted per unit time and is measured in Watts.

Figure 7(a) shows that the intensity of the radiation emitted by a blackbody varies with wavelength. Each curve has a peak with the radiation having the maximum intensity. The distribution of radiation in Figure 7(a) is known as the **Planck Distribution**.

For example, when the object in Figure 7(a) is at 6000 K, the intensity peaks in the blue region of the EM spectra. When the object is around 4000 K, the intensity peaks in the red region of the EM spectra.

Figure 7(a) shows a graph of the spectra of electromagnetic waves emitted from an ideal radiator at three different temperatures. The intensity or rate of radiation emission increases dramatically with temperature, and the spectrum shifts toward the visible and ultraviolet parts of the spectrum. The shaded portion denotes the visible part of the spectrum. The shift toward the ultraviolet with temperature makes the visible appearance shift from red to white to blue as temperature increases.

In Figure 7(b), note the variations in color corresponding to variations in flame temperature. (credit: Tuohirulla)

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](#).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

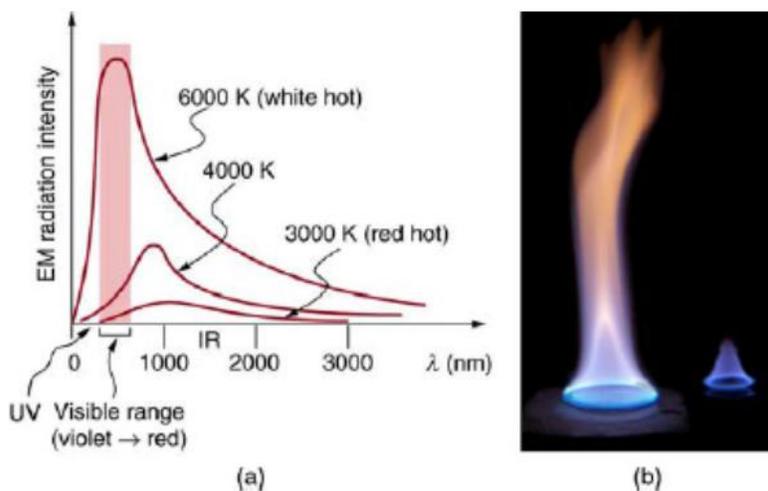


Figure 7: Energy distribution of a black body.

Stefan-Boltzmann's Law

The total power emitted by an object over all wavelengths is given by summing the intensities of radiation over all wavelength intervals. This sum gives rise to **Stefan-Boltzmann's Law**.

According to **Stefan-Boltzmann Law of radiation**, the power $P = \frac{Q}{t}$ (rate of transfer of heat), where Q is the heat radiated over a time t , by an object, is given by:

$$P = \frac{Q}{t} = \sigma eAT^4$$

Where $\sigma = 5.67 \times 10^{-8} \frac{J}{s m^2 K^4}$ is the Stefan-Boltzmann constant, A is the surface area of the object, and T is its absolute temperature in kelvin. The symbol e stands for the **emissivity** of the object, which is a measure of how well the object radiates.

An ideal jet-black (or black body) radiator has $e = 1$, whereas a perfect reflector has $e = 0$. Real objects fall between these two values. Take, for example, tungsten light bulb filaments, which have an emissivity, e , of about 0.5, and carbon black (a material used in printer toner), which has the (greatest known) emissivity of about 0.99.

Use Stefan-Boltzmann's Law to answer the following questions.

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

1. According to Stefan-Boltzmann's Law, what is the relationship between the rate of radiation of heat of an object and its absolute temperature? By what factor does the rate of radiation increase when the temperature is doubled?
 - a. According to Stefan-Boltzmann's Law, the rate of heat radiation is proportional to the fourth power of the object's absolute temperature.

When the absolute temperature of the object doubles, its rate of radiation increases by a factor of 16.

2. According to Stefan-Boltzmann's Law, what is the relationship between the rate of radiation of heat and the area of the object? By what factor does the rate of radiation increase when the area of the object is doubled?
 - a. According to Stefan-Boltzmann's the rate of heat radiation is directly proportional to the area of the object.

When the area of the object is doubled, the rate of radiation also doubles.

When the object is at a temperature T_{obj} is placed in the surroundings T_s , there is a transfer of heat from the surroundings to the object. Therefore, the net transfer of heat from the object is

$$P_{net} = \sigma eA(T_{obj}^4 - T_s^4)$$

If the object is at a higher temperature, then heat is transferred from the object to the surroundings. If the surroundings are at a higher temperature than the object, then heat is transferred from the surroundings to the object. The net heat transfer is from hot to cold.

Self-Assess

Question: What is radiation? What is an ideal radiator and an ideal absorber? State the Stefan-Boltzmann Law.

Answer: Radiation is a way for an object to lose or gain heat by emitting or absorbing electromagnetic waves.

An ideal radiator radiates all the energy incident on it. An ideal absorber absorbs all the energy incident on it. The rate of heat transfer by emitted radiation is determined by the **Stefan-Boltzmann law of radiation:**

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](#).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

$$\frac{Q}{t} = \sigma eAT^4$$

Where $\sigma = 5.67 \times 10^{-8} \text{ J/s m}^2\text{K}^4$ is the Stefan-Boltzmann constant, A is the surface area of the object, and T is its absolute temperature in kelvin. The symbol e stands for the **emissivity** of the object, which is a measure of how well the object radiates.

D. WORKED EXAMPLE: CALCULATING THE NET HEAT TRANSFER OF A PERSON

What is the rate of heat transfer by radiation of an unclothed person standing in a dark room whose ambient temperature is 22.0°C ? The person has a normal skin temperature of 33.0°C and a surface area of 1.50m^2 . The emissivity of skin is 0.97 in the infrared, the part of the spectrum where the radiation takes place.

Strategy

We can solve this by using the equation for the rate of radiative heat transfer.

$$\frac{Q}{t} = \sigma eA(T_2^4 - T_1^4).$$

Solution

Insert the temperature values $T_2 = 295 \text{ K}$ and $T_1 = 306 \text{ K}$, so that:

$$\begin{aligned} \frac{Q}{t} &= \sigma eA(T_2^4 - T_1^4) \\ &= \left(5.67 \times 10^{-8} \frac{\text{J}}{\text{s}} \text{m}^2\text{K}^4\right) (0.97)(1.50 \text{ m}^2)[(295 \text{ K})^4 - (306 \text{ K})^4] \\ &= -99 \text{ J/s} = -99 \text{ W} \end{aligned}$$

Significance

This value is a significant rate of heat transfer to the environment (note the minus sign), considering that a person at rest may produce energy at the rate of 125 W and that conduction and convection are also transferring energy to the environment. Indeed, we would probably expect this person to feel cold. Clothing significantly reduces heat transfer

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

to the environment by all mechanisms because clothing slows down both conduction and convection, and has a lower emissivity (especially if it is light-colored) than skin.

E. REGULATION OF BODY TEMPERATURE: THERMOREGULATION

Thermoregulation and Homeostasis

The body tightly regulates its body temperature through a process called **thermoregulation**, in which the body can maintain its temperature within certain boundaries, even when the surrounding temperature is very different. The core temperature of the body remains steady at around 36.5–37.5 °C (or 97.7–99.5 °F). The tendency of the human body to maintain a stable temperature is called temperature **homeostasis**. In the process of ATP (Adenosine Triphosphate, the energy source in cells) production by cells throughout the body, approximately 60 percent of the energy produced is in the form of heat used to maintain body temperature. Thermoregulation is an example of **negative feedback**.

The hypothalamus in the brain is the master switch that works as a thermostat to regulate the body's core temperature (Figure 8). If the temperature is too high, the hypothalamus can initiate several processes to lower it. These include increasing the circulation of the blood to the surface of the body to allow for the dissipation of heat through the skin and initiation of sweating to allow evaporation of water on the skin to cool its surface, as seen in Figure 8.

Conversely, if the temperature falls below the set core temperature, the hypothalamus can initiate shivering to generate heat. The body uses more energy and generates more heat. In addition, thyroid hormone will stimulate more energy use and heat production by cells throughout the body.

An environment is said to be **thermoneutral** when the body does not expend or release energy to maintain its core temperature. For a naked human, this is an ambient air temperature of around 84 °F. If the temperature is higher, for example, when wearing clothes, the body compensates with cooling mechanisms. The body loses heat through the mechanisms of heat exchange.

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](#).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

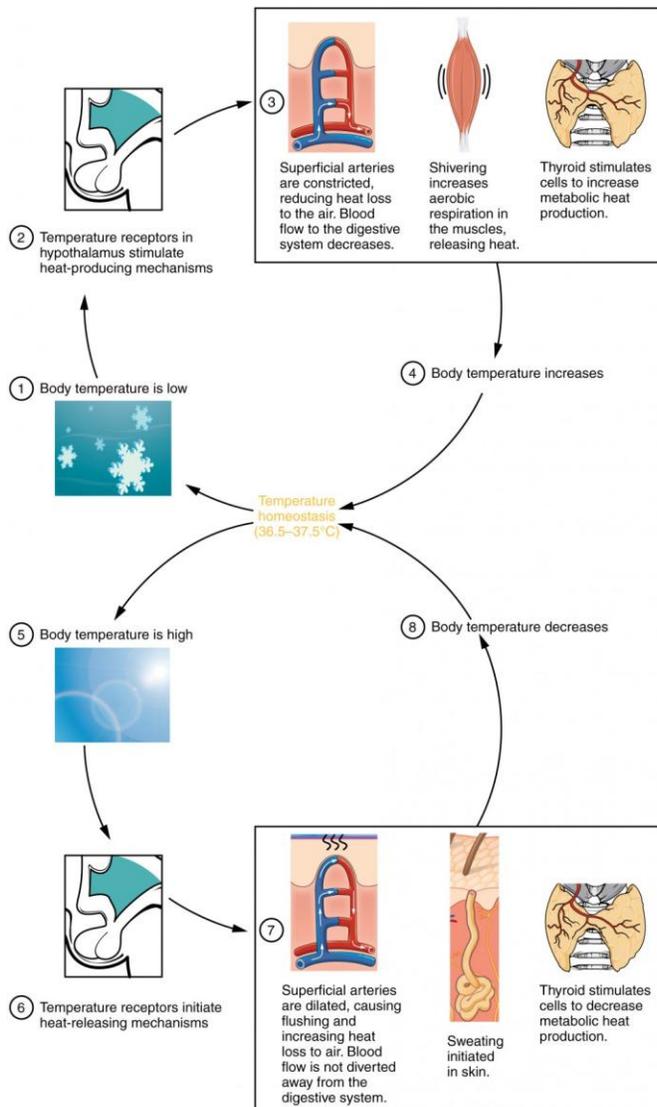


Figure 8: Hypothalamus controls thermoregulation. The figure shows the various mechanisms to regulate temperature.

Maintaining homeostasis requires that the body continuously monitor its internal conditions. From body temperature to blood pressure to levels of certain nutrients, each physiological condition has a particular **set point**. A set point is the physiological value around which the normal range fluctuates. A normal range (homeostatic range) is the restricted set of values that is optimally healthful and stable. The set point for normal human body temperature is approximately 37°C (98.6°F). Physiological parameters, such as body temperature and blood pressure, tend to fluctuate within a normal range, a few degrees above and below that point. Control centers in the brain and other parts of the body monitor and react to deviations from homeostasis using negative feedback. Negative

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

feedback is a mechanism that reverses a deviation from the set point. Therefore, negative feedback maintains body parameters within their normal range. The maintenance of homeostasis by negative feedback goes on throughout the body at all times, and an understanding of negative feedback is thus fundamental to an understanding of human physiology.

In physics terms, homeostasis refers to a **stable equilibrium**. For example, a ball at the bottom of a bowl (Figure 9) would experience a force back toward the equilibrium point (negative feedback) if moved away from the equilibrium point. This is illustrated in Figure 9(b). This is the case as long as the ball remains in the bowl.

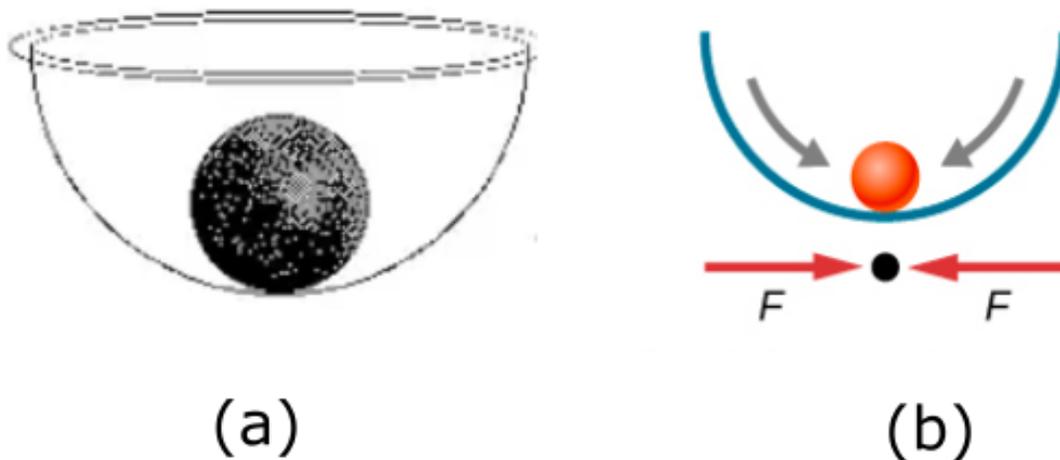


Figure 9: Example of stable equilibrium.

Question

In the ball/bowl analogy, what represents the following?

1. The set point for the body temperature (37°C)
2. The normal range ($\pm 0.5^{\circ}\text{C}$).
3. The negative feedback mechanism.

Solution

1. The set point for the body temperature: the location of the bottom of the bowl.
2. The normal range: the size of the bowl.
3. The negative feedback mechanism: the restoring normal force from the bowl on the ball.

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

Negative Feedback System

A negative feedback system has three basic components (Figure 10a). A **sensor**, also referred to as a **receptor**, is a component of a feedback system that monitors a physiological value. This value is reported to the **control center**. The control center is the component in a feedback system that compares the value to the normal range. If the value deviates too much from the set point, then the control center activates an **effector**. An effector is the component in a feedback system that causes a change to reverse the situation and return the value to the normal range. To set the system in motion, a stimulus must drive a physiological parameter beyond its normal range (that is, beyond homeostasis). This stimulus is “heard” by a specific sensor. For example, in the control of blood glucose, specific endocrine cells in the pancreas detect excess glucose (the stimulus) in the bloodstream. These pancreatic beta cells respond to the increased level of blood glucose by releasing the hormone insulin into the bloodstream. The insulin signals skeletal muscle fibers, fat cells (adipocytes), and liver cells to take up the excess glucose, removing it from the bloodstream. As glucose concentration in the bloodstream drops, the decrease in concentration—the actual negative feedback—is detected by pancreatic alpha cells, and insulin release stops. This prevents blood sugar levels from continuing to drop below the normal range. Humans have a similar temperature regulation feedback system that works by promoting either heat loss or heat gain (Figure 10b). When the brain’s temperature regulation center receives data from the sensors indicating that the body’s temperature exceeds its normal range, it stimulates a cluster of brain cells referred to as the **heat-loss center**. This stimulation has three major effects:

- Blood vessels in the skin begin to dilate, allowing more blood from the body's core to flow to the surface of the skin, allowing the heat to radiate into the environment.
- As blood flow to the skin increases, sweat glands are activated to increase their output. As the sweat evaporates from the skin surface into the surrounding air, it takes heat with it.
- The depth of respiration increases, and a person may breathe through an open mouth instead of through the nasal passageways. This further increases heat loss from the lungs.

In contrast, activation of the brain’s heat-gain center by exposure to cold reduces blood flow to the skin, and blood returning from the limbs is diverted into a network of deep veins. This arrangement traps heat closer to the body's core and restricts heat loss. If heat loss is severe, the brain triggers an increase in random signals to skeletal muscles, causing them

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](#).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

to contract and produce shivering. The muscle contractions of shivering release heat while using up ATP. The brain triggers the thyroid gland in the endocrine system to release thyroid hormone, which increases metabolic activity and heat production in cells throughout the body. The brain also signals the adrenal glands to release epinephrine (adrenaline), a hormone that causes the breakdown of glycogen into glucose, which can be used as an energy source. The breakdown of glycogen into glucose also results in increased metabolism and heat production.

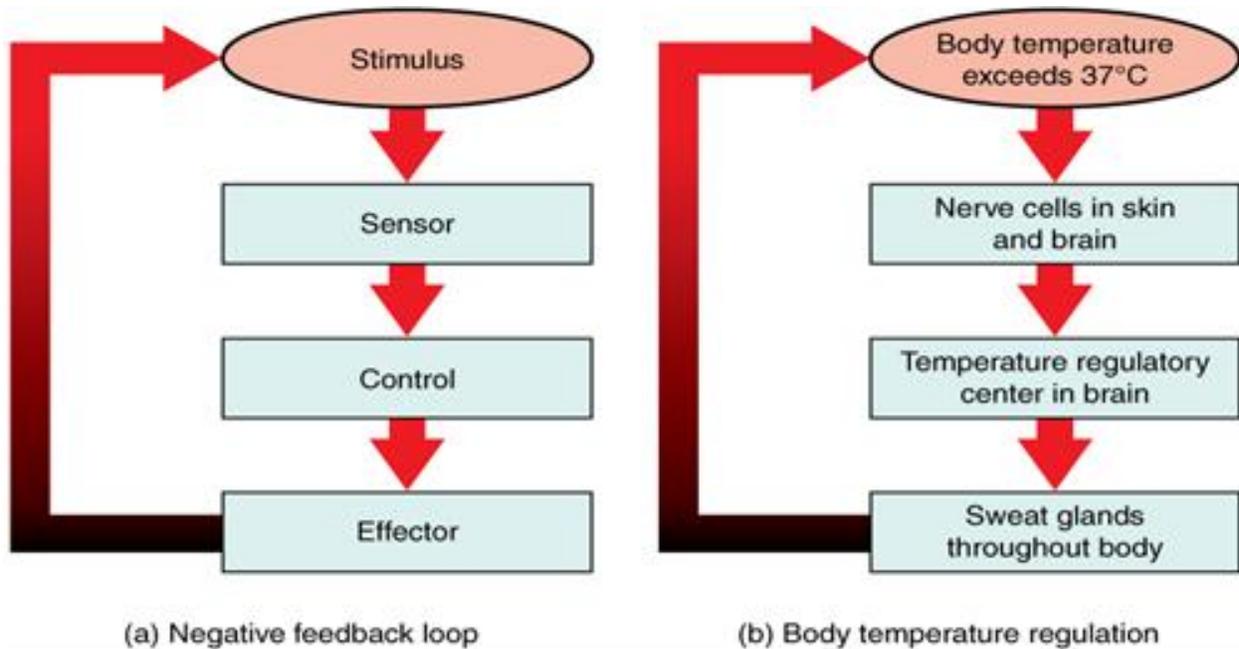


Figure 10: Negative Feedback Loop- In a negative feedback loop, a stimulus—a deviation from a set point—is resisted through a physiological process that returns the body to homeostasis. (a) A negative feedback loop has four basic parts. (b) Body temperature is regulated by negative feedback.

Question: Shivering is an involuntary response to lowered body temperature. What is the efficiency of the body when shivering, and is this a desirable value?

Solution: The efficiency is low as no work is produced when shivering. This is desirable as you are trying to convert energy into heat.

Positive Feedback System

Positive feedback intensifies a change in the body's physiological condition rather than reversing it. A deviation from the normal range results in more change, and the system moves farther away from the normal range. Positive feedback in the body is normal only

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

when there is a definite endpoint. Childbirth and the body's response to blood loss are two examples of positive feedback loops that are normal but are activated only when needed. Childbirth at full term is an example of a situation in which the maintenance of the existing body state is not desired. Enormous changes in the mother's body are required to expel the baby at the end of pregnancy. And the events of childbirth, once begun, must progress rapidly to a conclusion, or the life of the mother and the baby are at risk. The extreme muscular work of labor and delivery is the result of a positive feedback system (Figure 11).

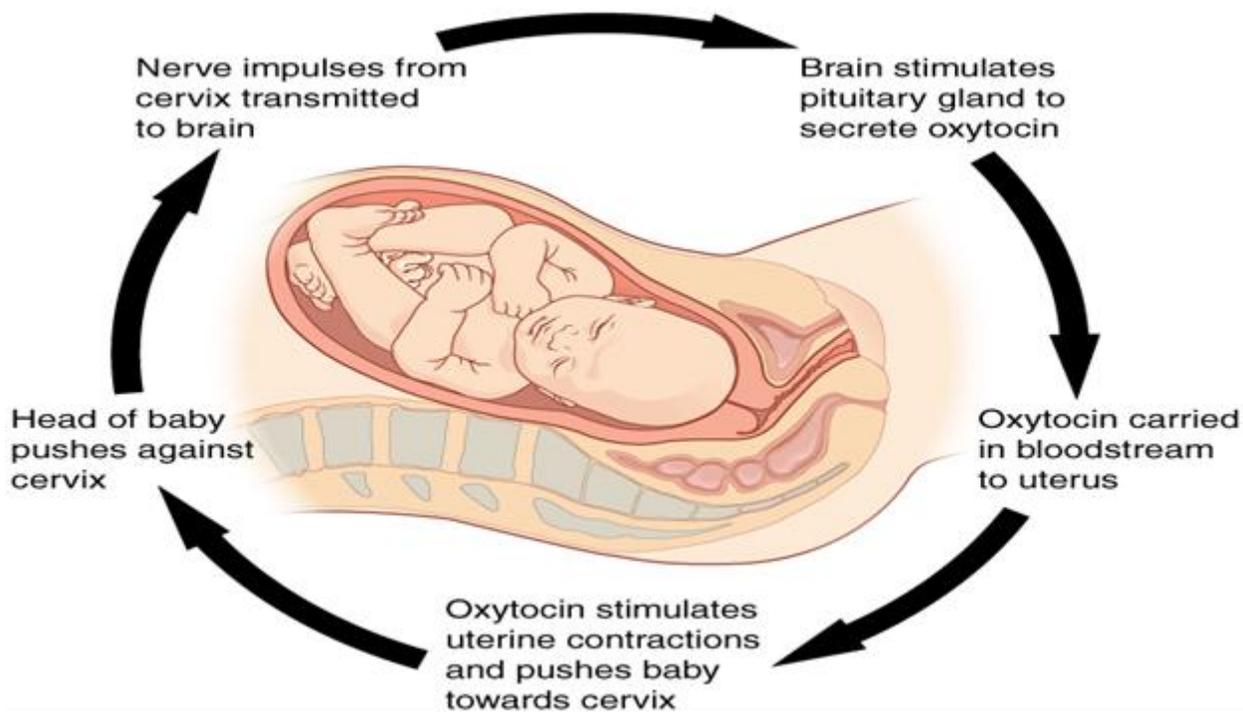


Figure 11: Positive Feedback Loop. Normal childbirth is driven by a positive feedback loop. A positive feedback loop results in a change in the body's status, rather than a return to homeostasis.

The first contractions of labor (the stimulus) push the baby toward the cervix (the lowest part of the uterus). The cervix contains stretch-sensitive nerve cells that monitor the degree of stretching (the sensors). These nerve cells send messages to the brain, which in turn causes the pituitary gland at the base of the brain to release the hormone oxytocin into the bloodstream. Oxytocin causes stronger contractions of the smooth muscles in the uterus (the effectors), pushing the baby further down the birth canal. This causes even greater stretching of the cervix. The cycle of stretching, oxytocin release, and increasingly more forceful contractions stops only when the baby is born. At this point, the stretching of the cervix halts, stopping the release of oxytocin.

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

A second example of positive feedback centers on reversing extreme damage to the body. Following a penetrating wound, the most immediate threat is excessive blood loss. Less blood circulating means reduced blood pressure and reduced perfusion (penetration of blood) to the brain and other vital organs. If perfusion is severely reduced, vital organs will shut down and the person will die. The body responds to this potential catastrophe by releasing substances in the injured blood vessel wall that begin the process of blood clotting. As each step of clotting occurs, it stimulates the release of more clotting substances. This accelerates the processes of clotting and sealing off the damaged area. Clotting is contained in a local area based on the tightly controlled availability of clotting proteins. This is an adaptive, life-saving cascade of events.

Positive feedback mechanisms in physics cause a system to be unstable and not return to an equilibrium point. This is seen in Figure 12, where a ball on top of an inverted bowl is in equilibrium, but the equilibrium is unstable. Small deviations from equilibrium will cause the ball to roll off.

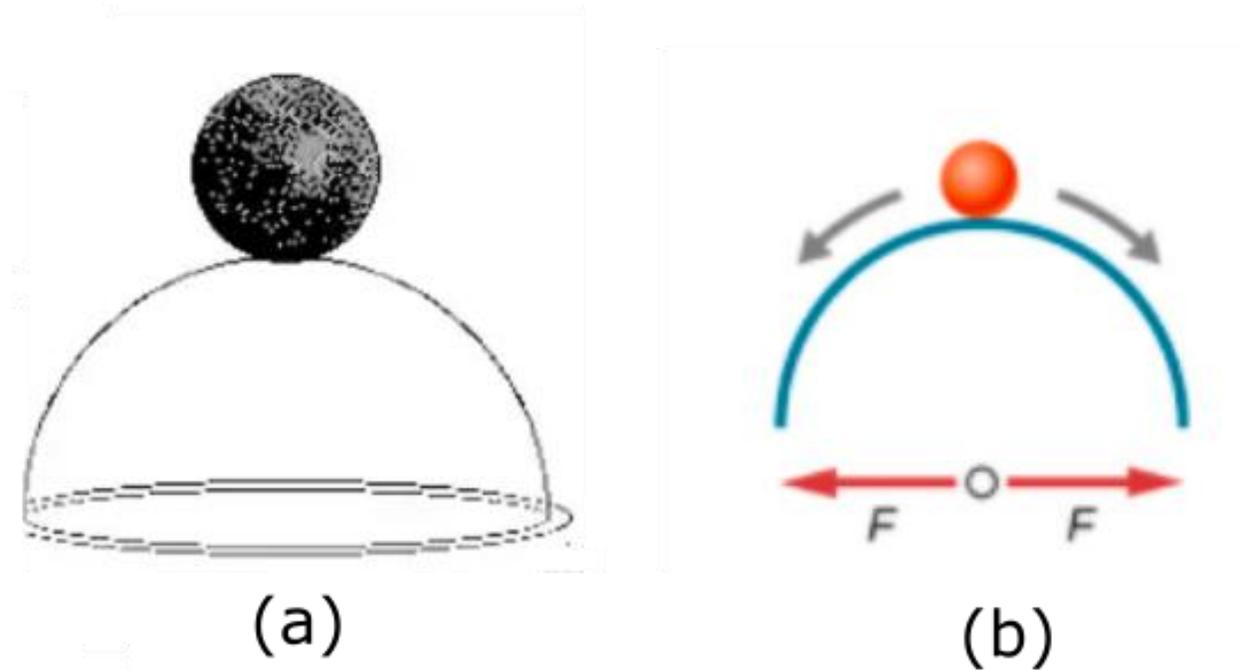


Figure 12: Example of unstable equilibrium

Question: Describe the system below in the context of homeostasis, normal range, negative, and positive feedback.

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

Solution: Homeostasis represents the block being stable on the surface. The normal range would be such that the Center of Mass (COM) would be within the width of the block. If the COM is within that range, the weight of the block would be exerting a torque to restore the block towards its equilibrium, and the torque would be a negative feedback to the disturbance. If the COM is outside the width of the block a positive feedback loop would result in the block falling over (away from the initial equilibrium state) and a positive feedback loop.

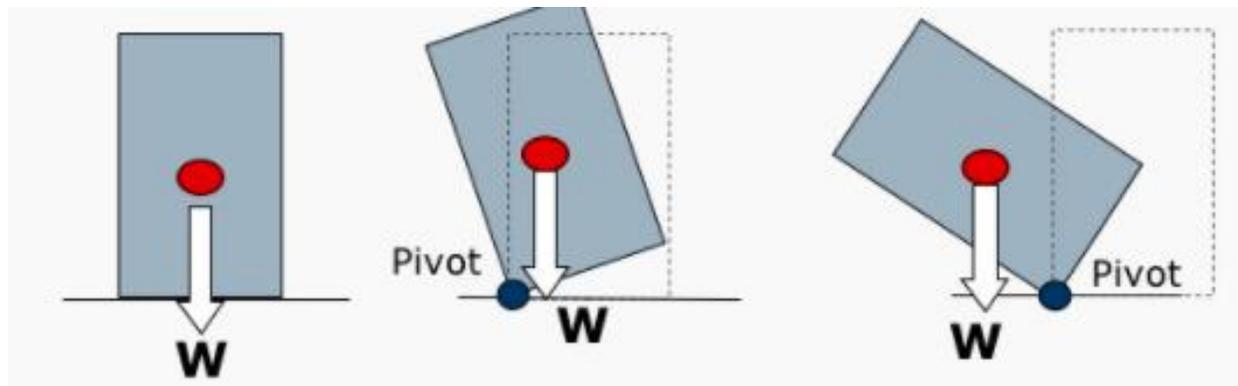


Figure 13: States of homeostasis

Mechanisms of Heat Exchange

When the environment is not thermoneutral, the body uses four mechanisms of heat exchange to maintain homeostasis: conduction, convection, radiation, and evaporation. Each of these mechanisms relies on the property of heat to flow from a higher temperature to a lower temperature; therefore, each of the mechanisms of heat exchange varies in rate according to the temperature and conditions of the environment.

Conduction is the transfer of heat by two objects that are in direct contact with one another. It occurs when the skin comes in contact with a cold or warm object. For example, when holding a glass of ice water, the heat from your skin will warm the glass and, in turn, melt the ice. Alternatively, on a cold day, you might warm up by wrapping your cold hands around a hot mug of coffee. Only about 3 percent of the body's heat is lost through conduction.

Convection is the transfer of heat to the air surrounding the skin. The warmed air rises away from the body and is replaced by cooler air that is subsequently heated. Convection can also occur in water. When the water temperature is lower than the body's temperature, the body loses heat by warming the water closest to the skin, which moves

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

away to be replaced by cooler water. The convection currents created by the temperature changes continue to draw heat away from the body more quickly than the body can replace it, resulting in hyperthermia. About 15 percent of the body's heat is lost through convection.

Radiation is the transfer of heat via electromagnetic waves. This occurs between any two objects when their temperatures differ. A radiator can warm a room via radiant heat. On a sunny day, the radiation from the sun warms the skin. The same principle works from the body to the environment. About 60 percent of the heat lost by the body is lost through radiation.

Evaporation is the transfer of heat by the evaporation of water. Because it takes a great deal of energy for a water molecule to change from a liquid to a gas, evaporating water (in the form of sweat) takes with it a great deal of energy from the skin. However, the rate at which evaporation occurs depends on relative humidity—more sweat evaporates in lower humidity environments. Sweating is the primary means of cooling the body during exercise, whereas at rest, about 20 percent of the heat lost by the body occurs through evaporation.

Self-Assess

Question: Thermoregulation is an example of what kind of feedback? Which part of the body is responsible for thermoregulation?

Answer: Thermoregulation is an example of positive feedback. The hypothalamus is responsible for thermoregulation.

F. TEMPERATURE MEASUREMENT IN THE HUMAN BODY

The temperature of the human body is a result of many physiological processes. The body tightly regulates body temperature with the core temperature between 36.5–37.5 °C (or 97.7–99.5 °F) through **thermoregulation**. The body maintains temperature within this narrow range, as certain processes essential for the functioning of the body can occur only within that temperature range. The body temperature can increase due to infections, menstruation, physical exertion, and extreme environmental temperatures. Prolonged low environmental temperatures can also cause hypothermia, a decrease in body temperature.

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](#).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

During illnesses caused by infections, monitoring fever is important. Both hypothermia and high fever can be life-threatening. Measuring body temperature is often the first thing done during a visit to a doctor's clinic or a hospital.

Body temperature is measured using different thermometers and at different sites, such as:

1. Armpit (axillary temperature)
2. Rectum (rectal temperature)
3. Mouth (oral temperature)
4. Ear (tympanic temperature)
5. Forehead

The temperature measurement in each site varies, with the rectal temperature and the tympanic temperature being typically higher than the oral temperature, followed by the axillary temperature. The normal temperature ranges at the different sites also differ based on sex.

Liquid-in-glass thermometers, electronic thermometers, and non-contact thermometers such as infrared (IR) thermometers based on measurement of radiation emitted by the tympanic membrane (eardrum) or the forehead of the patient are commonly used for measuring temperature.

Liquid-in-Glass Thermometers

Mercury thermometers are an example of liquid-in-glass thermometers. Other liquids used in glass thermometers are alcohols such as ethanol, usually dyed red for visibility.

Thermal expansion of substances is the principle behind liquid thermometers. As the temperature increases, both mercury and glass expand with different expansion rates. The temperature changes can be inferred from the amount of expansion. Mercury is a favored choice of the liquid because its volume expands most linearly with temperature, as compared to other liquids such as ethanol. The disadvantage of a mercury thermometer is that it is toxic and poses a risk when broken.

A typical thermometer is shown in Figure 14 and consists of

- a bulb which acts as the mercury reservoir,
- a stem made of glass containing a capillary tube connected to the bulb,
- a contraction chamber which serves to shorten the length of the thermometer by providing an additional reservoir for mercury,
- a main scale calibrated to read the temperature directly either in Celsius or Fahrenheit scales, and

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](#).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

- an expansion chamber acts as a reservoir to prevent breakage due to overheating.

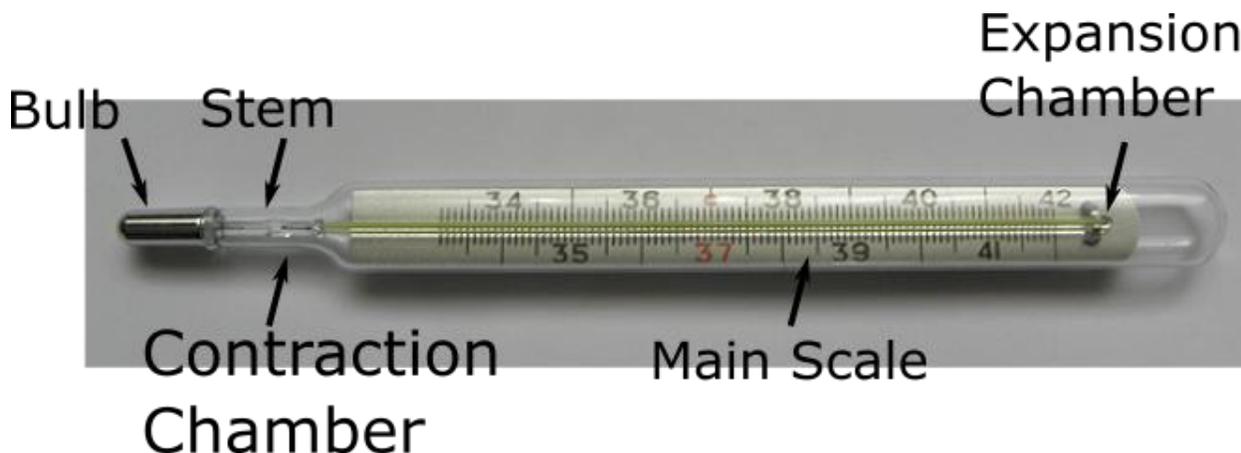


Figure 14: Mercury Thermometer

Electronic Thermometers

Electronic thermometers are based on the change of electrical properties of materials with temperature. The sensors used in electronic thermometers are broadly categorized as using **thermocouples** or **thermistors**. Thermocouples contain junctions of two dissimilar metals. When the junction is heated, a voltage is generated depending on the temperature of the junction. Thermistors, on the other hand, are semiconductor devices whose resistance changes nonlinearly with temperature.

You may have noticed that some thermometers display the temperature in 15-30 seconds, while others take about a minute. The thermometers that display in 15-30 seconds are predictive in that they predict the equilibrium temperature through extrapolation. Other thermometers display temperature only when equilibrium is reached.

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.



Figure 15: Images of electronic thermometers

Radiation Thermometers

All objects at any given temperature emit radiation. The radiation is in the form of electromagnetic waves with intensities distributed over a range of frequencies or wavelengths. The intensity distribution of the radiation with wavelength is determined by the temperature of the object. This correlation between temperature and the emitted wavelengths is used to determine an object's temperature in a radiation thermometer. Radiation thermometers do not need to be in contact with the object and have become popular as non-contact thermometers. This is particularly useful in recording temperature in case of highly infectious diseases such as COVID-19 or in pediatric settings. Tympanic or ear thermometers and forehead infrared thermometers are examples of radiation thermometers.

The distribution of the intensity of radiation with wavelength of the radiation was first measured for a blackbody, which is a perfect absorber of radiation as well as a perfect emitter. Blackbody radiation is often described in terms of intensity $I(\lambda, T)$, which depends on the wavelength of the radiation and temperature.

Intensity is the energy emitted by the blackbody per unit time per unit area per unit wavelength, as shown in Figure 16. Mathematically, intensity can be expressed by the equation below. Recall that power equals energy emitted per unit time and is measured in Watts. Recall that power equals energy emitted per unit time and is measured in Watts.

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](#).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

$$I(\lambda, T) = \frac{\text{Energy}}{\text{Time} \times \text{Area} \times \Delta\lambda} = \frac{\text{Power}}{\text{Area} \times \Delta\lambda}$$

Intensity of radiation in the wavelength range $\Delta\lambda$ is $I(\lambda, T)\Delta\lambda$.

Study the graph in Figure 16 and answer the following questions.

The intensity $I(\lambda, T)$ versus the wavelength of the radiation emitted is plotted in Figure 16. Each curve represents the distribution of energy at a given blackbody temperature. The shape of the curve is found from observations. Its exact nature was theoretically explained by Max Planck, and hence this distribution is known as **Planck's distribution**.

1. As you go from left to right on the x-axis, does the energy increase or decrease?
 - a. Wavelength increases to the right; therefore, the energy of the EM wave decreases as you move to the right of the x-axis.
2. For the graph of the blackbody at 5000 K, the radiation is emitted mostly in which region of the electromagnetic spectrum?
 - a. Visible region
3. As the temperature decreases, how does the peak of the distribution shift?
 - a. It shifts to a lower frequency or larger wavelength into the infrared region.

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](#).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

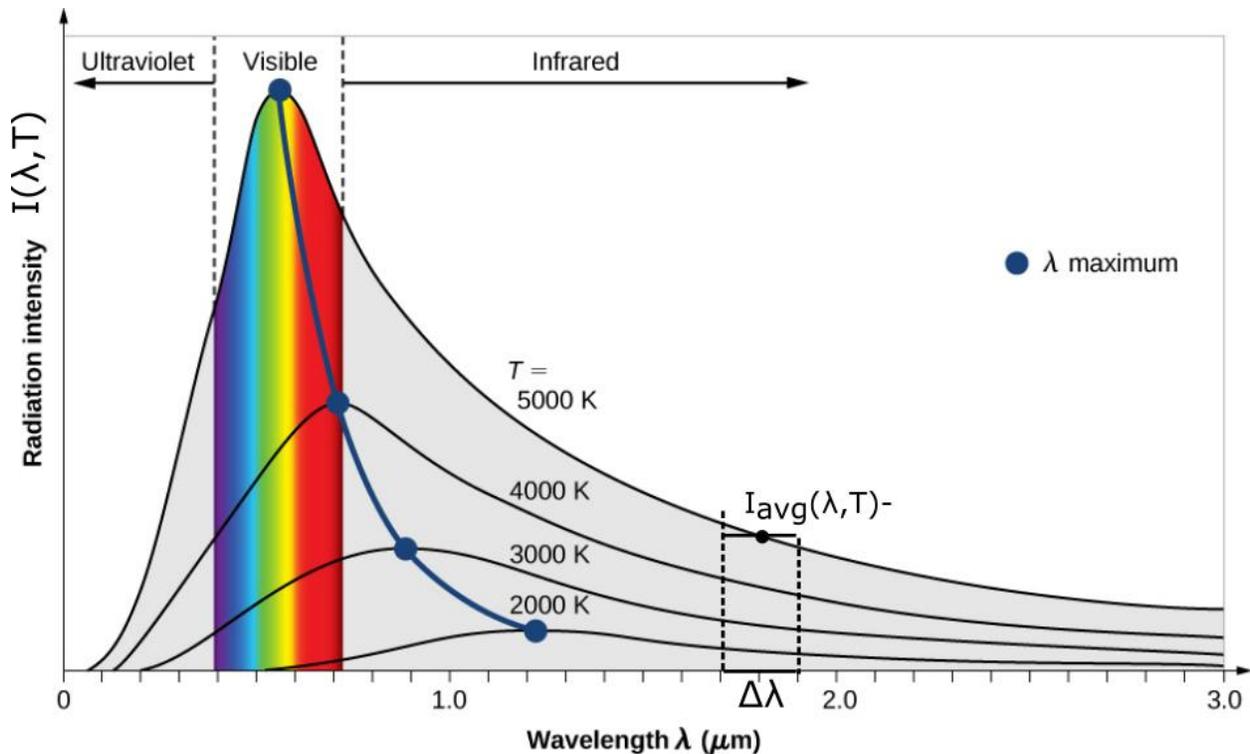


Figure 16: Relative intensity emitted by a blackbody versus the wavelength of radiation. Figure adapted from openstax.org

The wavelength of the EM radiation with maximum intensity depends on the absolute temperature, and the relationship between the two can be derived from the Planck distribution. The relationship between the peak wavelength and absolute temperature is known as **Wien's Law**. According to Wien's Law, for any given temperature, the product of the peak wavelength at a given temperature and the temperature itself is always constant,

$$\lambda_{peak}T = 2.898 \times 10^{-3} \text{ mK}.$$

This is a quick way to determine the peak wavelength being emitted by an object, given the temperature, and vice versa.

Let us calculate the intensity between the wavelengths λ and $\lambda + \Delta\lambda$ shown in Figure 16 around $2.0 \mu\text{m}$. The intensity is $I_{avg}(\lambda, T)\Delta\lambda$ where $I_{avg}(\lambda, T)$ is the **average intensity on the interval $\Delta\lambda$** .

1. Graphically, what does the intensity over the interval $\Delta\lambda$ represent?
 - a. The intensity over the interval $\Delta\lambda$ represents the area of the rectangle with sides $I_{avg}(\lambda, T)\Delta\lambda$.

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

2. If you need to find the total intensity over all wavelengths, how can you graphically find it?
 - a. You can divide the entire wavelength range into small segments and infer the intensity over each interval by measuring the area of the rectangle. By adding the areas of all rectangles, you can estimate the total intensity. You can improve the estimate by making the intervals as small as possible. When you do that, the total intensity radiated over all wavelengths is the **area under the curve**.

When you find the area under the curve, you get what is known as Stefan-Boltzmann's Law, given by

$$I(T) = \sigma T^4,$$

Where σ is the Stefan-Boltzmann constant; Temperature T is the absolute temperature in K.

The rate at which the blackbody emits energy is

$$P = I \times A = \sigma AT^4$$

Where A is the surface area of the object.

Notice that the rate at which the blackbody emits radiation is proportional to the fourth power of T .

Not all objects are ideal blackbodies. A fraction of the incident light will be either reflected or pass through the object entirely. The emissivity, e , is defined as the ratio of the emitted intensity of the real object (I_r) to a black body radiator (I_{bb}) at the same temperature,

$$e = \frac{I_r}{I_{bb}}, \quad 0 \leq e \leq 1$$

The emissivity is between 0 and 1, with 1 being the emissivity of a blackbody. Emissivity is usually experimentally determined.

Stefan-Boltzmann's Law for an object with emissivity e ,

$$P = \sigma eAT^4$$

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](#).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](#). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

Emissivity of objects may depend on wavelength, but also depends on the nature of the surface. Highly polished surfaces of a material have lower emissivity than rough surfaces of the same material. The human skin has an accepted emissivity of around 0.98, and different skin tones affect the emissivity slightly. A study based on 65 participants found emissivity in the range 0.96–0.99.¹

Forehead and Tympanic Thermometers

Two popular non-contact thermometers are the infrared thermometers that receive EM radiation from a patient's forehead or the tympanic membrane in the ear, as seen in Figure 17. Ear thermometers measure the radiation emitted by the tympanic membrane in the ear. The forehead thermometer measures the radiation emitted by a small spot on the forehead, usually illuminated by a laser. The function of the laser spot is only to highlight the region from which the EM radiation is being collected.



Figure 17: IR thermometer (a) Forehead thermometer, and (b) ear thermometer (a) https://commons.wikimedia.org/wiki/File:1024_Pyrometer-8445.jpg; under *Creative Commons Attribution-Share Alike 3.0 Unported* (b) Ear thermometer: Image: https://commons.wikimedia.org/wiki/File:Ear_Thermometer.png; under *Creative Commons Attribution-Share Alike 4.0 International*

Figure 18 shows the black body intensity curves for temperatures close to body temperature (36.5–37.5 °C or around 310 K).

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

Answer the following questions using Figure 18

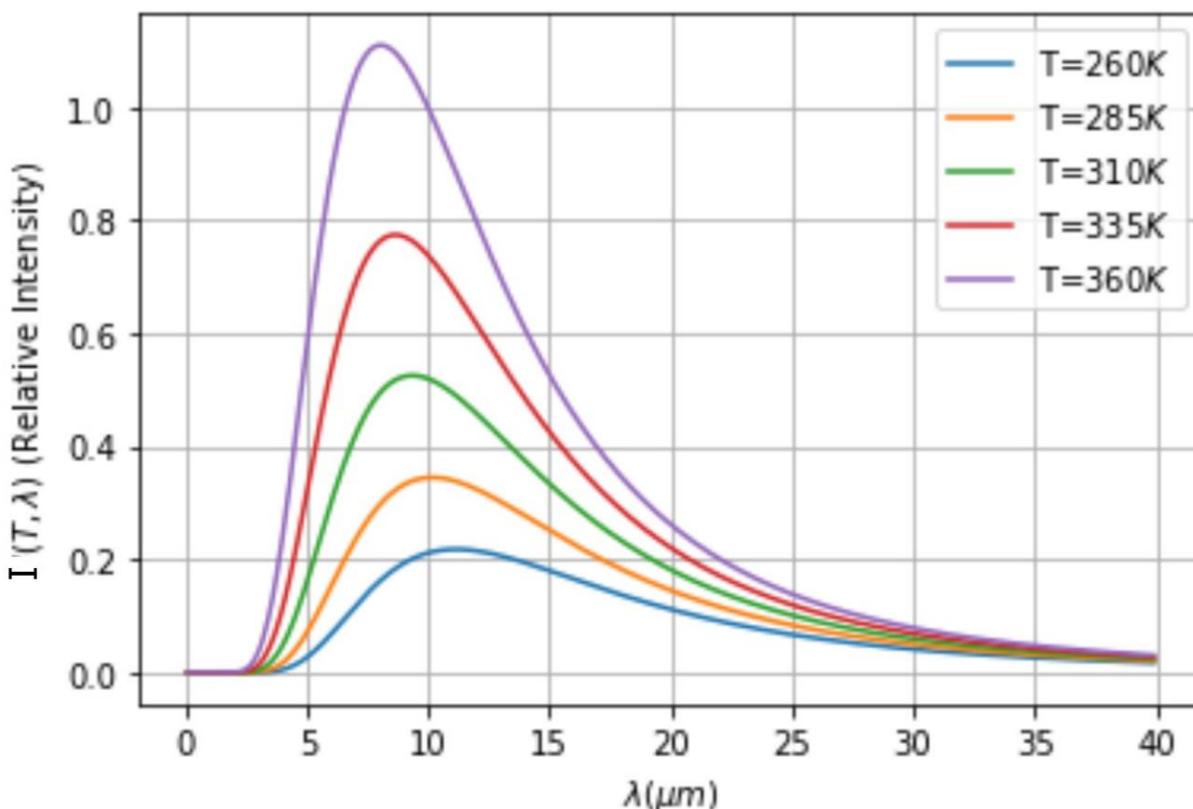


Figure 18: Blackbody radiation of objects close to the temperature of the human body

1. From Figure 18, in what region lies most of the EM radiation emitted from the human body?
 - a. In the infrared region.
2. Given that the average human body temperature is about 310K, estimate the peak wavelength emitted by humans from the graph of the Planck intensity distribution.
 - a. For $T=310\text{ K}$, the peak of the intensity distribution occurs around $7\text{-}8\mu\text{m}$.
3. What region of the EM spectrum does this wavelength lie in?
 - a. In the infrared region.
4. Verify your prediction from Exercise 1 using Wien's. Confirm that this is in the infrared range, ($0.75\mu\text{m} \rightarrow 1.0 \times 10^3\mu\text{m}$).

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.

There are many ways to construct an IR thermometer. Some IR thermometers measure radiation from a wide range of wavelengths emitted by the object. Other IR thermometers detect radiation in only a narrow wavelength interval.

There are also variations depending on how the IR radiation is sensed and converted into an electric signal. One type of IR detectors absorbs radiation emitted by the object that raises the temperature of a sensing element, which generates an electric voltage (thermopile), others change resistance (bolometers), or measure a change in polarization (pyrometers).

For temperature measurement in humans, thermopiles are commonly used. A thermopile is a device that converts thermal energy into electrical energy.

The factors that affect a reading of an IR thermometer are:

1. **Field of view of the thermometer:** The object whose temperature needs to be measured emits radiation in all directions. Only a portion of this is intercepted by the IR thermometer. The field of view is the extent of radiation emitted by the object incident on the thermometer detector. The field of view depends on the size of the object and the distance between the object and the thermometer. Usually, device specifications need to be followed to get an accurate reading.
2. **Emissivity of the object:** Some IR thermometers can let you select the emissivity reading, but others are built for specific applications and do not let you select the emissivity.
3. **Medium between the object and the sensor:** steam, gas, glass, or other media can affect the radiation emitted by the object.
4. **Temperature of the surroundings:** Usually, corrections need to be added to account for the radiation from the surroundings.

¹"The effect of constitutive pigmentation on the measured emissivity of human skin"; Matthew Charlton et al. PLoS One. 2020; 15(11): e0241843. Published online 2020 Nov 25. [doi: 10.1371/journal.pone.0241843](https://doi.org/10.1371/journal.pone.0241843)

Attribution Notice: The following materials contain adapted or excerpted content from openly licensed sources. Full attributions are listed below.

- General Physics, Lecture Notes by Priya Jamkhedkar & Ralf Widenhorn (2025), provided by Portland State University, licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).
- College Physics. OpenStax, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/books/college-physics>.
- University Physics Volume 1, Rice University. Licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Access for free at <https://openstax.org/details/books/university-physics-volume-1>.