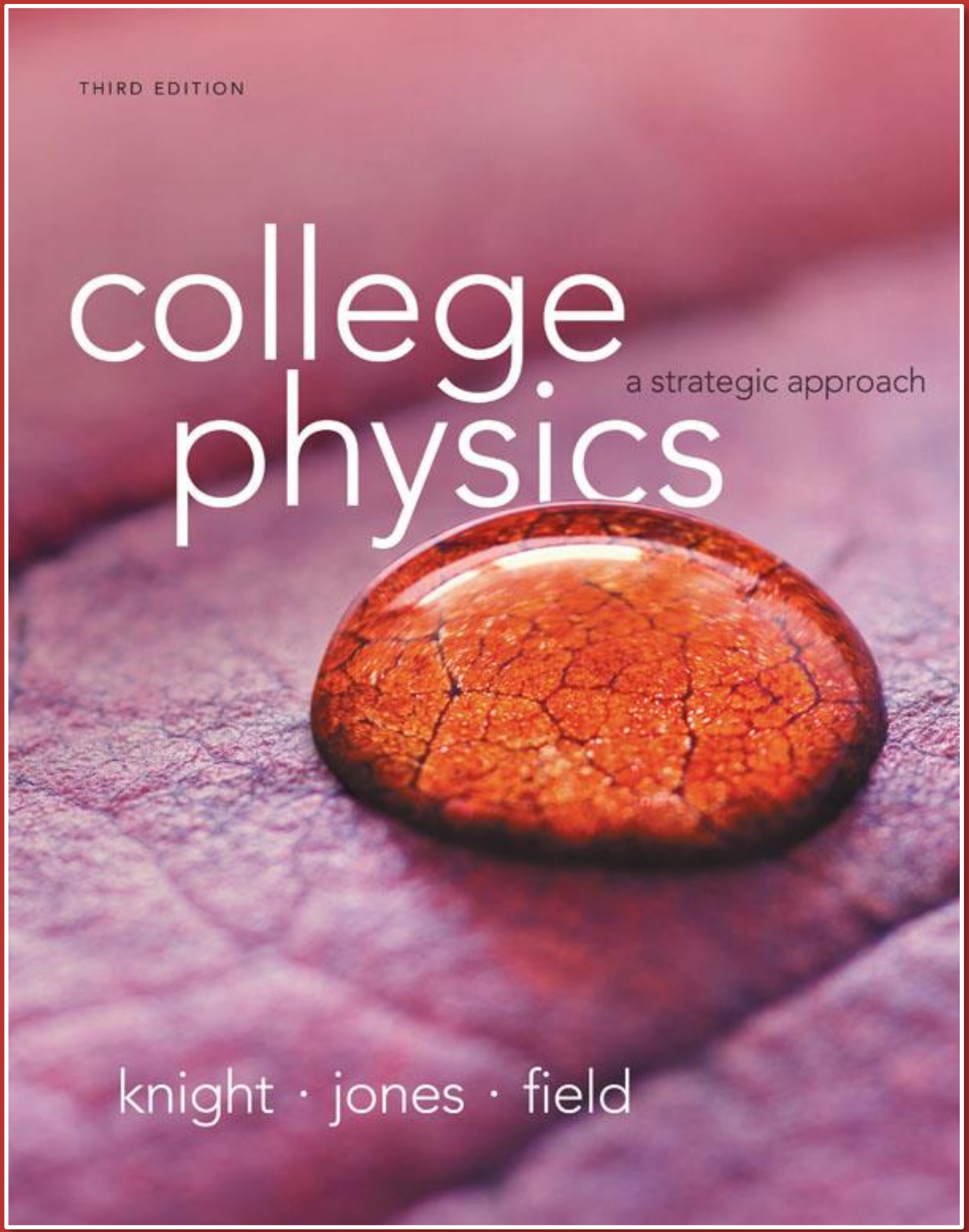


Lecture Presentation

Chapter 11

Using Energy

Suggested Videos for Chapter 11

- **Prelecture Videos**
  - *Efficiency*
  - *The Laws of Thermodynamics*
  - *Heat Engines and Heat Pumps*
- **Class Videos**
  - *Work and Thermal Energy in Gases*
- **Video Tutor Solutions**
  - *Using Energy*

Suggested Simulations for Chapter 11

- **ActivPhysics**
  - *8.1–8.3*

- **PhETs**
  - *Reversible Reactions*

Chapter 11 Using Energy

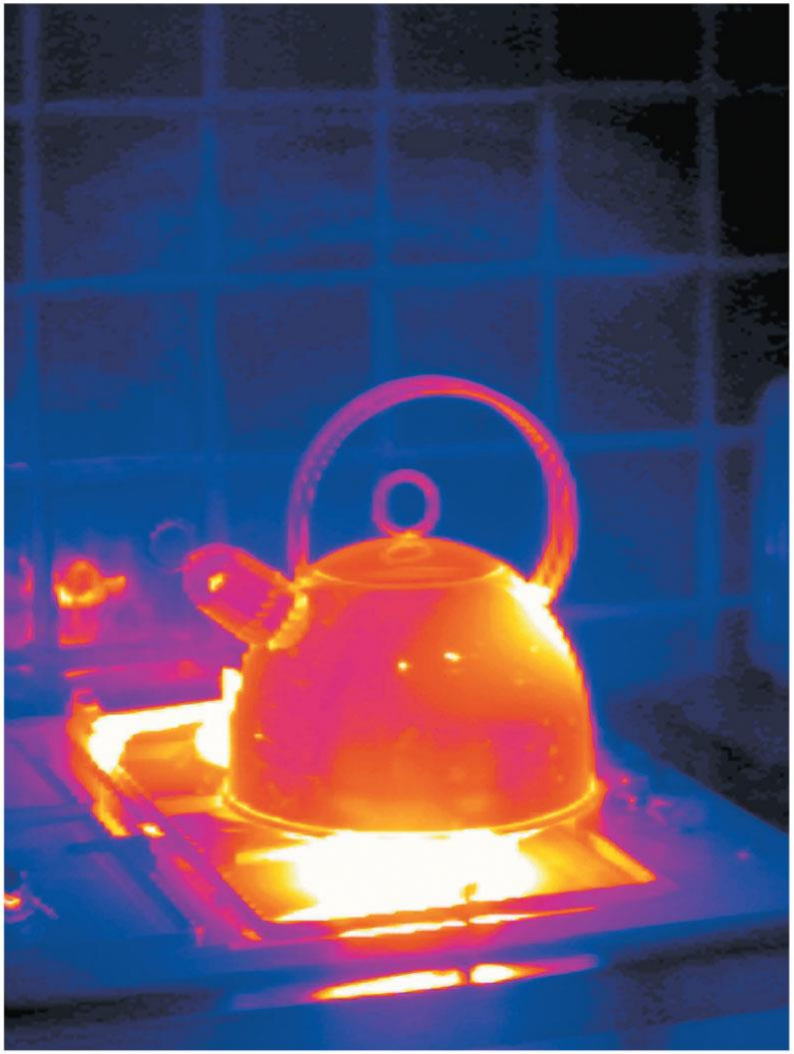
Chapter Goal: To learn about practical energy transformations and transfers, and the limits on how efficiently energy can be used.

Chapter 11 Preview
Looking Ahead: Energy Use in the Body

- An important example of the use of energy is the energy transformations that occur in the human body.
- You’ll learn how to calculate the energy this women uses to climb the stairs, and how efficiently she does so.

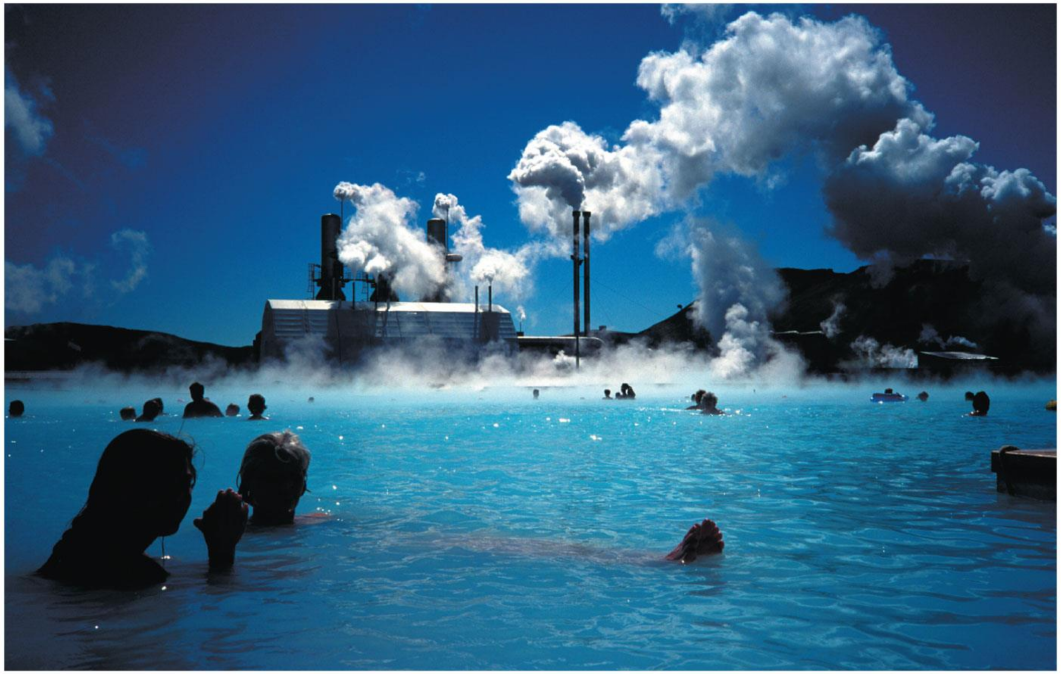
Chapter 11 Preview
Looking Ahead: Temperature and Heat

- This tea kettle gets hotter because of the transfer of energy from the burner as **heat**.
- You'll learn that *heat* is energy transferred due to a temperature difference between objects.



Chapter 11 Preview
Looking Ahead: Heat Engines

- A **heat engine** is a device, such as this geothermal power plant, that transforms thermal energy into useful work.



- You'll learn how to calculate the maximum efficiency for converting thermal energy into work.

Chapter 11 Preview
Looking Ahead

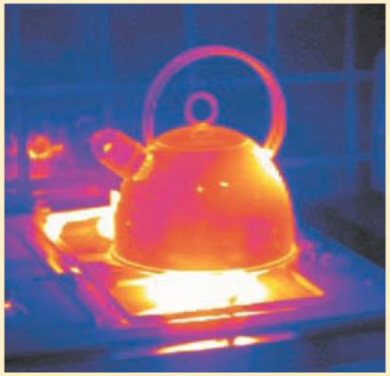
Energy Use in the Body

An important example of the use of energy is the energy transformations that occur in the human body.

You'll learn how to calculate the energy this woman uses to climb the stairs, and how efficiently she does so.

Temperature and Heat

This tea kettle gets hotter because of the transfer of energy from the burner as **heat.**



You'll learn that *heat* is energy transferred due to a temperature difference between objects.

Heat Engines

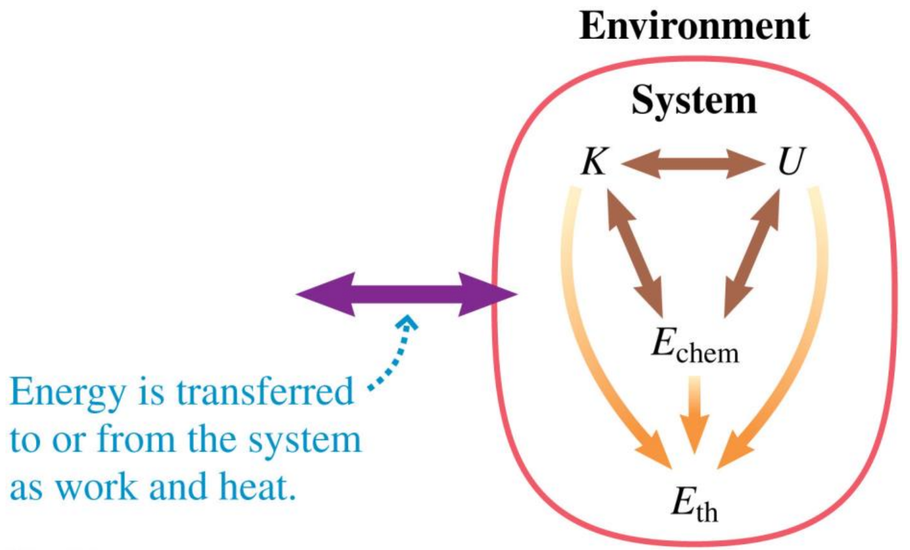
A **heat engine** is a device, such as this geothermal power plant, that transforms thermal energy into useful work.

You'll learn how to calculate the maximum efficiency for converting thermal energy into work.

Text: p. 318

Chapter 11 Preview
Looking Back: The Basic Energy Model

- The basic energy model you learned about in Chapter 10 emphasized work and mechanical energy. In this chapter, we'll focus on thermal energy, chemical energy, and energy transfers in the form of heat.



- Work and heat are energy transfers that change the system's total energy. If the system is isolated, the total energy is *conserved.*

Chapter 11 Preview
Stop to Think

Christina throws a javelin into the air. As she propels it forward from rest, she does 270 J of work on it. At its highest point, its gravitational potential energy has increased by 70 J. What is the javelin's kinetic energy at this point?

A. 270 J
B. 340 J
C. 200 J
D. –200 J
E. –340 J

Reading Question 11.1

A typical efficiency of the human body is about

A. 5%
B. 10%
C. 25%
D. 50%
E. 80%

Reading Question 11.1

A typical efficiency of the human body is about

A. 5%
B. 10%
✔ C. 25%
D. 50%
E. 80%

Reading Question 11.2

A machine uses 1000 J of electric energy to raise a heavy mass, increasing its potential energy by 300 J. What is the efficiency of this process?

A. 100%
B. 85%
C. 70%
D. 35%
E. 30%

Reading Question 11.2

A machine uses 1000 J of electric energy to raise a heavy mass, increasing its potential energy by 300 J. What is the efficiency of this process?

A. 100%
B. 85%
C. 70%
D. 35%
✔ E. 30%

Reading Question 11.3

When the temperature of an ideal gas is increased, which of the following also increases? (There may be more than one correct answer.)

A. The thermal energy of the gas
B. The average kinetic energy of the gas atoms
C. The average potential energy of the gas atoms
D. The mass of the gas atoms
E. The number of gas atoms

Reading Question 11.3

When the temperature of an ideal gas is increased, which of the following also increases? (There may be more than one correct answer.)

✔ A. The thermal energy of the gas
✔ B. The average kinetic energy of the gas atoms
C. The average potential energy of the gas atoms
D. The mass of the gas atoms
E. The number of gas atoms

Reading Question 11.4

A refrigerator is an example of a

A. Reversible process.
B. Heat pump.
C. Cold reservoir.
D. Heat engine.
E. Hot reservoir.

Reading Question 11.4

A refrigerator is an example of a

A. Reversible process.
B. Heat pump.
C. Cold reservoir.
✔ D. Heat engine.
E. Hot reservoir.

Reading Question 11.5

The entropy of an isolated system

A. Always increases.
B. Always decreases.
C. Remains constant.
D. Either increases or remains constant.
E. Either decreases or remains constant.

Reading Question 11.5

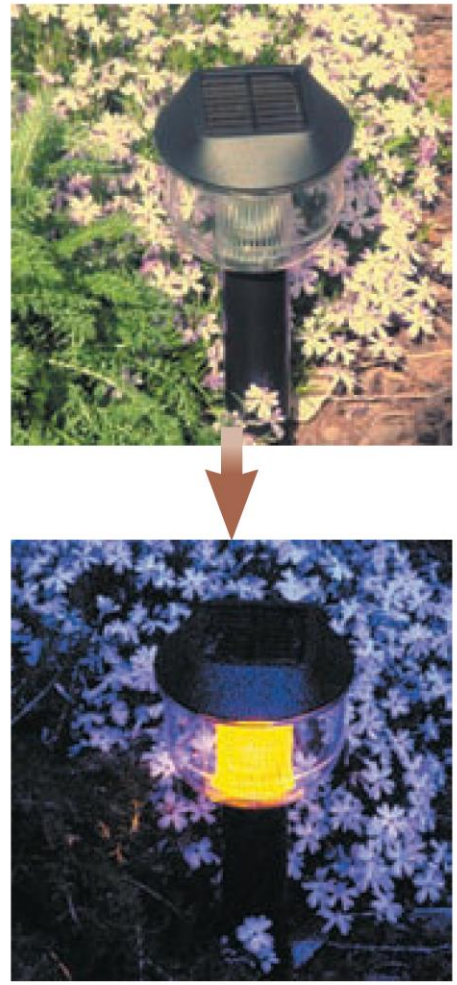
The entropy of an isolated system

A. Always increases.
B. Always decreases.
C. Remains constant.
✔ D. Either increases or remains constant.
E. Either decreases or remains constant.

Section 11.1 Transforming Energy

Transforming Energy

- Energy cannot be created or destroyed, but it can be *transformed*.
- The energy in these transformations is not lost; it is converted to other forms that are less useful to us.



Light energy hitting a solar cell on top of this walkway light is converted to electric energy and then stored as chemical energy in a battery.

At night, the battery's chemical energy is converted to electric energy that is then converted to light energy in a light-emitting diode.

Text: p. 319

Transforming Energy

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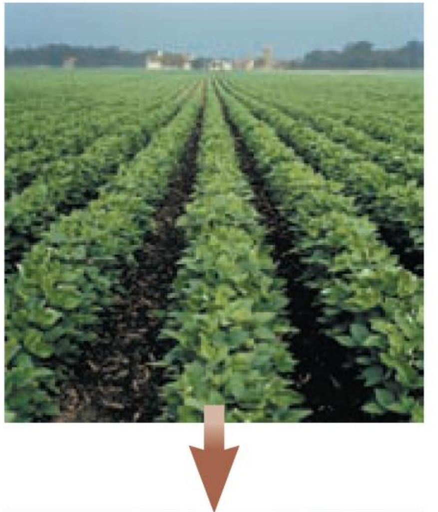


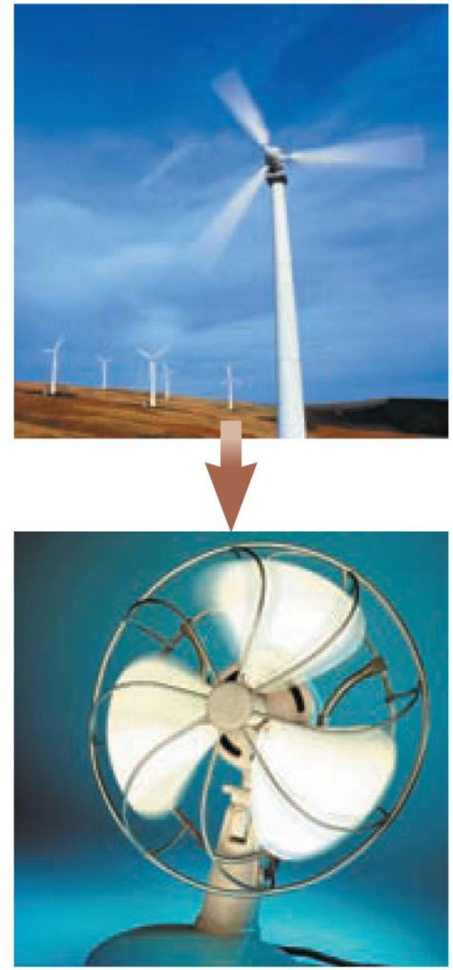
Light energy is absorbed by photo-synthetic pigments in soybean plants, which use this energy to create concentrated chemical energy.

The soybeans are har-vested and their oil is used to make candles. When the candle burns, the stored chemical energy is transformed into light energy and thermal energy.

Text: p. 319

Transforming Energy

- Energy cannot be created or destroyed, but it can be *transformed*.
- The energy in these transformations is not lost; it is converted to other forms that are less useful to us.



A wind turbine converts the translational kinetic energy of moving air into electric energy.

Miles away, this energy can be used by a fan, which transforms the electric energy back into the kinetic energy of moving air.

Text: p. 319

QuickCheck 11.1

When you walk at a constant speed on level ground, what energy transformation is taking place?

A. $E_{\text{chem}} \rightarrow U_{\text{g}}$
B. $U_{\text{g}} \rightarrow E_{\text{th}}$
C. $E_{\text{chem}} \rightarrow K$
D. $E_{\text{chem}} \rightarrow E_{\text{th}}$
E. $K \rightarrow E_{\text{th}}$

QuickCheck 11.1

When you walk at a constant speed on level ground, what energy transformation is taking place?

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C. $E_{\text{chem}} \rightarrow K$
✔ D. $E_{\text{chem}} \rightarrow E_{\text{th}}$
E. $K \rightarrow E_{\text{th}}$

Transforming Energy

- The work-energy equation includes work, an energy transfer. We now include electric and radiant energy in our definition of work:

$$\Delta E = \Delta K + \Delta U + \Delta E_{\text{th}} + \Delta E_{\text{chem}} + \cdots = W$$

- Work is **positive** when energy is transferred **into** the system and **negative** when energy is transferred **out** of the system.
- When other forms of energy are transformed into thermal energy the change is *irreversible*. **The energy isn't lost, but it is lost to our use.**

QuickCheck 11.3

Which is the largest increase of temperature?

A. An increase of 1°F
B. An increase of 1°C
C. An increase of 1 K
D. Both B and C, which are the same and larger than A
E. A, B, and C are all the same increase.

QuickCheck 11.3

Which is the largest increase of temperature?

A. An increase of 1°F
B. An increase of 1°C
C. An increase of 1 K
✔ D. Both B and C, which are the same and larger than A
E. A, B, and C are all the same increase.

Efficiency

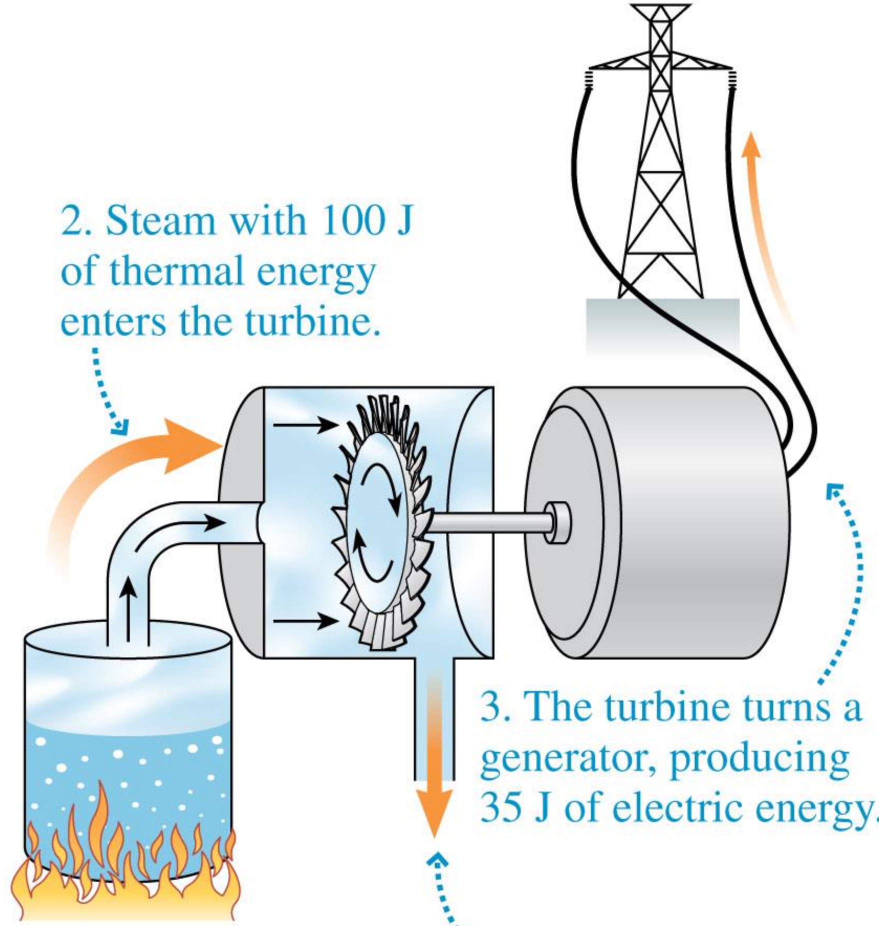
$$e = \frac{\text{what you get}}{\text{what you had to pay}}$$

General definition of efficiency

- The larger the energy losses in a system, the lower its efficiency.
- Reductions in efficiency are caused by **process limitations** and **fundamental limitations.**
- Process limitations cause an energy loss due to practical details.
- Fundamental limitations cause an energy loss due to physical laws.

Efficiency

- 35% efficiency is close to the theoretical maximum for power plants due to fundamental limitations.



Efficiency

PROBLEM-SOLVING STRATEGY 11.1 **Energy efficiency problems**

You can calculate the efficiency of a process once you know the energy output (what you get) and the energy input (what you had to pay).

PREPARE To find these two key components of efficiency:

1. Choose what energy to count as "what you get." This could be the useful energy output of an engine or process or the work that is done in completing a process. For example, when you climb a flight of stairs, "what you get" is your change in potential energy.
2. Decide what energy is "what you had to pay." This will generally be the total energy input needed for an engine, task, or process. For example, when you run your air conditioner, "what you had to pay" is the electric energy input.

SOLVE You may need to do additional calculations:

- Compute values for "what you get" and "what you had to pay."
- Be certain that all energy values are in the same units.

After this, compute the efficiency using $e = \dfrac{\text{what you get}}{\text{what you had to pay}}$.

ASSESS Check your answer to see if it is reasonable, given what you know about typical efficiencies for the process under consideration.

Text: p. 321

Example 11.1 Lightbulb efficiency

A 15 W compact fluorescent bulb and a 75 W incandescent bulb each produce 3.0 W of visible-light energy. What are the efficiencies of these two types of bulbs for converting electric energy into light?

Example 11.1 Lightbulb efficiency (cont.)

PREPARE The problem statement doesn't give us values for energy; we are given values for power. But 15 W is 15 J/s, so we will consider the value for the power to be the energy in 1 second. For each of the bulbs, "what you get" is the visible-light output—3.0 J of light every second for each bulb. "What you had to pay" is the electric energy to run the bulb. This is how the bulbs are rated. A bulb labeled "15 W" uses 15 J of electric energy each second. A 75 W bulb uses 75 J each second.

Example 11.1 Lightbulb efficiency (cont.)

SOLVE The efficiencies of the two bulbs are computed using the energy in 1 second:

$$e(\text{compact fluorescent bulb}) = \frac{3.0\ \text{J}}{15\ \text{J}} = 0.20 = 20\%$$

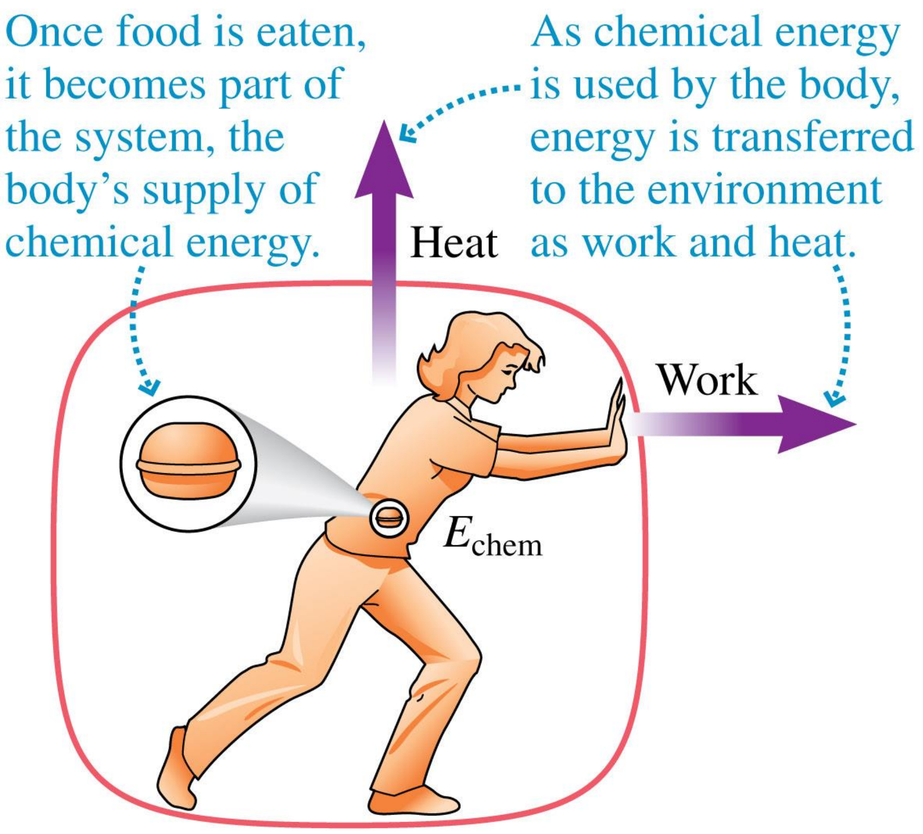
$$e(\text{incandescent bulb}) = \frac{3.0\ \text{J}}{75\ \text{J}} = 0.040 = 4\%$$

ASSESS Both bulbs produce the same visible-light output, but the compact fluorescent bulb does so with a significantly lower energy input, so it is more efficient. Compact fluorescent bulbs are more efficient than incandescent bulbs, but their efficiency is still relatively low—only 20%.

Section 11.2 Energy in the Body

Getting Energy from Food: Energy Inputs

- The chemical energy in food provides the necessary energy input for your body to function.



Getting Energy from Food: Energy Inputs

- Chemical energy in food is broken down into simpler molecules such as glucose and glycogen. They are metabolized in the cells by combining with oxygen.

Glucose from the digestion of food combines with oxygen that is breathed in to produce . . .

. . . carbon dioxide, which is exhaled; water, which can be used by the body; and energy.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$$

Glucose — Oxygen — Carbon dioxide — Water

- Oxidation reactions "burn" the fuel you obtain by eating.

Getting Energy from Food: Energy Inputs

- Burning food transforms all of its chemical energy into thermal energy.
- Thermal energy is measured in units of **calories (cal).**
- 1.00 calorie = 4.19 joules

Getting Energy from Food: Energy Inputs

TABLE 11.1 Energy in fuels

Fuel	Energy in 1 g of fuel (in kJ)
Hydrogen	121
Gasoline	44
Fat (in food)	38
Coal	27
Carbohydrates (in food)	17
Wood chips	15

Getting Energy from Food: Energy Inputs

TABLE 11.2 Energy content of foods

Food	Energy content in Cal	Energy content in kJ	Food	Energy content in Cal	Energy content in kJ
Carrot (large)	30	125	Slice of pizza	300	1260
Fried egg	100	420	Frozen burrito	350	1470
Apple (large)	125	525	Apple pie slice	400	1680
Beer (can)	150	630	Fast-food meal:		
BBQ chicken wing	180	750	burger, fries,		
Latte (whole milk)	260	1090	drink (large)	1350	5660

Example 11.2 Energy in Food

A 12 oz can of soda contains approximately 40 g (or a bit less than 1/4 cup) of sugar, a simple carbohydrate. What is the chemical energy in joules? How many Calories is this?

Example 11.2 Energy in Food (cont.)

SOLVE From Table 11.1, 1 g of sugar contains 17 kJ of energy, so 40 g contains

$$40 \text{ g} \times \frac{17 \times 10^3 \text{ J}}{1 \text{ g}} = 68 \times 10^4 \text{ J} = 680 \text{ kJ}$$

Converting to Calories, we get

$$680 \text{ kJ} = 6.8 \times 10^5 \text{ J} = (6.8 \times 10^5 \text{ J})\frac{1.00 \text{ cal}}{4.19 \text{ J}}$$

$$= 1.6 \times 10^5 \text{ cal} = 160 \text{ Cal}$$

ASSESS 160 Calories is a typical value for the energy content of a 12 oz can of soda (check the nutrition label on one to see), so this result seems reasonable.

Using Energy in the Body: Energy Outputs

- At rest, your body uses energy to build and repair tissue, digest food and keep warm.
- Your body uses approximately 100 W of energy at rest.
- The energy is converted almost entirely into thermal energy, which is transferred as heat to the environment.

Using Energy in the Body: Energy Outputs

TABLE 11.3 Energy use at rest

Organ	Resting power (W) of 68 kg individual
Liver	26
Brain	19
Heart	7
Kidneys	11
Skeletal muscle	18
Remainder of body	19
Total	**100**

Using Energy in the Body: Energy Outputs

- When you engage in an activity, your cells require oxygen to metabolize carbohydrates.
- You can measure your body's energy use by measuring how much oxygen it is using.
- *Total metabolic energy use* is all of the energy used by the body while performing an activity.

Using Energy in the Body: Energy Outputs

TABLE 11.4 Metabolic power use during activities

Activity	Metabolic power (W) of 68 kg individual
Typing	125
Ballroom dancing	250
Walking at 5 km/h	380
Cycling at 15 km/h	480
Swimming at a fast crawl	800
Running at 15 km/h	1150

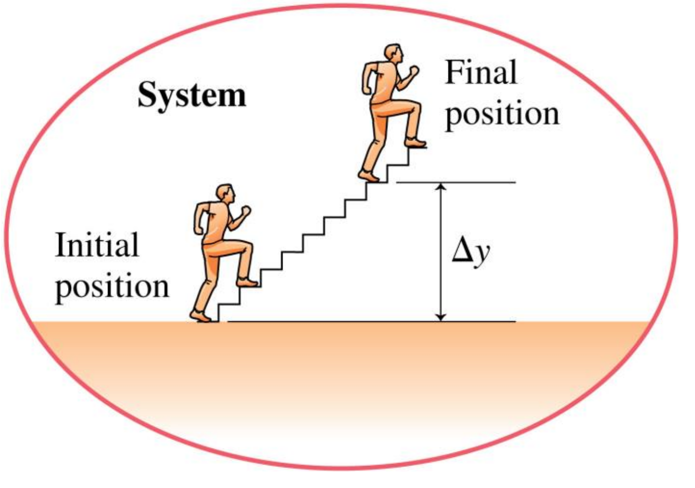
Efficiency of the Human Body

- As you climb stairs, you change your potential energy. If you climb 2.7 m and your mass is 68 kg then your potential energy is

$$\Delta U_g = (68\text{ kg})(9.8\text{ m/s}^2)(2.7\text{ m}) = 1800\text{ J}$$

- On average, you use 7200 J to climb the stairs:

$$|E_{chem}| = 7200\text{ J}$$

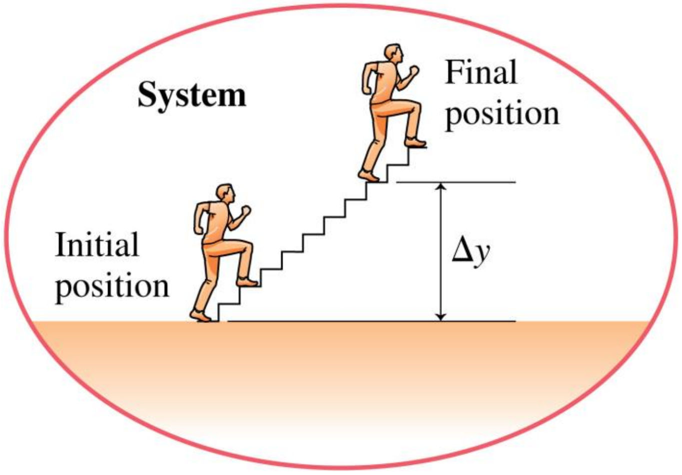


Efficiency of the Human Body

- We compute the efficiency of climbing the stairs:

$$e = \frac{\Delta U_g}{|\Delta E_{chem}|} = \frac{1800\ \text{J}}{7200\ \text{J}} = 0.25 = 25\%$$

- **We typically consider the body's efficiency to be 25%.**



Example Problem

A 75 kg person climbs the 248 steps to the top of the Cape Hatteras lighthouse, a total climb of 59 m. How many Calories does he or she burn?

Energy Storage

- Energy from food that is not used will be stored.
- If energy input from food continuously exceeds the energy outputs of the body, the energy is stored as fat under the skin and around the organs.

Example 11.6 Running out of fuel

The body stores about 400 g of carbohydrates. Approximately how far could a 68 kg runner travel on this stored energy?

PREPARE Table 11.1 gives a value of 17 kJ per g of carbohydrate. The 400 g of carbohydrates in the body contain an energy of

$$E_{\text{chem}} = (400\ \text{g})(17 \times 10^3\ \text{J/g}) = 6.8 \times 10^6\ \text{J}$$

Example 11.6 Running out of fuel (cont.)

SOLVE Table 11.4 gives the power used in running at 15 km/h as 1150 W. The time that the stored chemical energy will last at this rate is

$$\Delta t = \frac{\Delta E_{\text{chem}}}{P} = \frac{6.8 \times 10^6 \text{ J}}{1150 \text{ W}} = 5.91 \times 10^3 \text{ s} = 1.64 \text{ h}$$

And the distance that can be covered during this time at 15 km/h is

$$\Delta x = v\Delta t = (15 \text{ km/h})(1.64 \text{ h}) = 25 \text{ km}$$

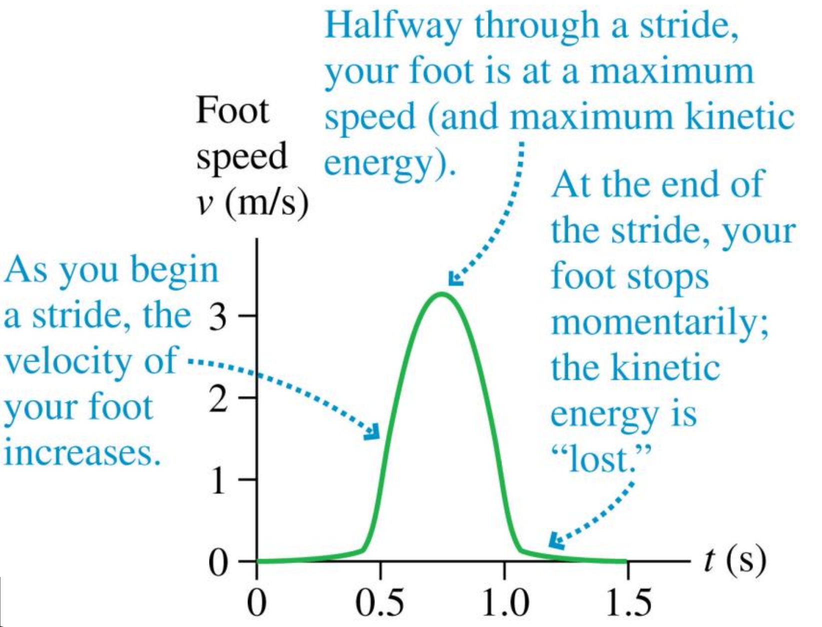
to two significant figures.

Example 11.6 Running out of fuel (cont.)

ASSESS A marathon is longer than this—just over 42 km. Even with "carbo loading" before the event (eating high-carbohydrate meals), many marathon runners "hit the wall" before the end of the race as they reach the point where they have exhausted their store of carbohydrates. The body has other energy stores (in fats, for instance), but the rate that they can be drawn on is much lower.

Energy and Locomotion

- When you walk at a constant speed on level ground, your kinetic and potential energy are constant.
- You need energy to walk because the kinetic energy of your leg and foot is transformed into thermal energy in your muscles and shoes, which is lost.



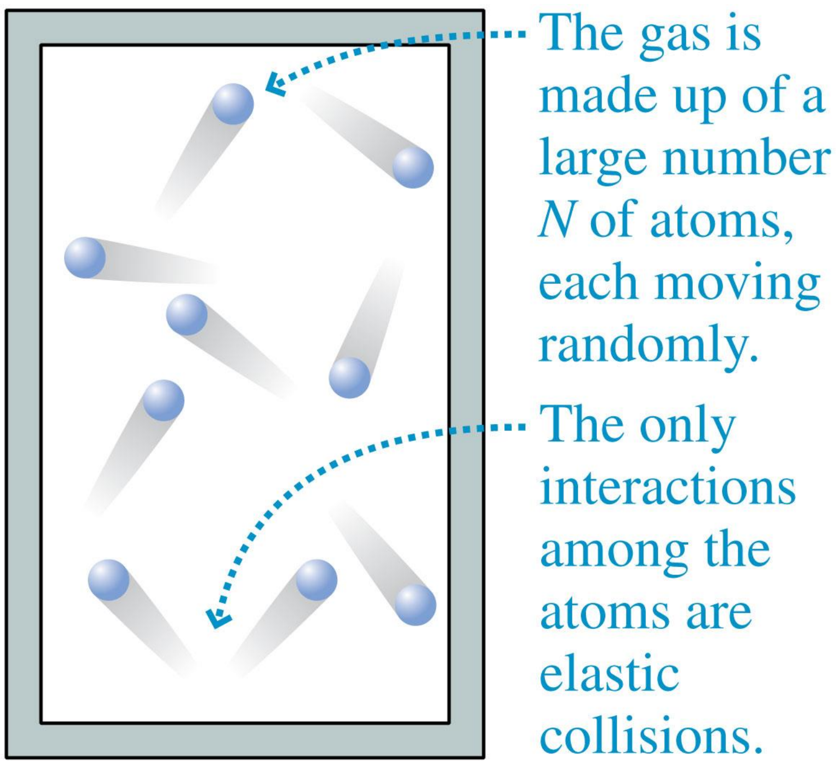
Example Problem

How far could a 68 kg person cycle at 15 km/hr on the energy in one slice of pizza? How far could he or she walk, at 5 km/hr? How far could he or she run, at 15 km/hr? Do you notice any trends in the distance values that you've calculated? Chemical energy from food is used for each of these activities. What happens to this energy—that is, in what form does it end up?

Section 11.3 Temperature, Thermal Energy, and Heat

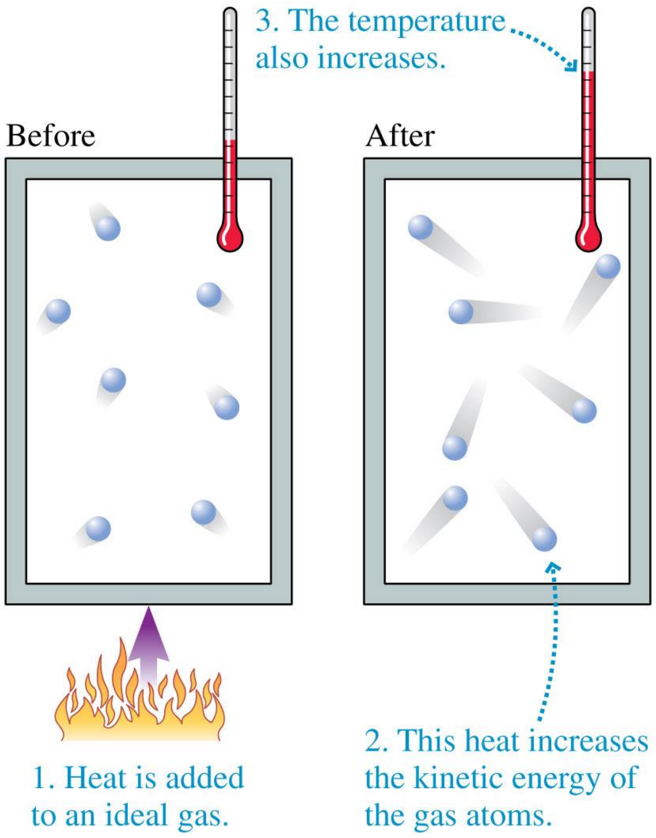
An Atomic View of Thermal Energy and Temperature

- **The thermal energy of an ideal gas is equal to the total kinetic energy of the moving atoms in the gas.**



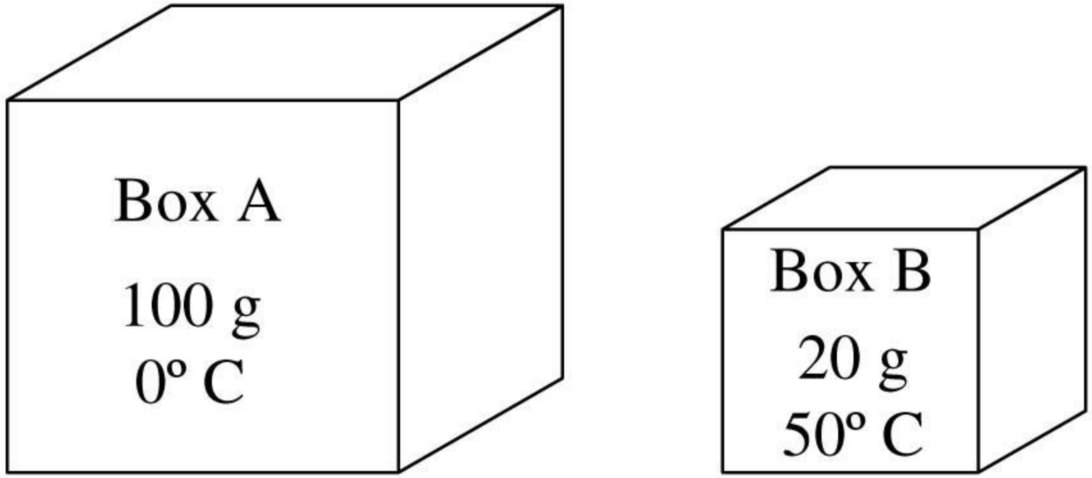
An Atomic View of Thermal Energy and Temperature

- Heating a gas causes the atoms to move faster, increasing the thermal energy of the gas.
- Heating also causes an increase in temperature.
- **The temperature of an ideal gas is a measure of the *average* kinetic energy of the atoms that make up the gas.**



QuickCheck 11.6

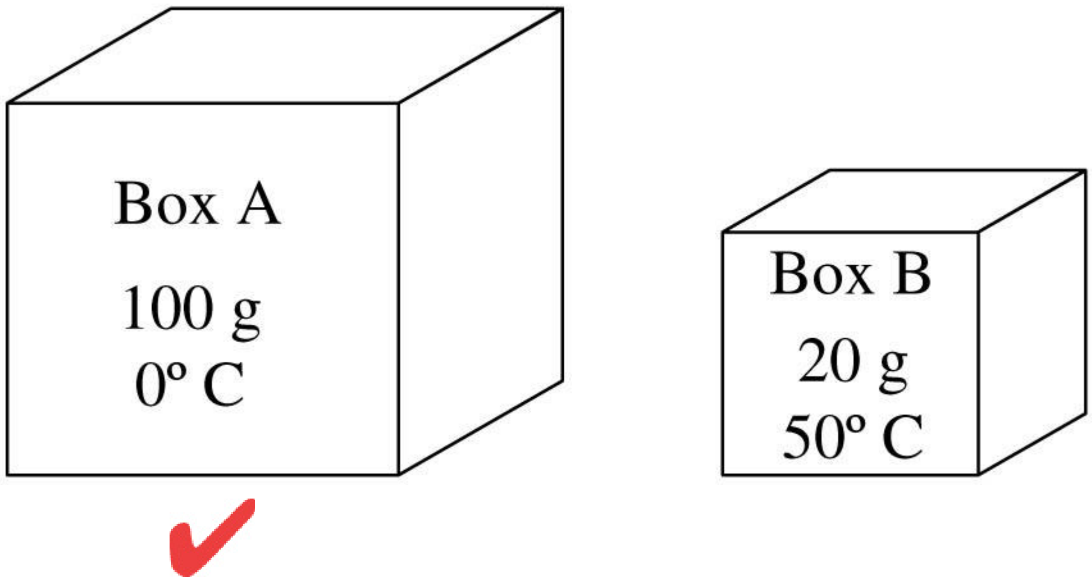
Two containers of the same gas (which we assume to be ideal) have the following masses and temperatures:



Which box has the gas with the largest thermal energy?

QuickCheck 11.6

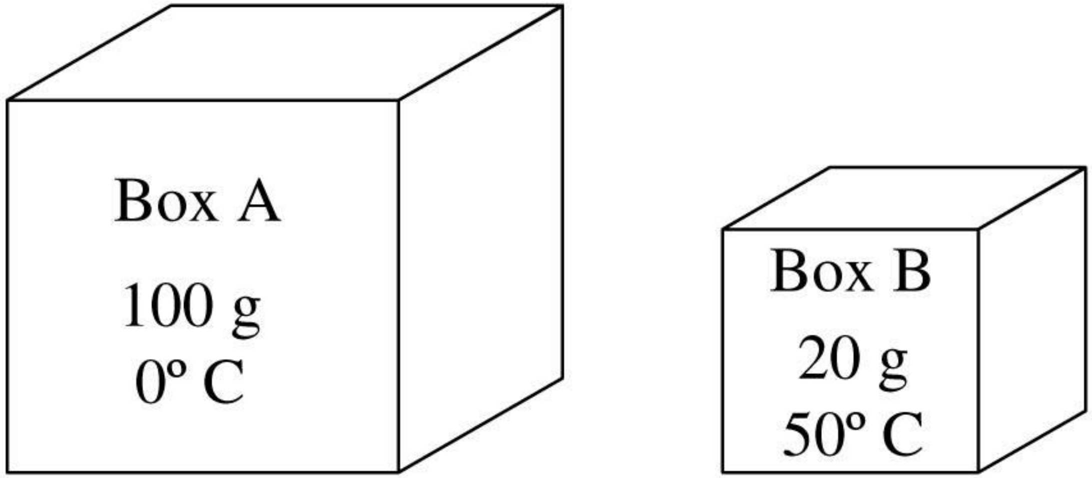
Two containers of the same gas (which we assume to be ideal) have the following masses and temperatures:



Which box has the gas with the largest thermal energy?

QuickCheck 11.5

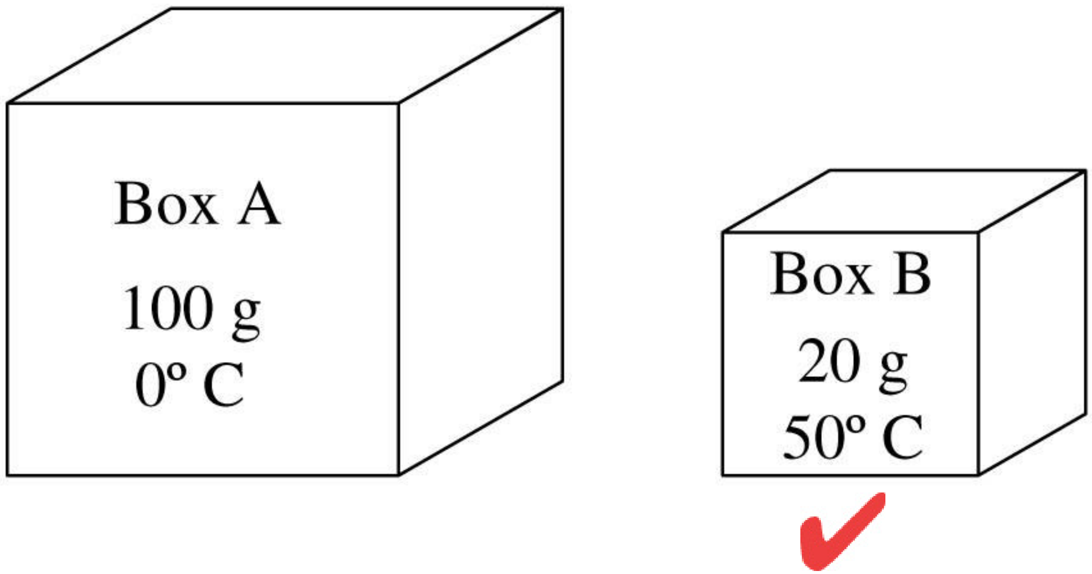
Two containers of the same gas (which we assume to be ideal) have the following masses and temperatures:



Which box has the gas with the largest average kinetic energy per molecule?

QuickCheck 11.5

Two containers of the same gas (which we assume to be ideal) have the following masses and temperatures:



Which box has the gas with the largest average kinetic energy per molecule?

QuickCheck 11.10

100 J is added to a sample of ideal gas as heat. The gas then expands against a piston, doing 70 J of work. During this process

A. The temperature of the gas increases.
B. The temperature of the gas decreases.
C. The temperature of the gas stays the same.

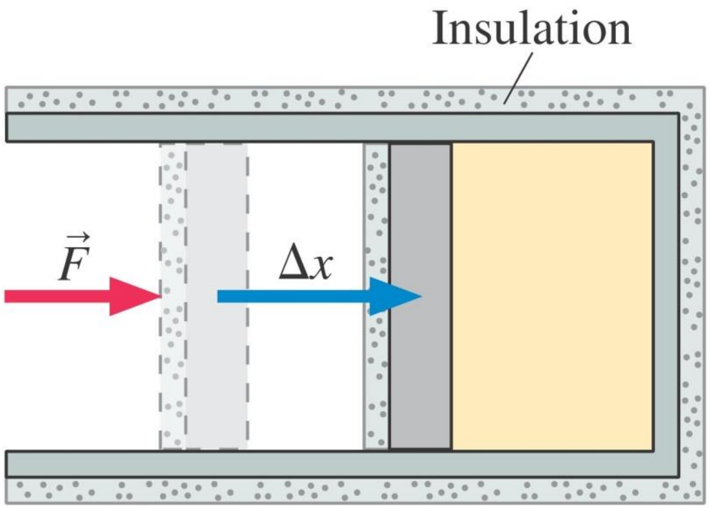
QuickCheck 11.10

100 J is added to a sample of ideal gas as heat. The gas then expands against a piston, doing 70 J of work. During this process

✔ A. The temperature of the gas increases.
B. The temperature of the gas decreases.
C. The temperature of the gas stays the same.

QuickCheck 11.7

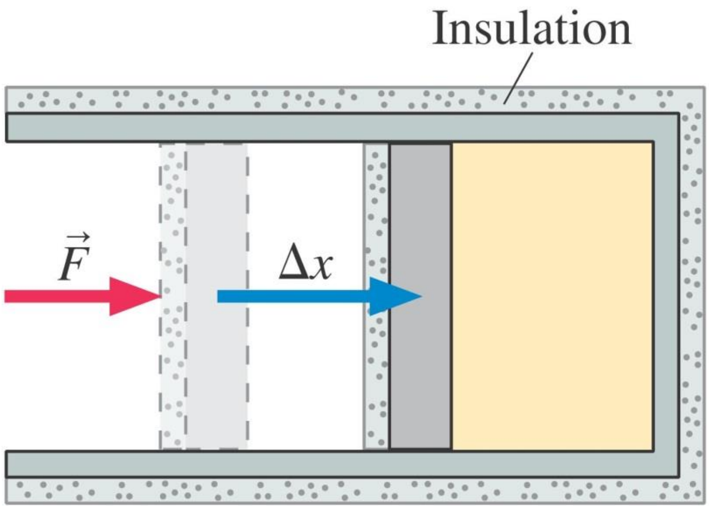
A steady force pushes in the piston of a well-insulated cylinder. In this process, the temperature of the gas



A. Increases.
B. Stays the same.
C. Decreases.
D. There's not enough information to tell.

QuickCheck 11.7

A steady force pushes in the piston of a well-insulated cylinder. In this process, the temperature of the gas



✔ A. Increases.
B. Stays the same.
C. Decreases.
D. There's not enough information to tell.

No heat flows (well insulated) ...

... but work is done on the gas.

First law: $Q + W = \Delta E_{th}$

Work increases the gas's thermal energy and with it the temperature.

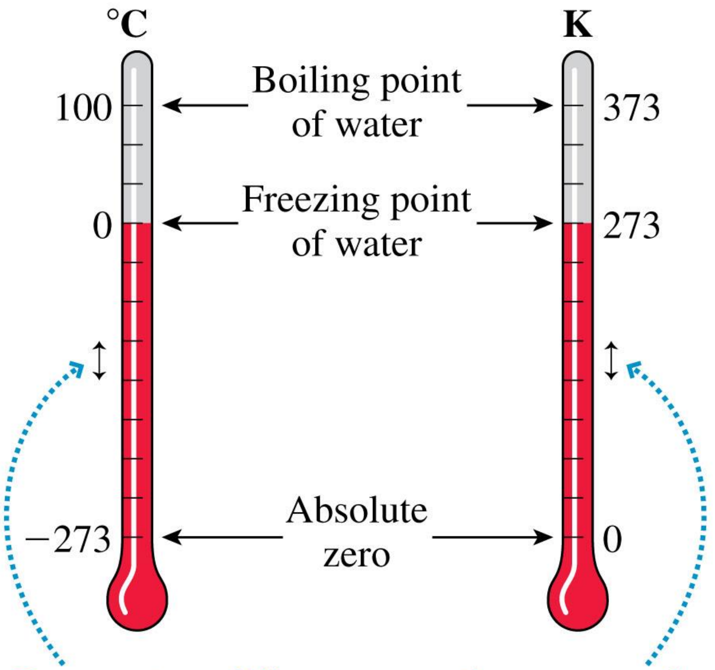
Temperature Scales

- The Celsius scale is defined so that the freezing point of water is 0°C. The Fahrenheit scale is related to the Celsius scale:

$$T(°\text{C}) = \frac{5}{9}(T(°\text{F}) - 32°) \qquad T(°\text{F}) = \frac{9}{5}T(°\text{C}) + 32°$$

Temperature Scales

- For the *Kelvin scale*, **zero degrees is the point at which the kinetic energy of the atoms is zero.**
- Kinetic energy is always positive, so zero on this scale is an **absolute zero.**
- All temperatures on the Kelvin scale are positive, so it is often called the *absolute temperature scale*.
- The units are “kelvin” (K).



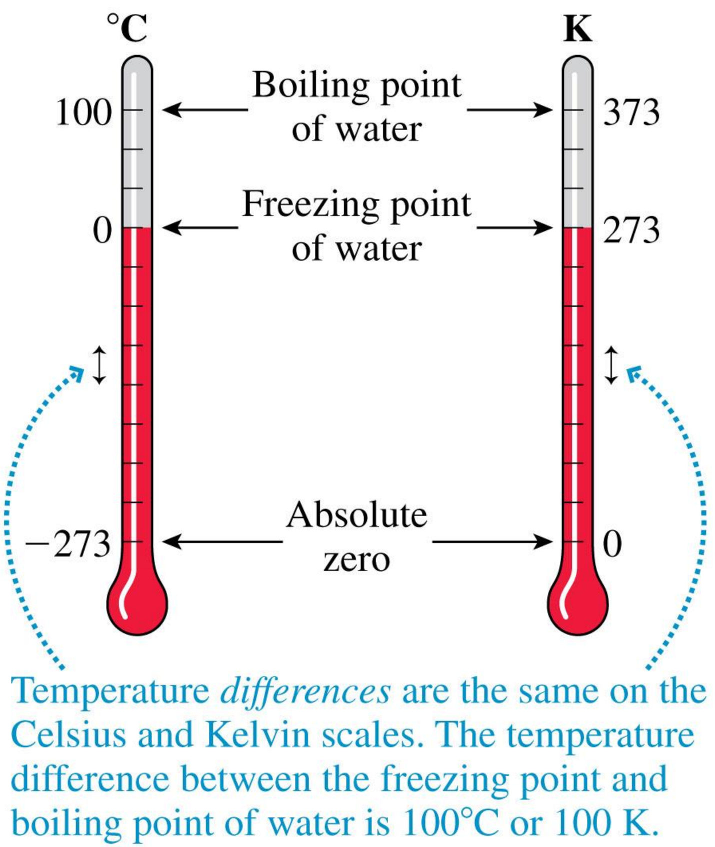
Temperature *differences* are the same on the Celsius and Kelvin scales. The temperature difference between the freezing point and boiling point of water is 100°C or 100 K.

Temperature Scales

- The spacing between divisions on the Kelvin scale is the same as that on the Celsius scale.
- Absolute zero is –273°C:

$$T(\text{K}) = T(^\circ\text{C}) + 273$$

$$T(^\circ\text{C}) = T(\text{K}) - 273$$



QuickCheck 11.3

Which is the largest increase of temperature?

A. An increase of 1°F
B. An increase of 1°C
C. An increase of 1 K
D. Both B and C, which are the same and larger than A
E. A, B, and C are all the same increase.

QuickCheck 11.3

Which is the largest increase of temperature?

A. An increase of 1°F
B. An increase of 1°C
C. An increase of 1 K
✔ D. Both B and C, which are the same and larger than A
E. A, B, and C are all the same increase.

QuickCheck 11.4

Which is the correct ranking of temperatures, from highest to lowest?

A. 300°C > 300 K > 300°F
B. 300°C > 300°F > 300 K
C. 300 K > 300°F > 300°C
D. 300 K > 300°C > 300°F
E. 300°F > 300 K > 300°C

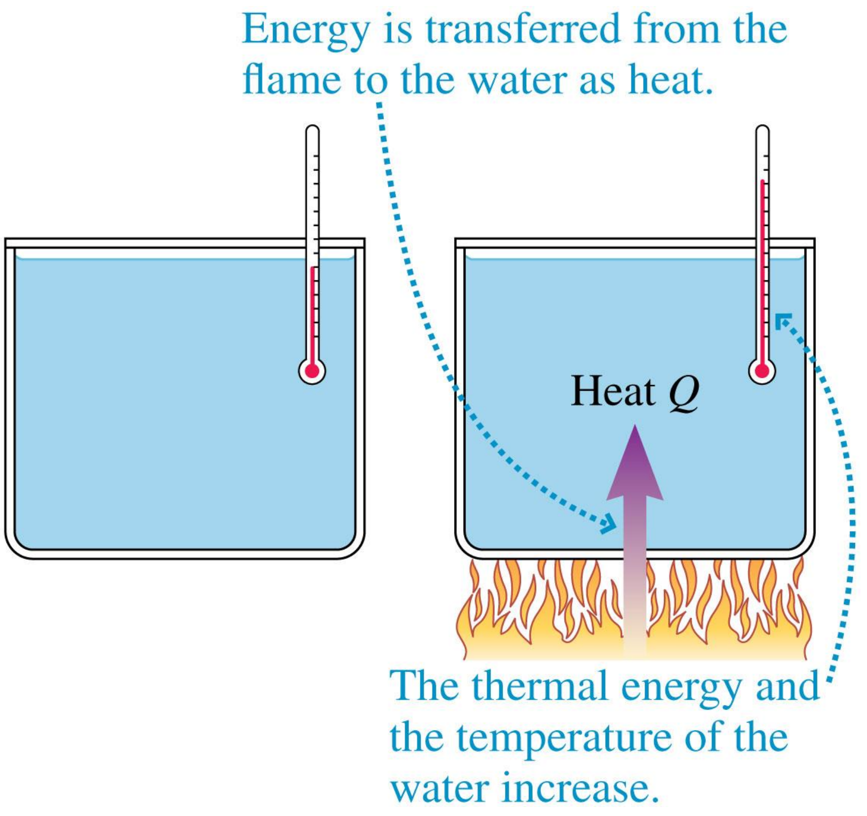
QuickCheck 11.4

Which is the correct ranking of temperatures, from highest to lowest?

A. 300°C > 300 K > 300°F
✔ B. 300°C > 300°F > 300 K
C. 300 K > 300°F > 300°C
D. 300 K > 300°C > 300°F
E. 300°F > 300 K > 300°C

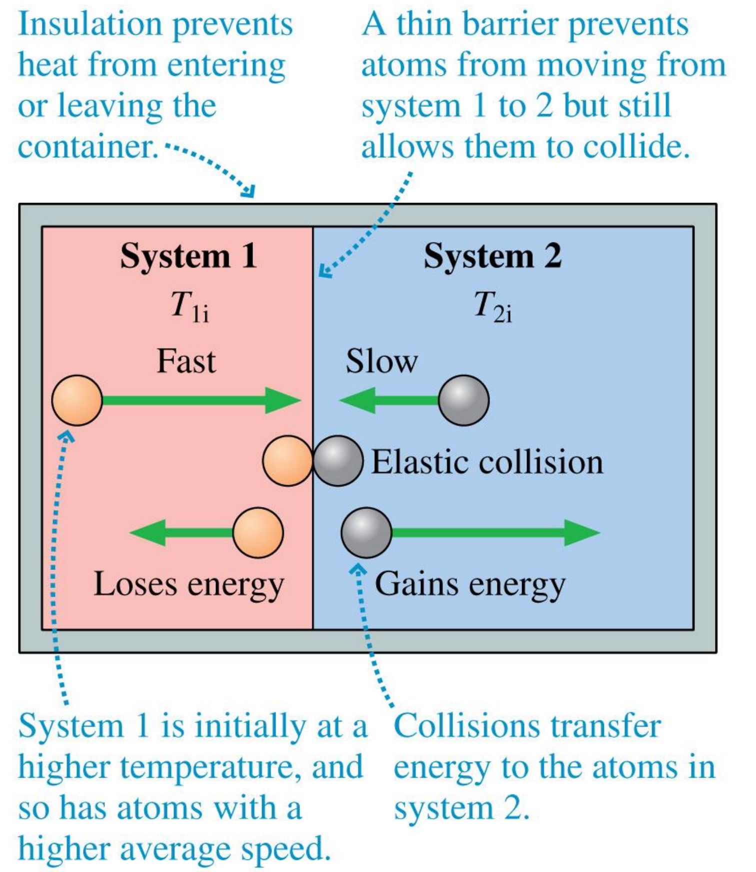
What Is Heat?

- **Thermodynamics** is the study of thermal energy and heat and their relationships to other forms of energy and energy transfer.
- **Heat is energy transferred between two objects because of a temperature difference between them.**
- Heat (*Q*) always flows from the hotter object to the cooler one.



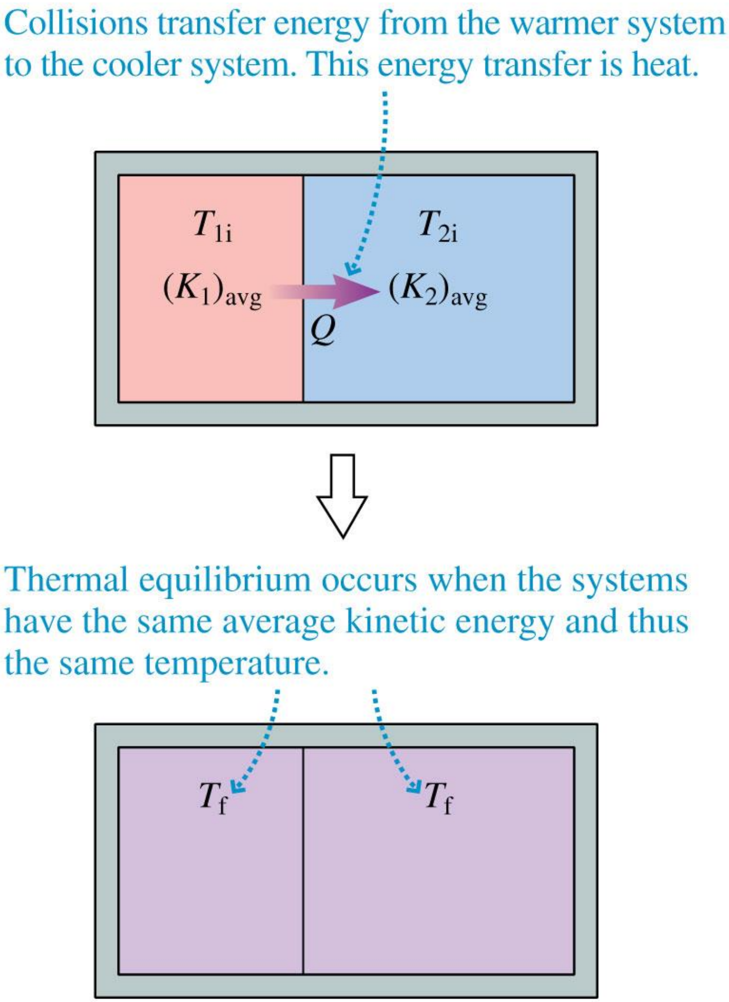
An Atomic Model of Heat

- **Thermal energy is transferred from the faster moving atoms on the warmer side to the slower moving atoms on the cooler side.**
- The transfer will continue until a stable situation, or **thermal equilibrium,** is reached.



An Atomic Model of Heat

- **Two systems placed in thermal contact will transfer thermal energy from hot to cold until their final temperatures are the same.**



QuickCheck 11.2

Consider your body as a system. Your body is “burning” energy in food, but staying at a constant temperature. This means that, for your body,

A. $Q > 0$
B. $Q = 0$
C. $Q < 0$

QuickCheck 11.2

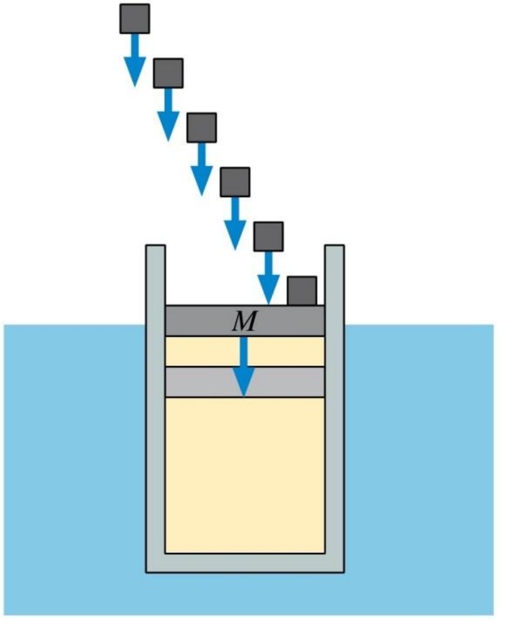
Consider your body as a system. Your body is “burning” energy in food, but staying at a constant temperature. This means that, for your body,

✔ A. $Q > 0$

B. $Q = 0$

C. $Q < 0$

QuickCheck 11.9



A cylinder of gas has a frictionless but tightly sealed piston of mass *M*. Small masses are placed onto the top of the piston, causing it to slowly move downward. A water bath keeps the temperature constant. In this process

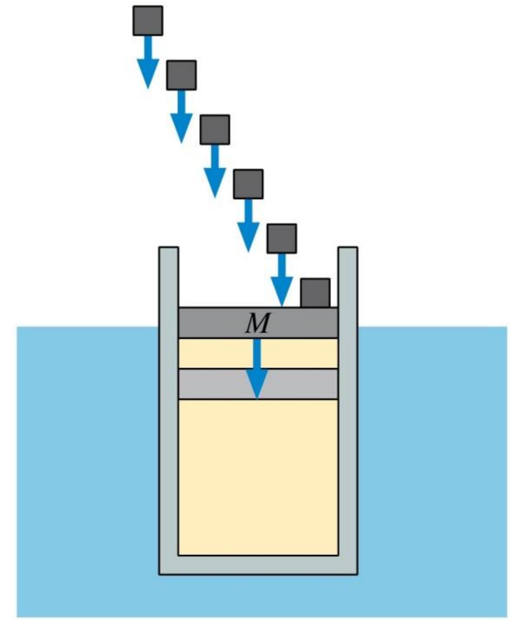
A. $Q > 0$

B. $Q = 0$

C. $Q < 0$

D. There's not enough information to say anything about the heat.

QuickCheck 11.9



A cylinder of gas has a frictionless but tightly sealed piston of mass *M*. Small masses are placed onto the top of the piston, causing it to slowly move downward. A water bath keeps the temperature constant. In this process

A. $Q > 0$

B. $Q = 0$

✔ C. $Q < 0$

D. There's not enough information to say anything about the heat.

$$\overset{0}{\Delta E_{th}} = \overset{+}{W} + \overset{-}{Q}$$

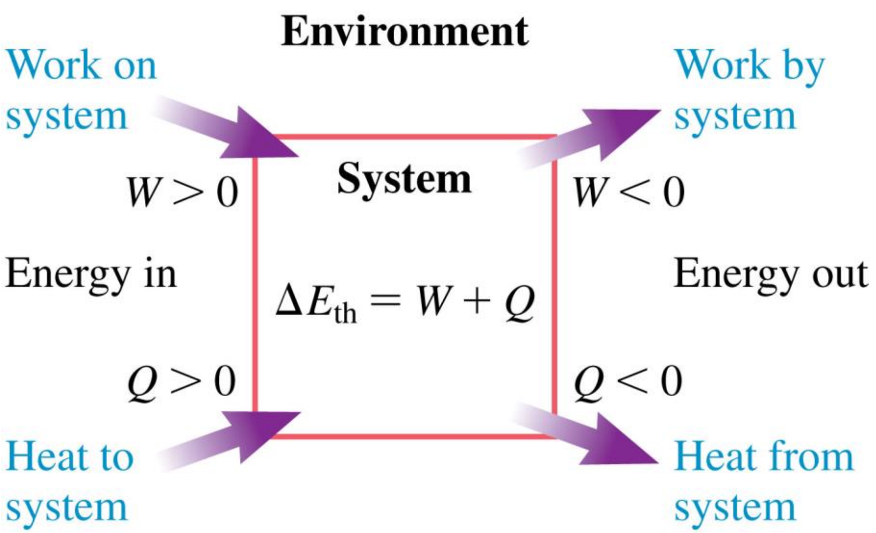
No temperature change

Energy flows out to the water to keep the temperature from changing

Section 11.4 The First Law of Thermodynamics

The First Law of Thermodynamics

- Systems that are not moving and are not changing chemically, but whose temperatures can change, are the province of **thermodynamics**.

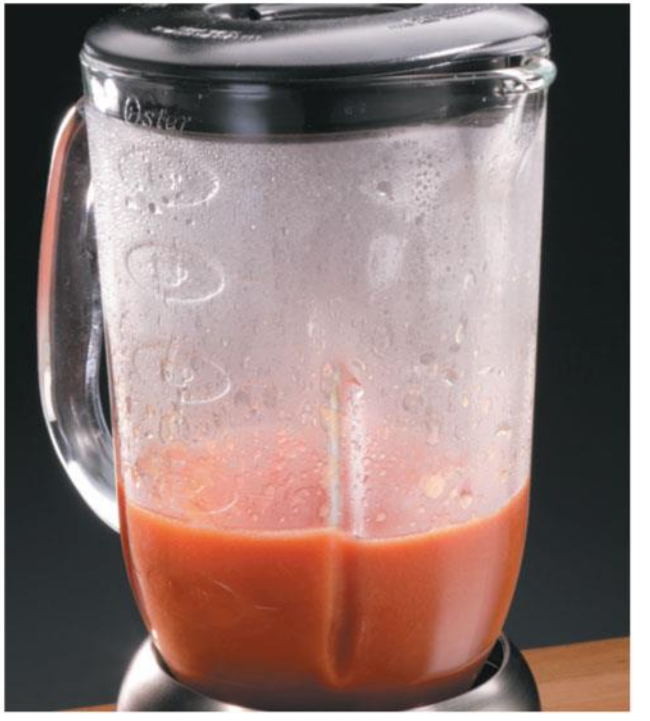


First law of thermodynamics For systems in which only the thermal energy changes, the change in thermal energy is equal to the energy transferred into or out of the system as work W, heat Q, or both:

$$\Delta E_{th} = W + Q$$

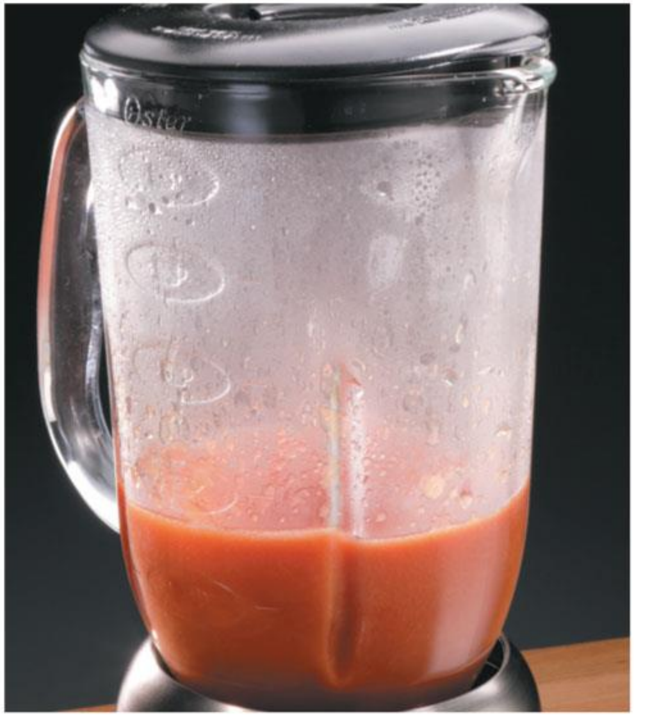
Example 11.9 Energy transfers in a blender

If you mix food in a blender, the electric motor does work on the system, which consists of the food inside the container. This work can noticeably warm up the food. Suppose the blender motor runs at a power of 250 W for 40 s. During this time, 2000 J of heat flow from the now-warmer food to its cooler surroundings. By how much does the thermal energy of the food increase?

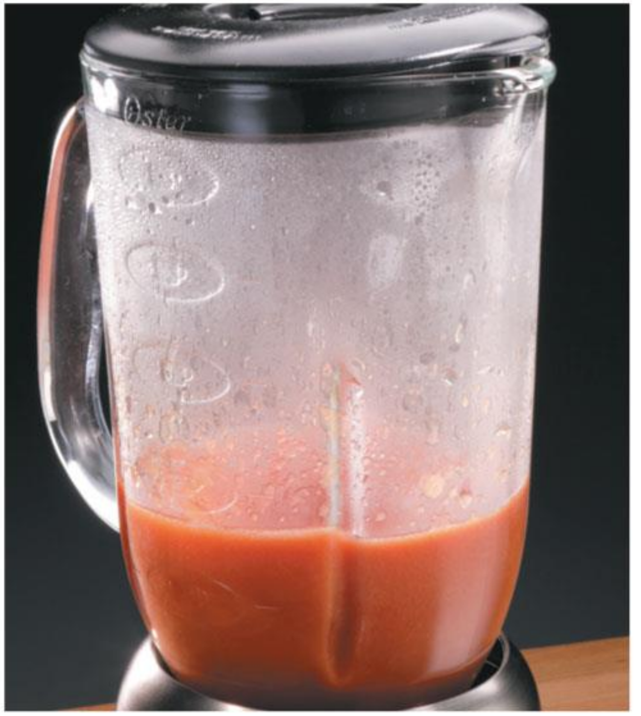


Example 11.9 Energy transfers in a blender (cont.)

PREPARE Only the thermal energy of the system changes, so we can use the first law of thermodynamics, Equation 11.8. We can find the work done by the motor from the power it generates and the time it runs.



Example 11.9 Energy transfers in a blender (cont.)

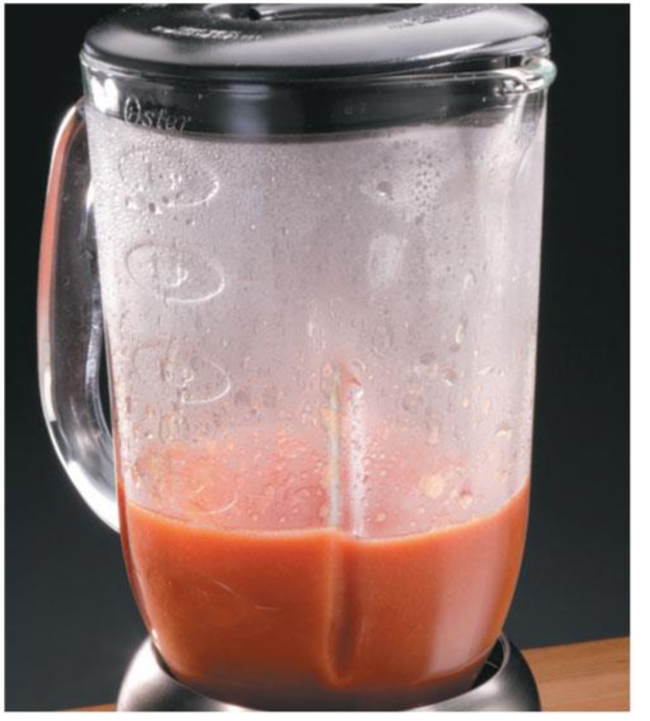


SOLVE From Equation 10.22, the work done is $W = P\,\Delta t =$ (250 W)(40 s) = 10,000 J. Because heat *leaves* the system, its sign is negative, so $Q = -2000$ J. Then the first law of thermo-dynamics gives

$$\Delta E_{\text{th}} = W + Q = 10{,}000\text{ J} - 2000\text{ J} = 8000\text{ J}$$

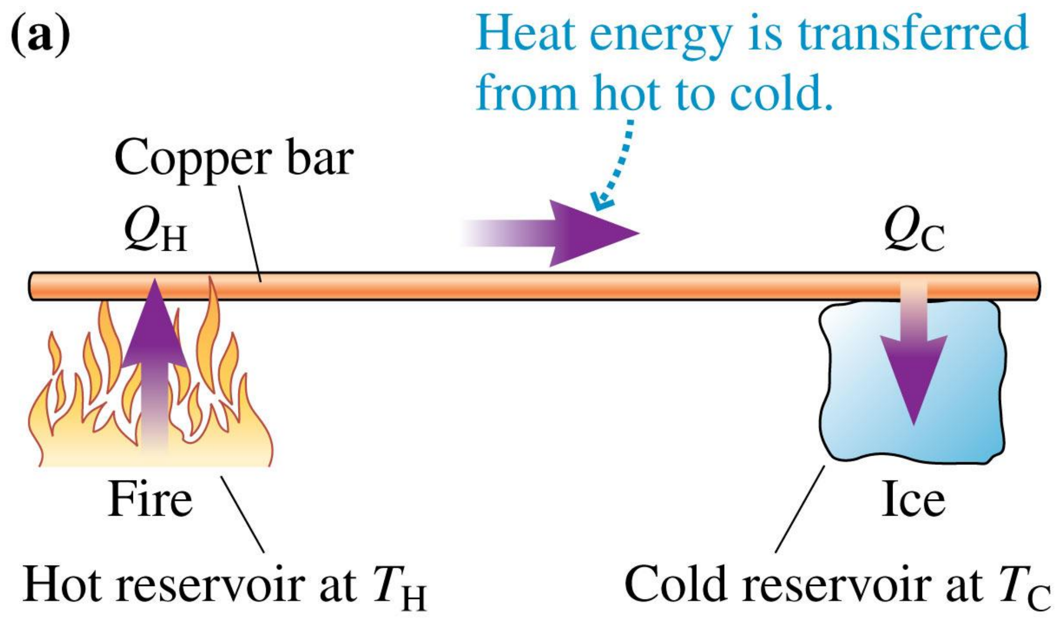
Example 11.9 Energy transfers in a blender (cont.)

ASSESS It seems reasonable that the work done by the powerful motor rapidly increases the thermal energy, while thermal energy only slowly leaks out as heat. The increased thermal energy of the food implies an increased temperature. If you run a blender long enough, the food can actually start to steam, as the photo shows.



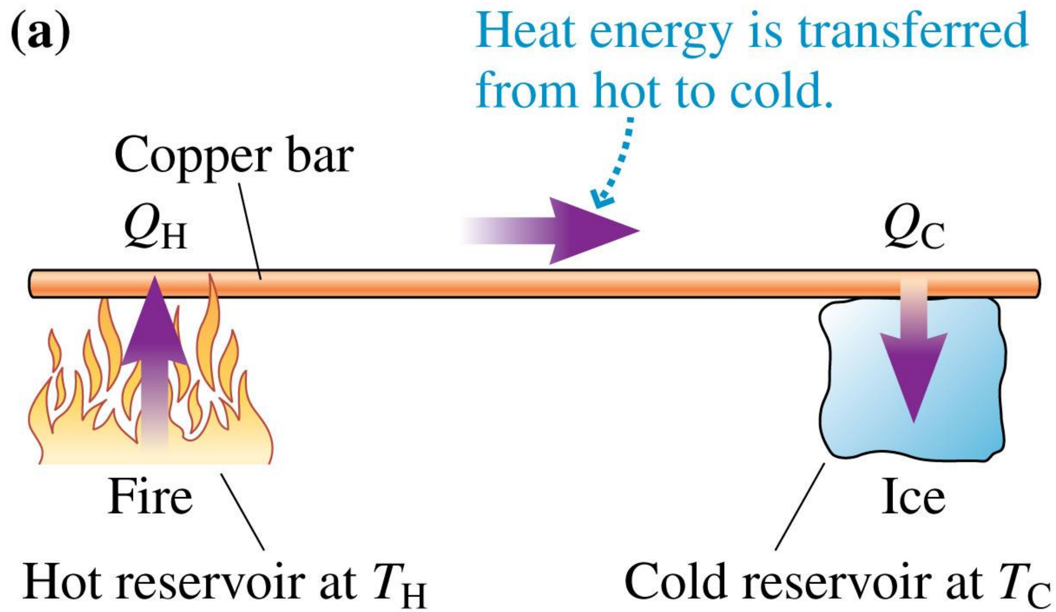
Energy-Transfer Diagrams

- An **energy reservoir** is an object or a part of the environment so large that its temperature does not noticeably change when heat is transferred between the system and the reservoir.



Energy-Transfer Diagrams

- A reservoir at higher temperatures is a *hot reservoir* (T_H), and one at lower temperatures is a *cold reservoir* (T_C).
- Q_H and Q_C are the amount of heat transferred to or from a hot and cold reservoir, respectively.
- **By definition, Q_H and Q_C are *positive* quantities.**



QuickCheck 11.11

A large –20°C ice cube is dropped into a super-insulated container holding a small amount of 5°C water, then the container is sealed. Ten minutes later, is it possible that the temperature of the ice cube will be colder than –20°C?

A. Yes
B. No
C. Maybe. It would depend on other factors.

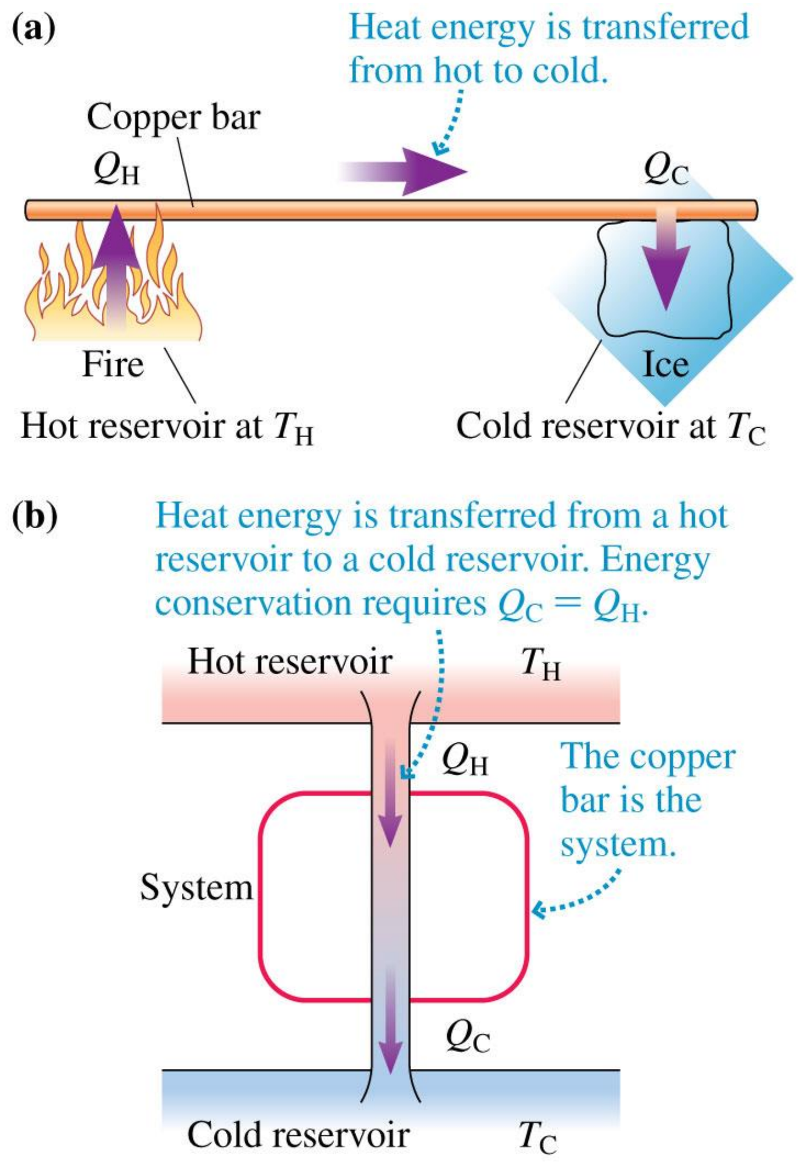
QuickCheck 11.11

A large –20°C ice cube is dropped into a super-insulated container holding a small amount of 5°C water, then the container is sealed. Ten minutes later, is it possible that the temperature of the ice cube will be colder than –20°C?

A. Yes
✔ B. No
C. Maybe. It would depend on other factors.

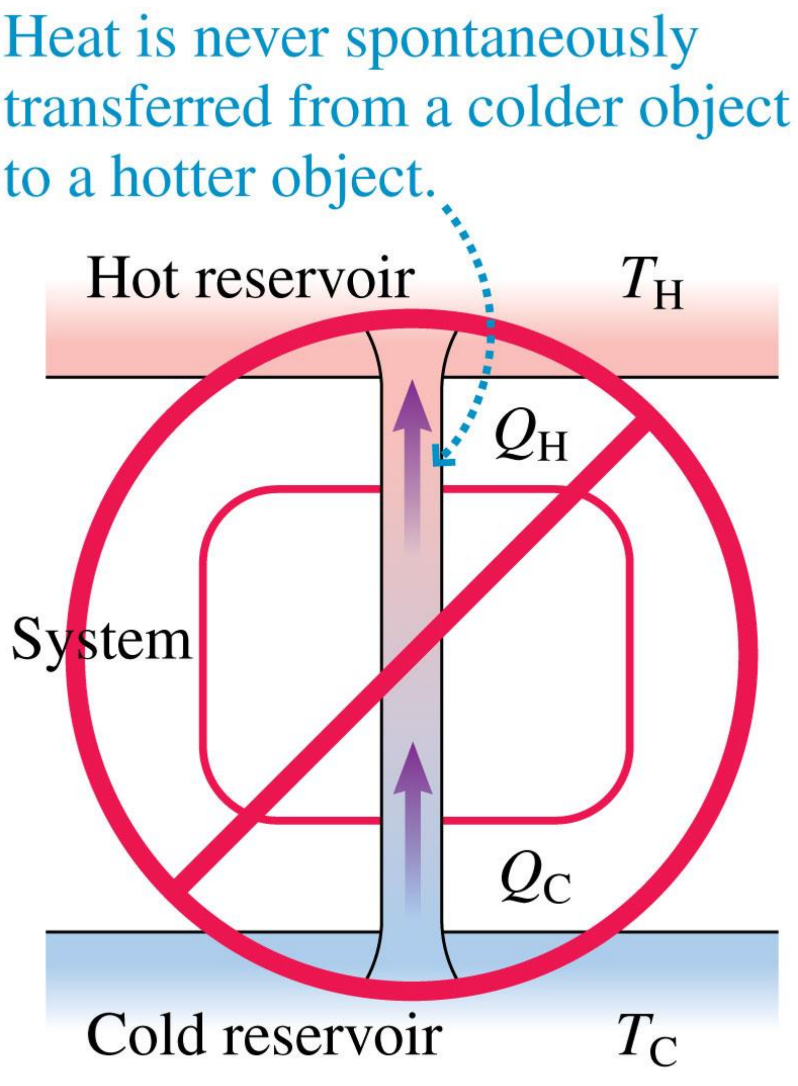
Energy-Transfer Diagrams

- **Energy-transfer diagrams:** The hot reservoir is drawn at the top, the cold at the bottom, and the system (the copper bar) between them.
- The "pipes" connect the reservoir and system and show the energy transfers.



Energy-Transfer Diagrams

- Spontaneous transfers go in one direction only: from hot to cold.



Conceptual Example 11.10 Energy transfers and the body

Why—in physics terms—is it more taxing on the body to exercise in very hot weather?

REASON Your body continuously converts chemical energy to thermal energy, as we have seen. In order to maintain a constant body temperature, your body must continuously transfer heat to the environment. This is a simple matter in cool weather when heat is spontaneously transferred to the environment, but when the air temperature is higher than your body temperature, your body cannot cool itself this way and must use other mechanisms to transfer this energy, such as perspiring. These mechanisms require additional energy expenditure.

ASSESS Strenuous exercise in hot weather can easily lead to a rise in body temperature if the body cannot exhaust heat quickly enough.

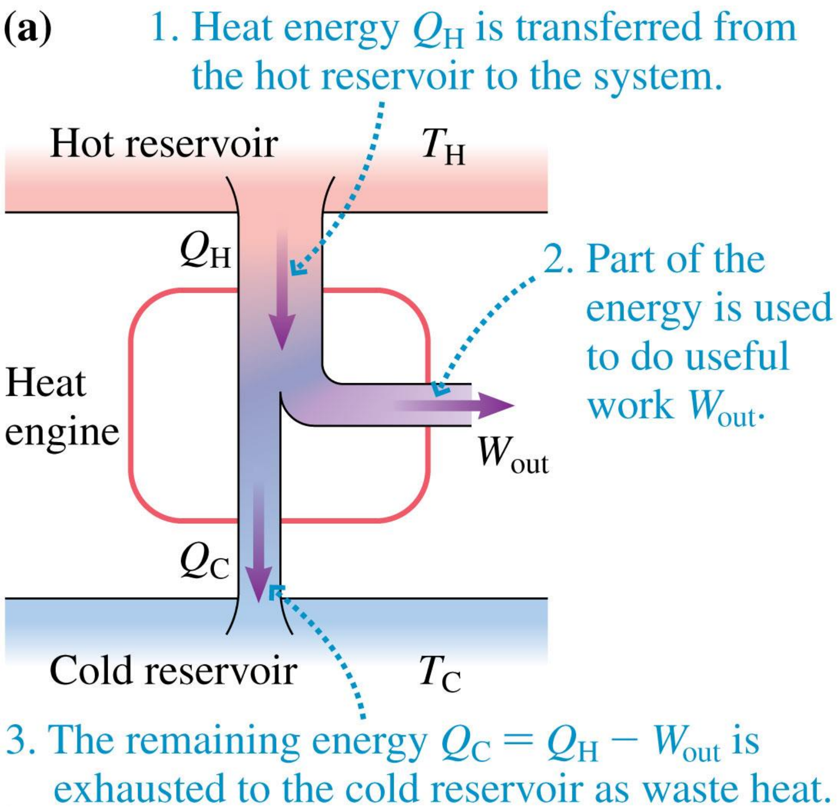
Section 11.5 Heat Engines

Heat Engines

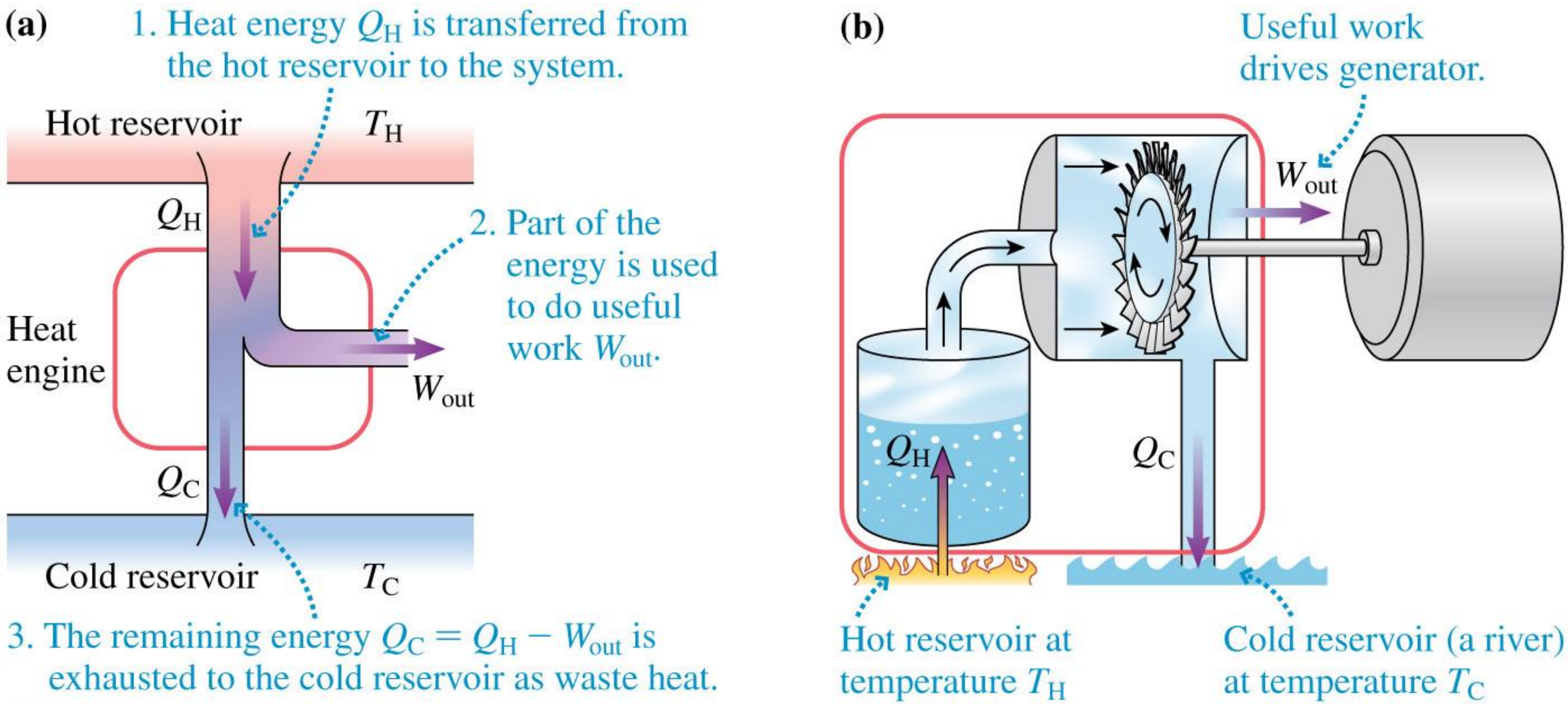
- Thermal energy is naturally transferred from a hot reservoir to a cold reservoir.
- A **heat engine** takes some of the energy as it is transferred and converts it to other forms.

Heat Engines

- The heat engine takes energy as heat from the hot reservoir, turns some into useful work, and exhausts the balance as waste heat into the cold reservoir.



Heat Engines



Heat Engines

- Most of the energy that you use daily comes from the conversion of that energy into other forms.

Most of the electricity that you use was generated by heat engines. Coal or other fossil fuels are burned to produce high-temperature, high-pressure steam. The steam does work by spinning a turbine attached to a generator, which produces electricity. Some of the energy of the steam is extracted in this way, but more than half simply flows "downhill" and is deposited in a cold reservoir, often a lake or a river.

Text: p. 333

Heat Engines

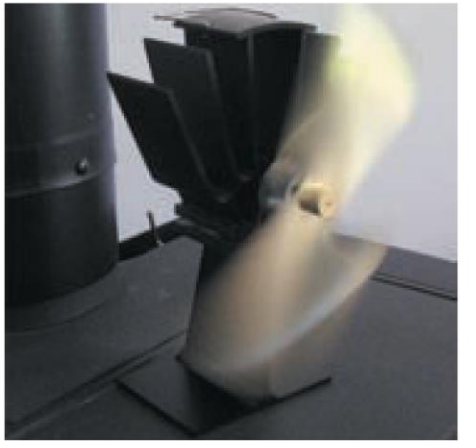
- Most of the energy that you use daily comes from the conversion of that energy into other forms.

Your car gets the energy it needs to run from the chemical energy in gasoline. The gasoline is burned; the resulting hot gases are the hot reservoir. Some of the thermal energy is converted into the kinetic energy of the moving vehicle, but more than 90% is lost as heat to the surrounding air via the radiator and the exhaust, as shown in this thermogram.

Text: p. 333

Heat Engines

- Most of the energy that you use daily comes from the conversion of that energy into other forms.



There are many small, simple heat engines that are part of things you use daily. This fan, which can be put on top of a wood stove, uses the thermal energy of the stove to provide power to drive air around the room. Where are the hot and cold reservoirs in this device?

Text: p. 333

Heat Engines

- The work extracted is equal to the difference between the heat energy transferred from the hot reservoir and the heat exhausted into the cold reservoir:

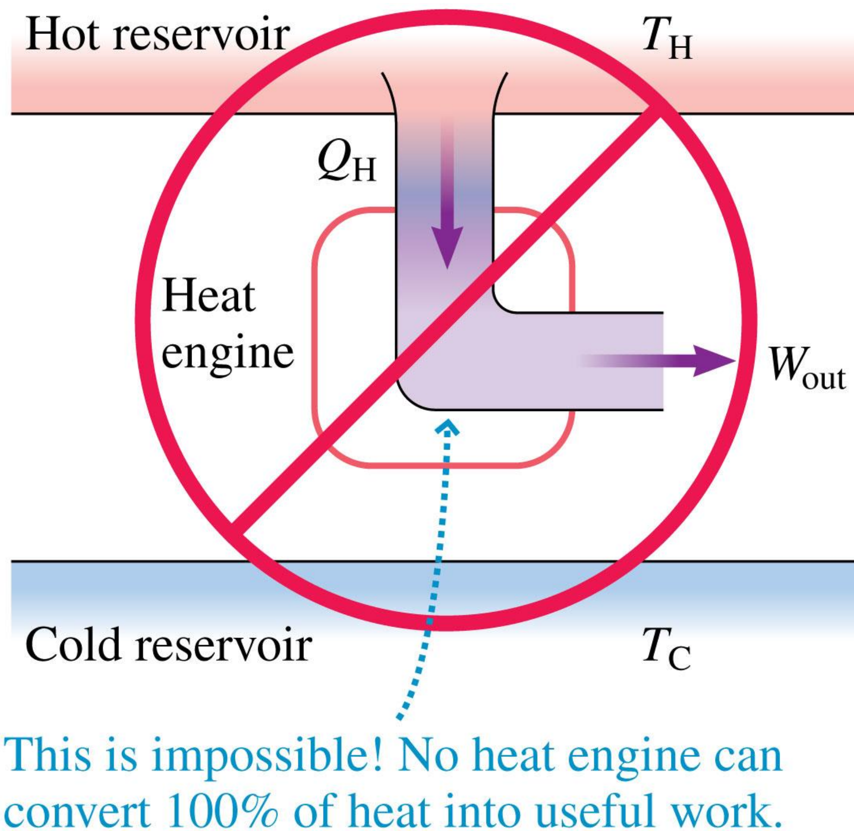
$$W_{\text{out}} = Q_{\text{H}} - Q_{\text{C}}$$

- The heat engine's efficiency is

$$e = \frac{\text{what you get}}{\text{what you had to pay}} = \frac{W_{\text{out}}}{Q_{\text{H}}} = \frac{Q_{\text{H}} - Q_{\text{C}}}{Q_{\text{H}}}$$

Heat Engines

- **No heat engine can operate without exhausting some fraction of the heat into a cold reservoir.**



Heat Engines

- The maximum efficiency is fixed by the *second law of thermodynamics*:

Maximum efficiency of a heat engine

$$e_{\text{max}} = 1 - \frac{T_C}{T_H}$$

T_C: Temperature of cold reservoir

T_H: Temperature of hot reservoir

Both T_C and T_H must be in *kelvin*.

QuickCheck 11.14

The following pairs of temperatures represent the temperatures of hot and cold reservoirs for heat engines. Which heat engine has the highest possible efficiency?

A. 300°C, 30°C
B. 250°C, 30°C
C. 200°C, 20°C
D. 100°C, 10°C
E. 90°C, 0°C

QuickCheck 11.14

The following pairs of temperatures represent the temperatures of hot and cold reservoirs for heat engines. Which heat engine has the highest possible efficiency?

✔ A. 300°C, 30°C

B. 250°C, 30°C

C. 200°C, 20°C

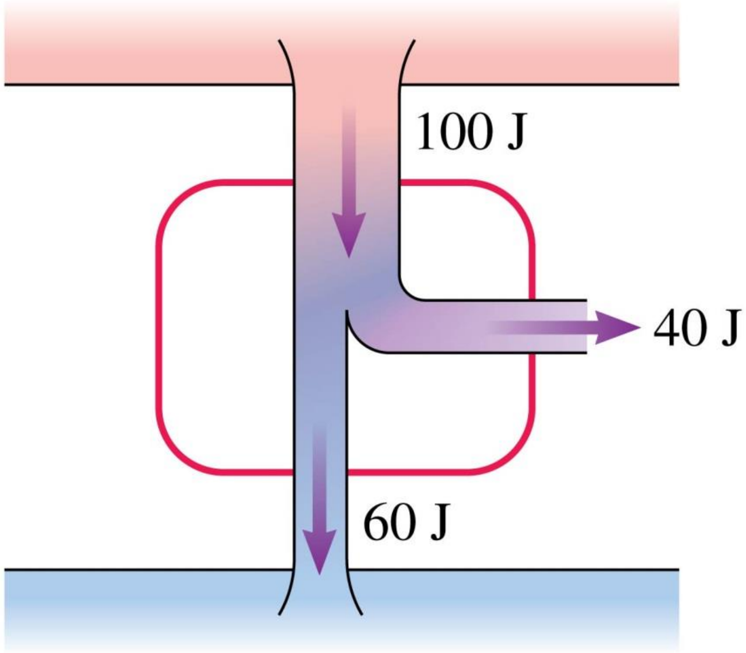
D. 100°C, 10°C

E. 90°C, 0°C

QuickCheck 11.12

The efficiency of this heat engine is

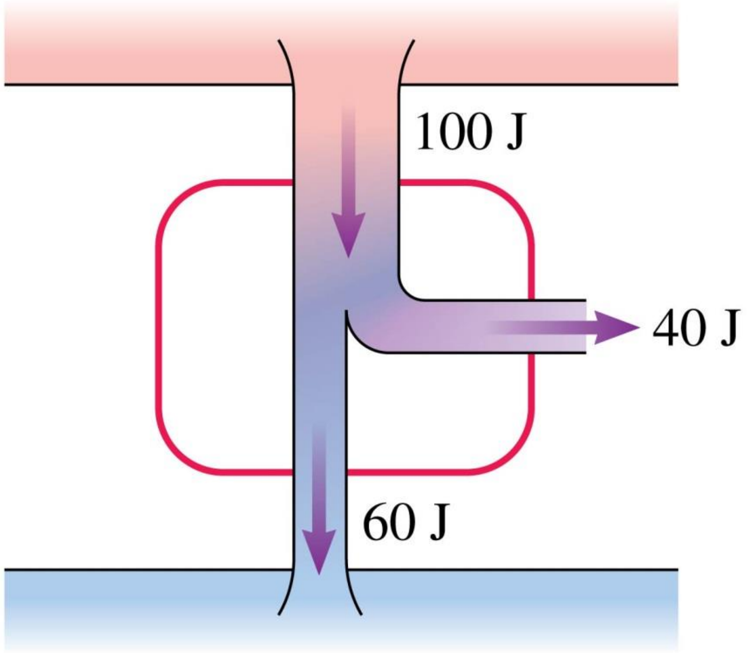
A. 1.00
B. 0.60
C. 0.50
D. 0.40
E. 0.20



QuickCheck 11.12

The efficiency of this heat engine is

A. 1.00
B. 0.60
C. 0.50
✔ D. 0.40
E. 0.20



Example 11.11 The efficiency of a nuclear power plant

Energy from nuclear reactions in the core of a nuclear reactor produces high-pressure steam at a temperature of 290°C. After the steam is used to spin a turbine, it is condensed (by using cooling water from a nearby river) back to water at 20°C. The excess heat is deposited in the river. The water is then reheated, and the cycle begins again. What is the maximum possible efficiency that this plant could achieve?

Example 11.11 The efficiency of a nuclear power plant (cont.)

PREPARE A nuclear power plant is a heat engine, with energy transfers as illustrated in Figure 11.18a. Q_H is the heat energy transferred to the steam in the reactor core. T_H is the temperature of the steam, 290°C. The steam is cooled and condensed, and the heat Q_C is exhausted to the river. The river is the cold reservoir, so T_C is 20°C. In kelvin, these temperatures are

$$T_H = 290°C = 563\ K \qquad T_C = 20°C = 293\ K$$

Example 11.11 The efficiency of a nuclear power plant (cont.)

SOLVE We use Equation 11.10 to compute the maximum possible efficiency:

$$e_{\text{max}} = 1 - \frac{T_{\text{C}}}{T_{\text{H}}} = 1 - \frac{293\ \text{K}}{563\ \text{K}} = 0.479 \approx 48\%$$

ASSESS This is the maximum possible efficiency. There are practical limitations as well that limit real power plants, whether nuclear or coal- or gas-fired, to an efficiency $e \approx 0.35$. This means that 65% of the energy from the fuel is exhausted as waste heat into a river or lake, where it may cause problematic warming in the local environment.

Example Problem

A person lifts a 20 kg box from the ground to a height of 1.0 m. A metabolic measurement shows that in doing this work her body uses 780 J of energy. What is her efficiency?

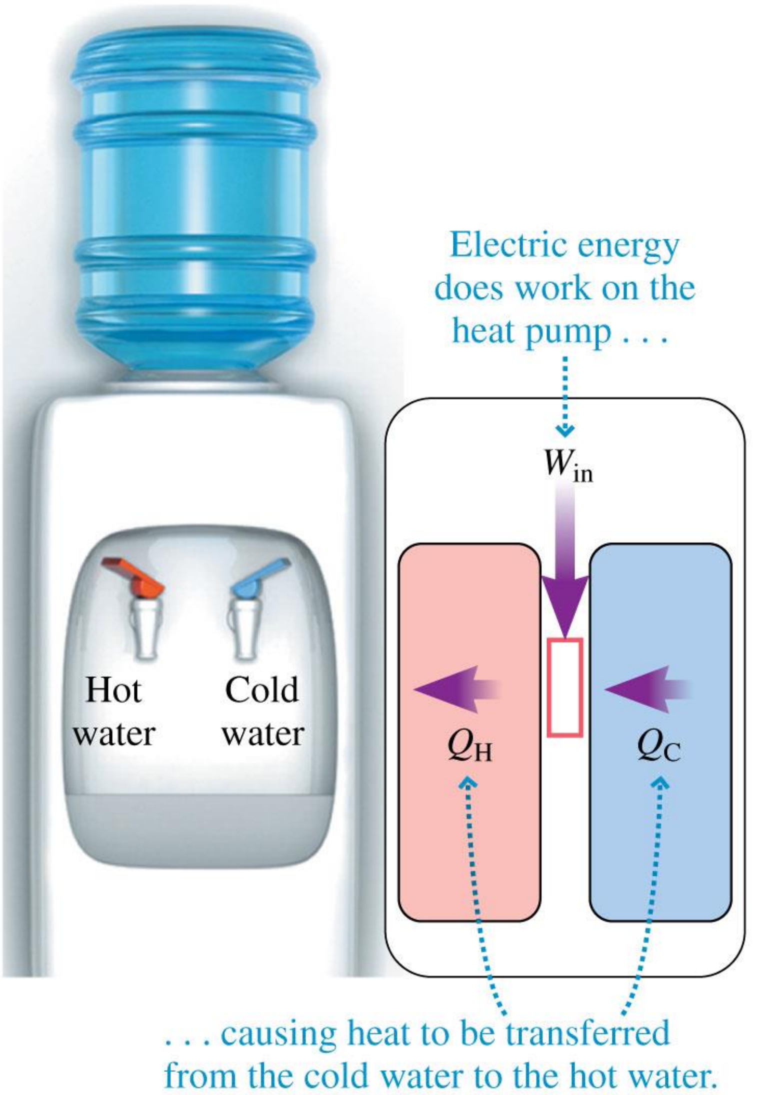
Example Problem

Light bulbs are rated by the power that they consume, not the light that they emit. A 100 W incandescent bulb emits approximately 4 W of visible light. What is the efficiency of the bulb?

Section 11.6 Heat Pumps, Refrigerators, and Air Conditioners

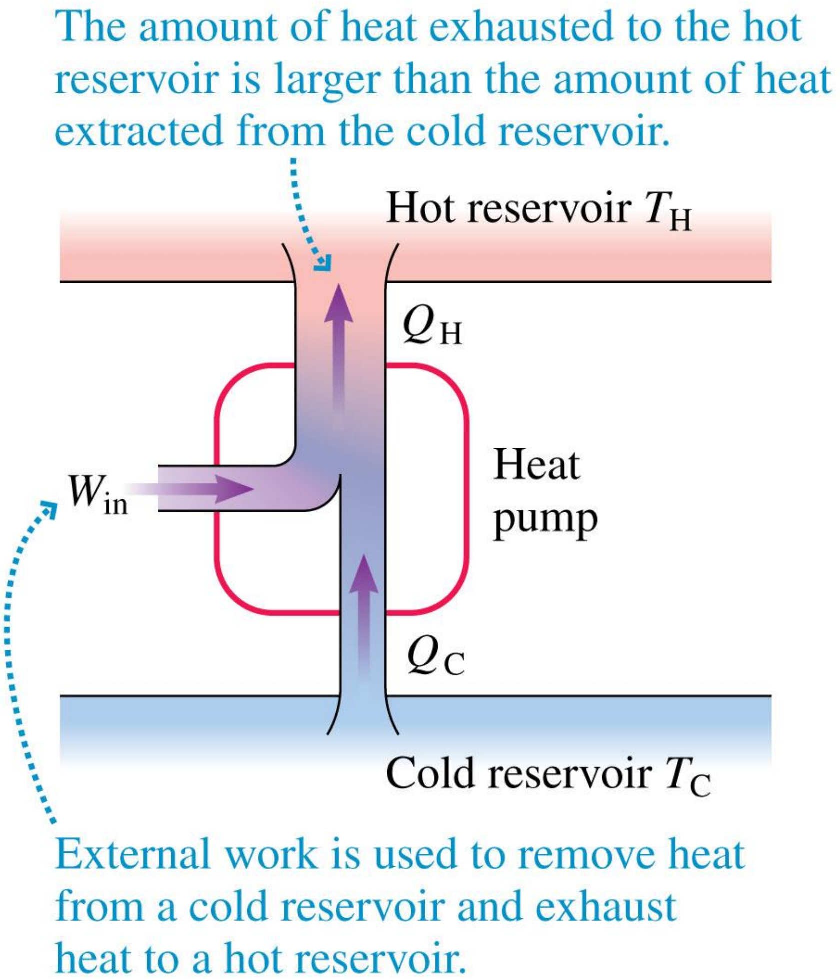
Heat Pumps

- Transferring heat energy from a cold reservoir to a hot reservoir is the job of a **heat pump**.



Heat Pumps

- For heat pumps, instead of efficiency we compute the **coefficient of performance (COP).**



Heat Pumps

- If we use the heat pump for cooling, we define COP as

$$\text{COP} = \frac{\text{what you get}}{\text{what you had to pay}}$$

$$= \frac{\text{energy removed from the cold reservoir}}{\text{work required to perform the transfer}} = \frac{Q_C}{W_{in}}$$

$$\text{COP}_{max} = \frac{T_C}{T_H - T_C}$$

Theoretical maximum coefficient of performance of a heat pump used for cooling

Heat Pumps

- If we use the heat pump for heating, we define COP as

$$\text{COP} = \frac{\text{what you get}}{\text{what you had to pay}}$$

$$= \frac{\text{energy added to the hot reservoir}}{\text{work required to perform the transfer}} = \frac{Q_\text{H}}{W_\text{in}}$$

$$\text{COP}_\text{max} = \frac{T_\text{H}}{T_\text{H} - T_\text{C}}$$

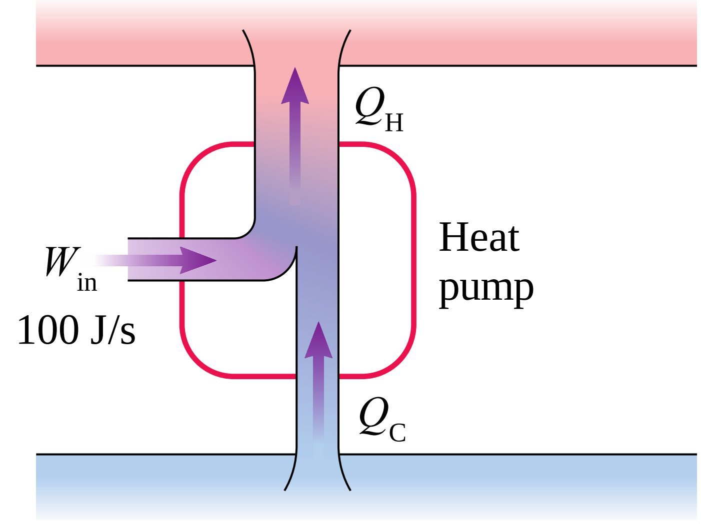
Theoretical maximum coefficient of performance of a heat pump used for heating

- **In both cases, a larger coefficient of performance means a more efficient heat pump.**

QuickCheck 11.15

A *Peltier* cooler is a heat pump that can be set to either cool or heat its contents. One such cooler uses 100 W of input power whether heating or cooling. Which is greater, its coefficient of performance for cooling or its coefficient of performance for heating?

A. Cooling
B. Heating
C. The two coefficients are the same.



QuickCheck 11.15

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A. Cooling

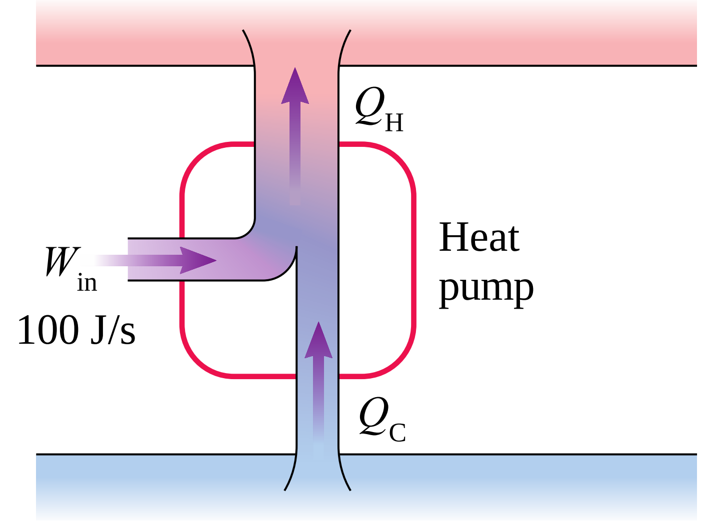
✔ B. Heating

C. The two coefficients are the same.

$$COP_{cooling} = Q_C / W_{in}$$

$$COP_{heating} = Q_H / W_{in}$$

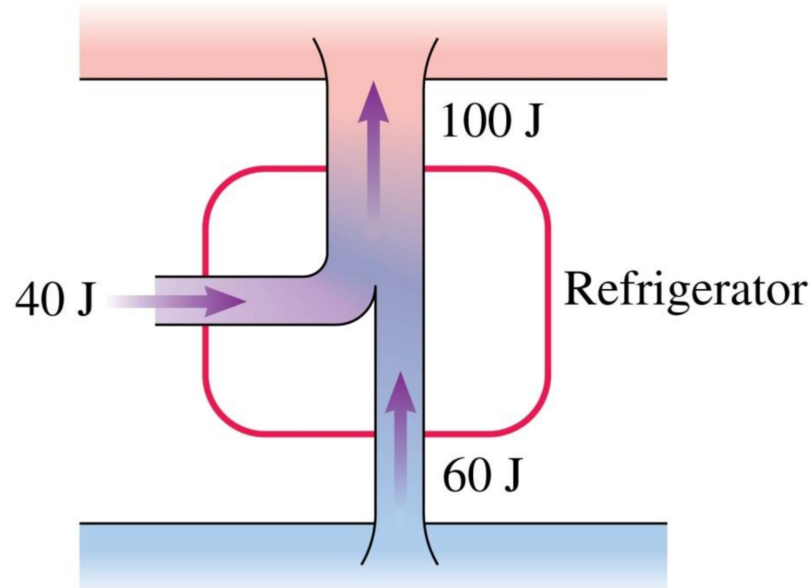
$$Q_H > Q_C$$



QuickCheck 11.13

The coefficient of performance of this refrigerator is

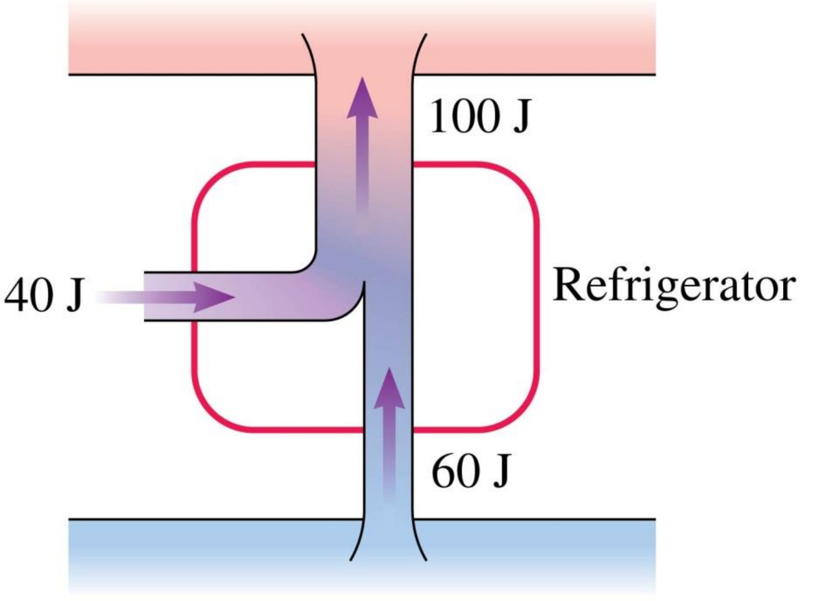
A. 0.40
B. 0.60
C. 1.50
D. 1.67
E. 2.00



QuickCheck 11.13

The coefficient of performance of this refrigerator is

A. 0.40
B. 0.60
✔ C. 1.50
D. 1.67
E. 2.00



Example 11.12 Coefficient of performance of a refrigerator

The inside of your refrigerator is approximately 0°C. Heat from the inside of your refrigerator is deposited into the air in your kitchen, which has a temperature of approximately 20°C. At these operating temperatures, what is the maximum possible coefficient of performance of your refrigerator?

PREPARE The temperatures of the hot side and the cold side must be expressed in kelvin:

$$T_H = 20°C = 293\ K \qquad T_C = 0°C = 273\ K$$

Example 11.12 Coefficient of performance of a refrigerator (cont.)

SOLVE We use Equation 11.11 to compute the maximum coefficient of performance:

$$\mathrm{COP}_{\max} = \frac{T_C}{T_H - T_C} = \frac{273\ \mathrm{K}}{293\ \mathrm{K} - 273\ \mathrm{K}} = 13.6$$

ASSESS A coefficient of performance of 13.6 means that we pump 13.6 J of heat for an energy cost of 1 J. Due to practical limitations, the coefficient of performance of an actual refrigerator is typically ≈5. Other factors affect the overall efficiency of the appliance, including how well insulated it is.

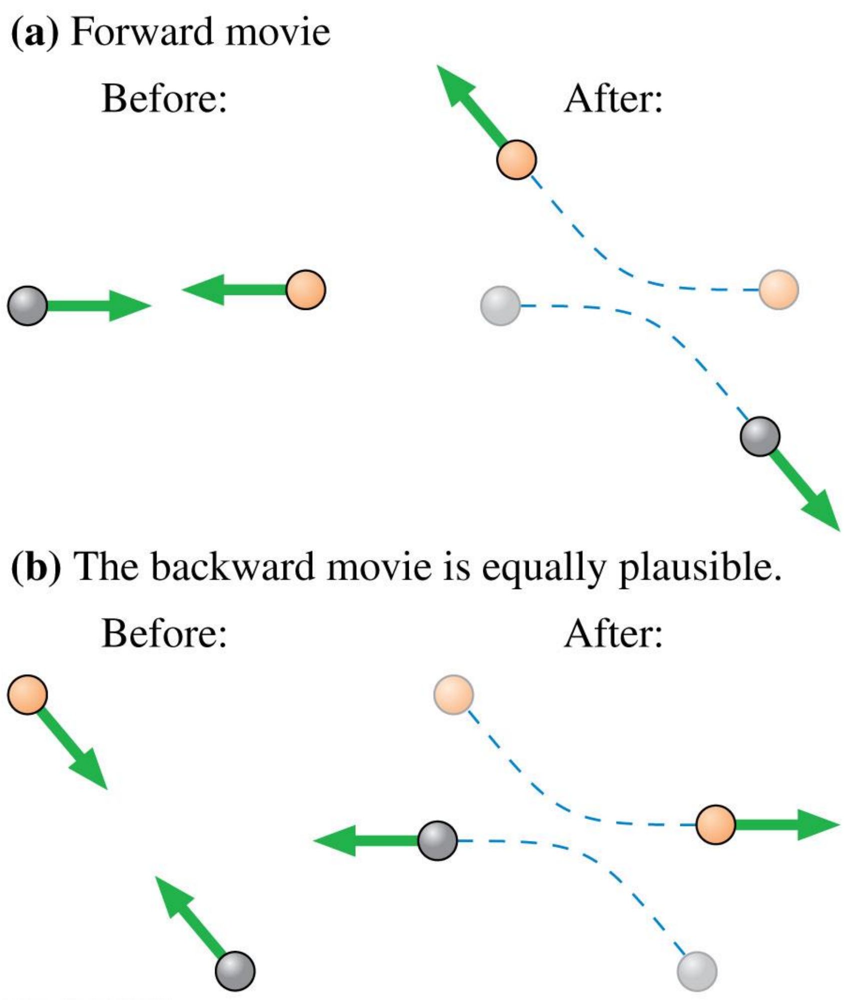
Section 11.7 Entropy and the Second Law of Thermodynamics

Entropy and the Second Law of Thermodynamics

- The spontaneous transfer of heat from hot to cold is an **irreversible** process; it can happen in only one direction.
- The **second law of thermodynamics** prevents the spontaneous transfer of heat from cold to hot.

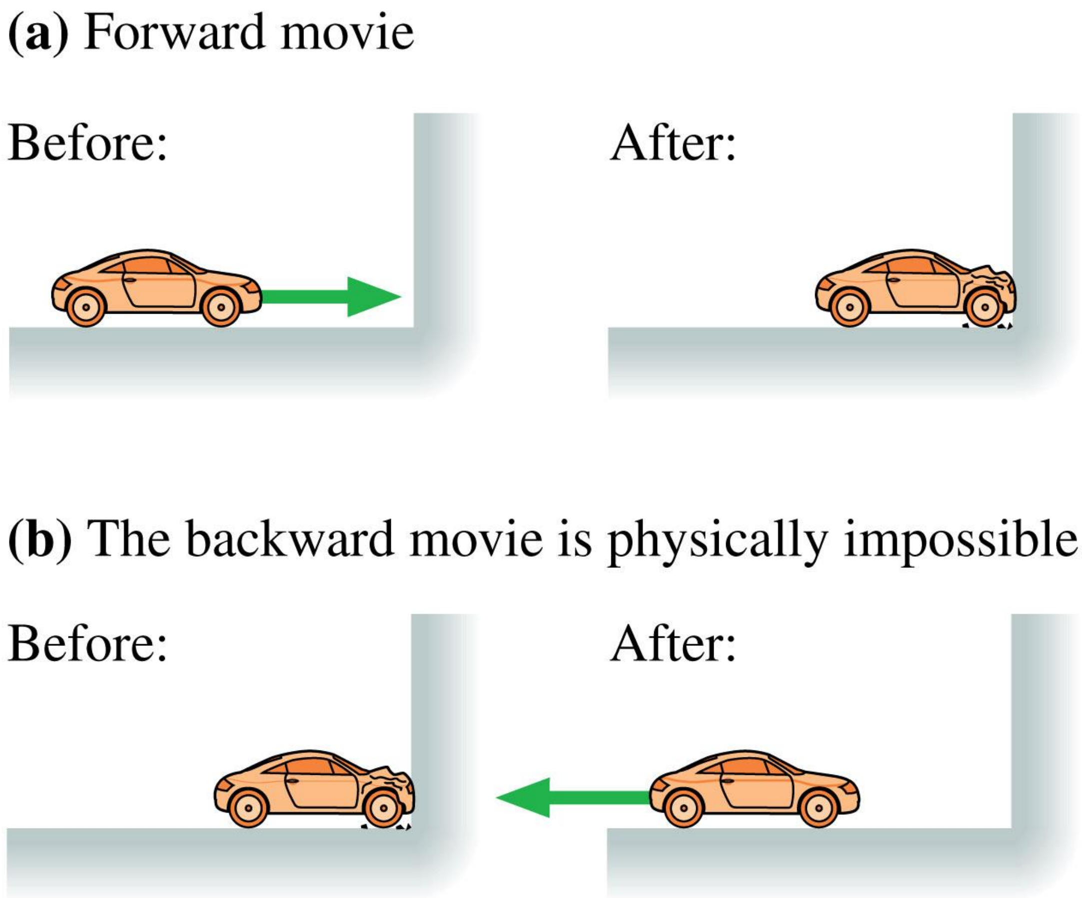
Reversible and Irreversible Processes

- At the microscopic level, collisions between molecules are reversible.



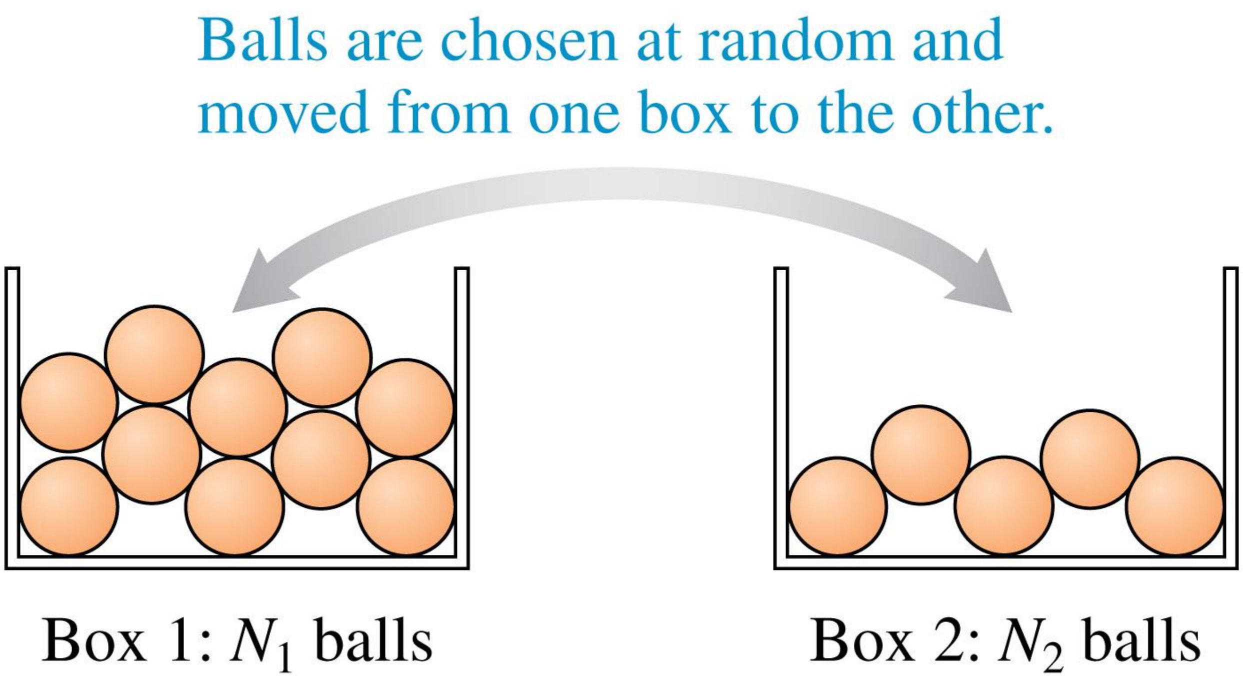
Reversible and Irreversible Processes

- At the macroscopic level, collisions are usually irreversible.



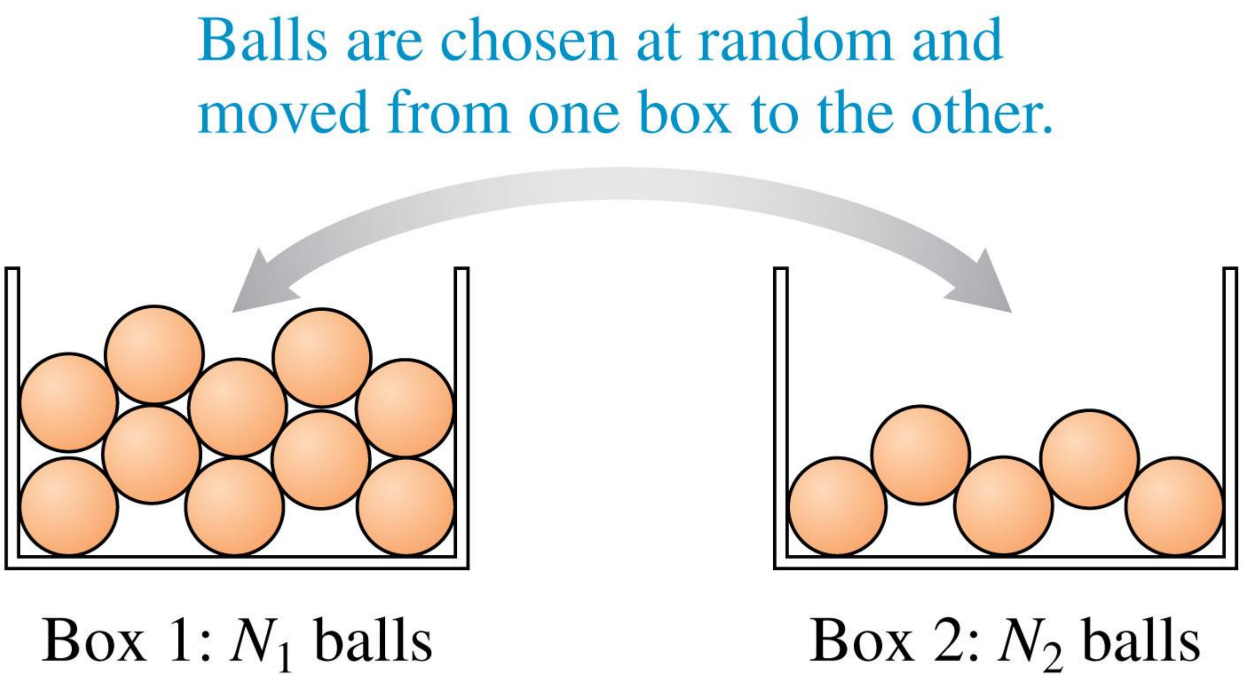
Which Way to Equilibrium?

- If Box 1 has more balls than Box 2, and you randomly pick any ball to switch boxes, there is a higher probability you will pick a ball from Box 1.
- There is a net flow of balls moving from Box 1 to Box 2 until equilibrium is reached.



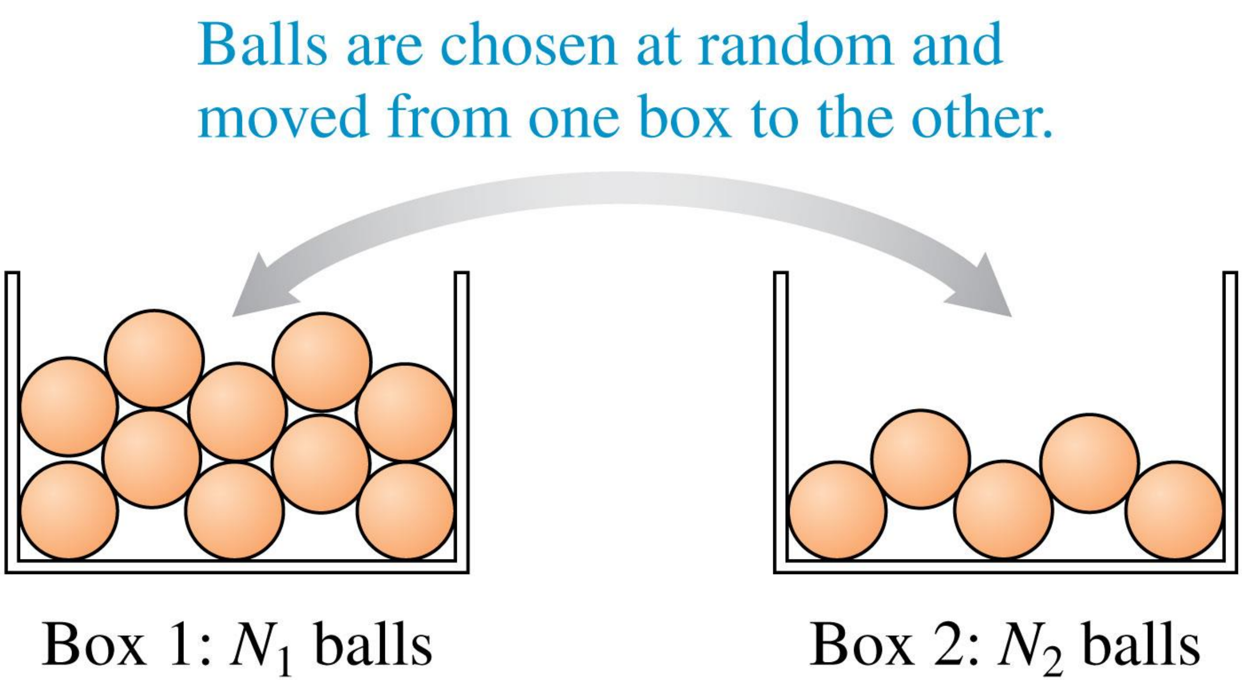
Which Way to Equilibrium?

- The process is reversible (a ball can be moved back to Box 1).
- **The statistics of large numbers make it overwhelmingly likely that the system will evolve toward a state in which $N_1 \approx N_2$.**



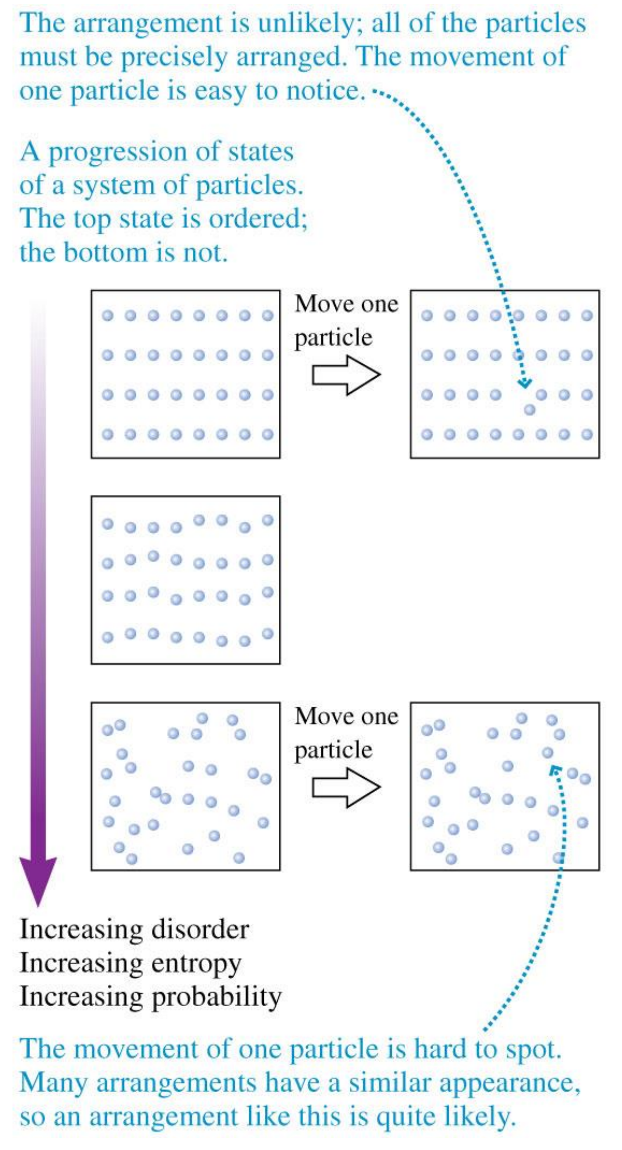
Which Way to Equilibrium?

- Systems reach thermal equilibrium because **equilibrium is the most probable state in which to be.**
- Reversible microscopic events lead to irreversible macroscopic behavior because some macroscopic states are vastly more probable than others.



Order, Disorder, and Entropy

- **Entropy** quantifies the probability that a certain state of a system will occur.
- **Entropy increases as two systems with initially different temperatures move toward thermal equilibrium.**



Order, Disorder, and Entropy

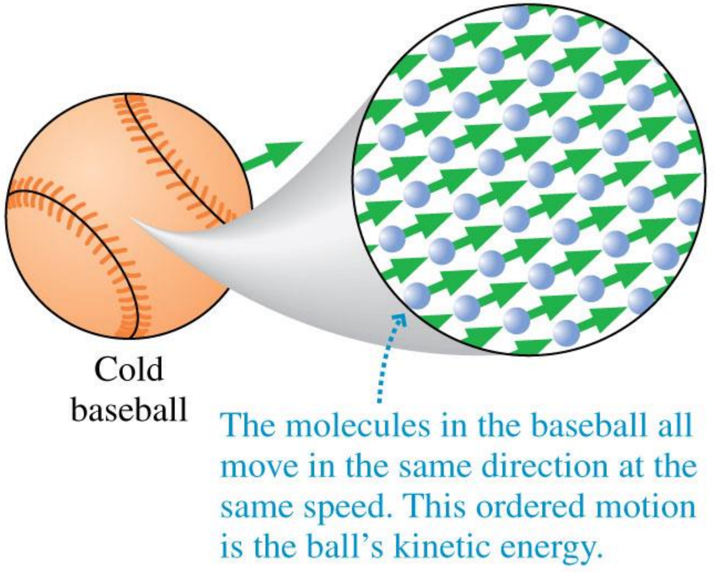
Second law of thermodynamics The entropy of an isolated system never decreases. The entropy either increases, until the system reaches equilibrium, or, if the system began in equilibrium, stays the same.

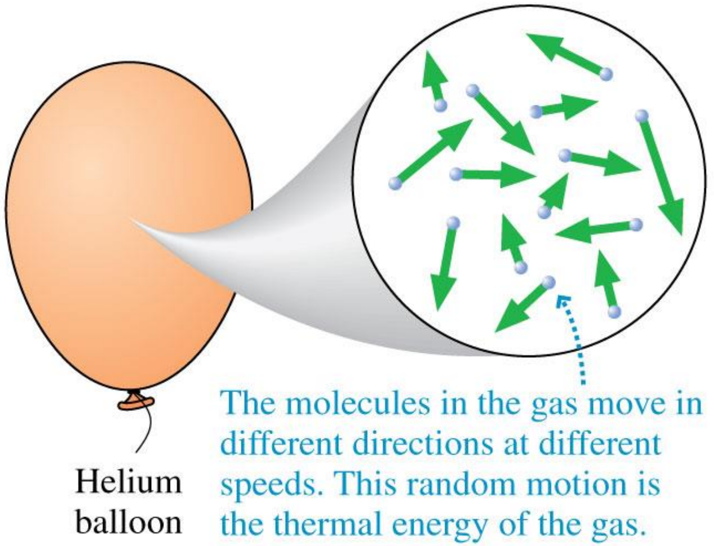
Order, Disorder, and Entropy

- The second law of thermodynamics tells us that an isolated system evolves such that:
  - Order turns into disorder and randomness.
  - Information is lost rather than gained.
  - The system "runs down" as other forms of energy are transformed into thermal energy.

Entropy and Thermal Energy

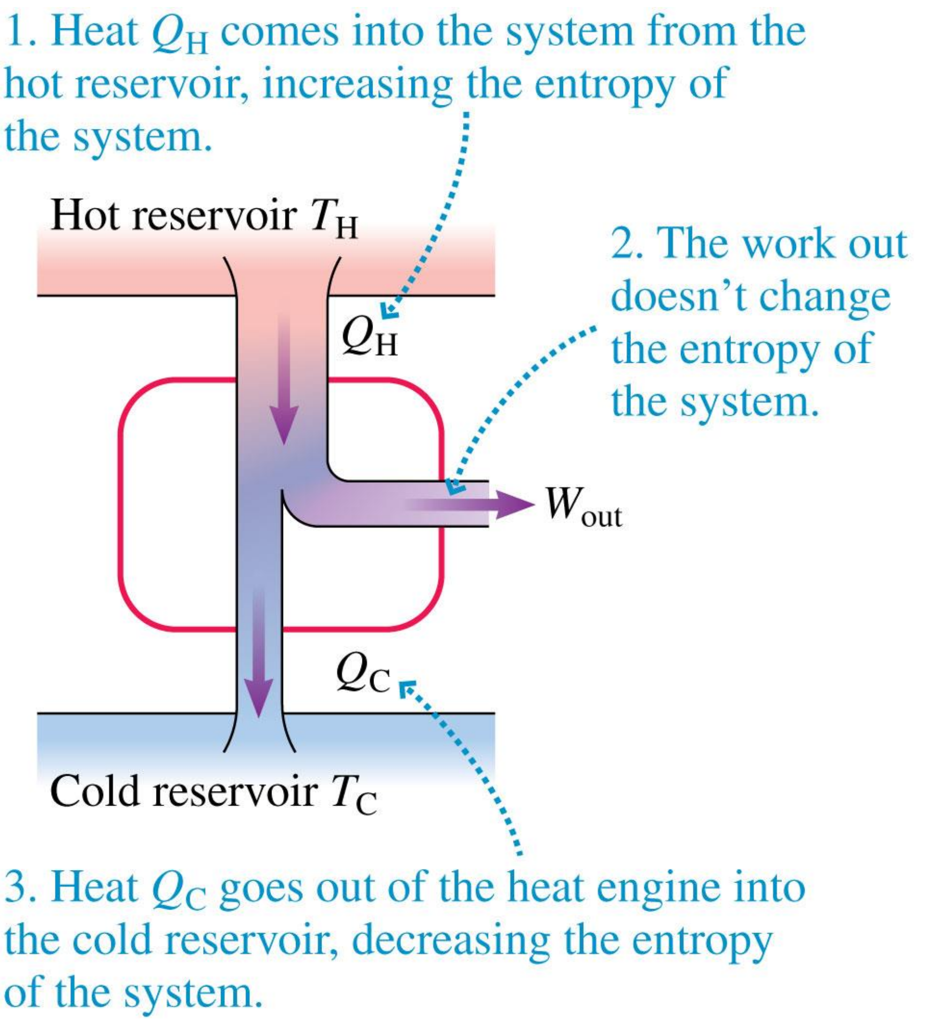
- In a very cold, moving baseball, all of the atoms are moving in the same direction and same speed. It has low entropy.
- In a stationary helium balloon, the atoms are disorganized and have random motion (thermal energy). It has high entropy.





Entropy and Thermal Energy

- **When another form of energy is converted into thermal energy, there is an increase in entropy.**
- This is why converting thermal energy into other forms cannot be done with 100% efficiency.



QuickCheck 11.16

A large –20°C ice cube is dropped into a super-insulated container holding a small amount of 5°C water, then the container is sealed. Ten minutes later, the temperature of the ice (and any water that has melted from the ice) will be warmer than –20°C. This is a consequence of

A. The first law of thermodynamics.
B. The second law of thermodynamics.
C. The third law of thermodynamics.
D. Both the first and the second laws.
E. Joule’s law.

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Conceptual Example 11.14 Efficiency of hybrid vehicles

Hybrid vehicles are powered by a gasoline engine paired with an electric motor and batteries. Hybrids get much better mileage in the stop and go of city driving than conventional vehicles do. When you brake to a stop in a conventional car, friction converts the kinetic energy of the car's motion into thermal energy in the brakes. In a typical hybrid car, some of this energy is converted into chemical energy in a battery. Explain how this makes a hybrid vehicle more efficient.

Conceptual Example 11.14 Efficiency of hybrid vehicles (cont.)

REASON When energy is transformed into thermal energy, the increase in entropy makes this change irreversible. When you brake a conventional car, the kinetic energy is transformed into the thermal energy of hot brakes and is lost to your use. In a hybrid vehicle, the kinetic energy is converted into chemical energy in a battery. This change is reversible; when the car starts again, the energy can be transformed back into kinetic energy.

ASSESS Whenever energy is converted to thermal energy, it is in some sense “lost,” which reduces efficiency. The hybrid vehicle avoids this transformation, and so is more efficient.

Example Problem

At the Geysers geothermal power plant in northern California, electricity is generated by using the temperature difference between the 15°C surface and 240°C rock deep underground. What is the maximum possible efficiency? What happens to the energy that is extracted from the steam that is not converted to electricity?

Try It Yourself: Typing Shakespeare

Make a new document in your word processor. Close your eyes and type randomly for a while. Now open your eyes. Did you type any recognizable words? There is a chance that you did, but you probably didn't. One thousand chimps in a room, typing away randomly, *could* type the works of Shakespeare. Molecular collisions *could* transfer energy from a cold object to a hot object. But the probability is so tiny that the outcome is never seen in the real world.

Section 11.8 Systems, Energy, and Entropy

The Conservation of Energy and Energy Conservation

- Energy cannot be created or destroyed, but when energy is transformed, some of it is converted to thermal energy. The change is irreversible.
- To “conserve energy” we must concentrate on efficiency.

Entropy and Life

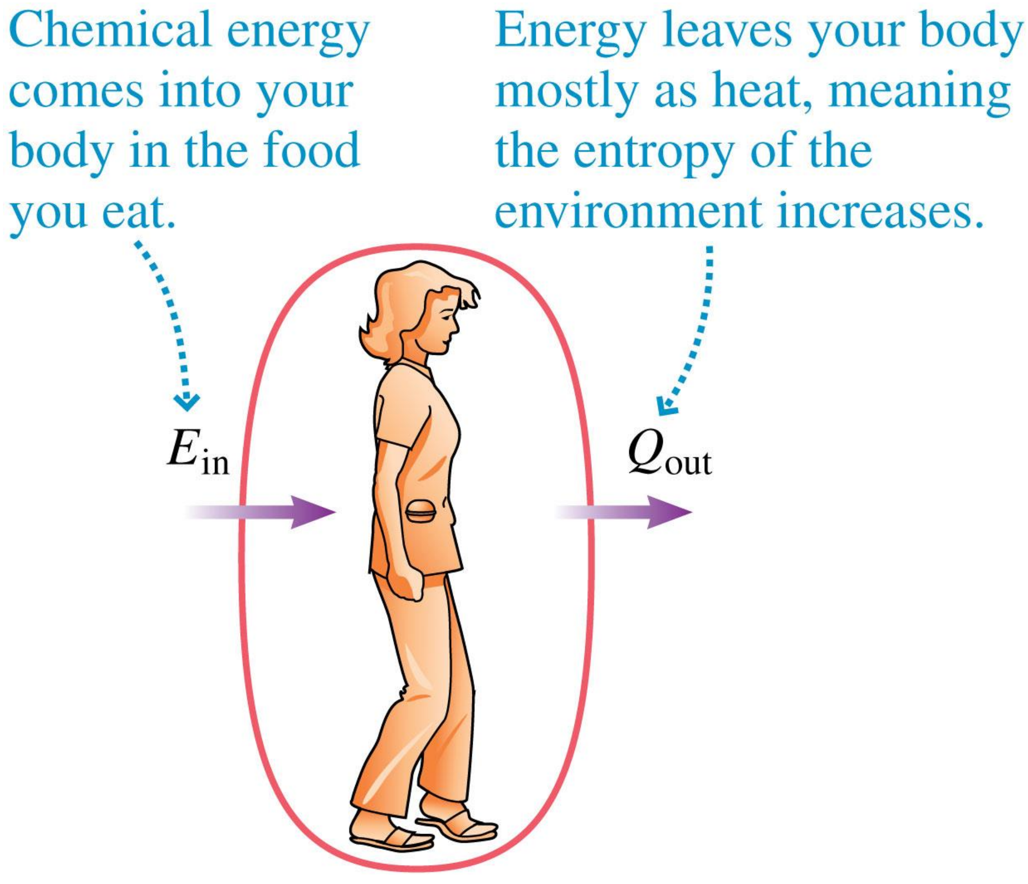
- Life seems to violate the second law of thermodynamics:
  - Plants grow from simple seeds to complex entities.
  - Single-celled fertilized eggs grow into complex adult organisms.
  - Over the last billion years, life has evolved from unicellular organisms to complex forms.

Entropy and Life

- The second law of thermo-dynamics only applies to **isolated systems:** systems that do not exchange energy with their environment.

Entropy and Life

- Your body is not an isolated system.
- The entropy of your body is approximately the same, but the entropy of the environment is increasing due to thermal energy from your body.



Summary: General Principles

Energy and Efficiency

When energy is transformed from one form into another, some may be "lost," usually to thermal energy, due to practical or theoretical constraints. This limits the efficiency of processes. We define **efficiency** as

Efficiency: Used for heat engines → $e = \dfrac{\text{what you get}}{\text{what you had to pay}} = \text{COP}$ ← COP: Used for heat pumps

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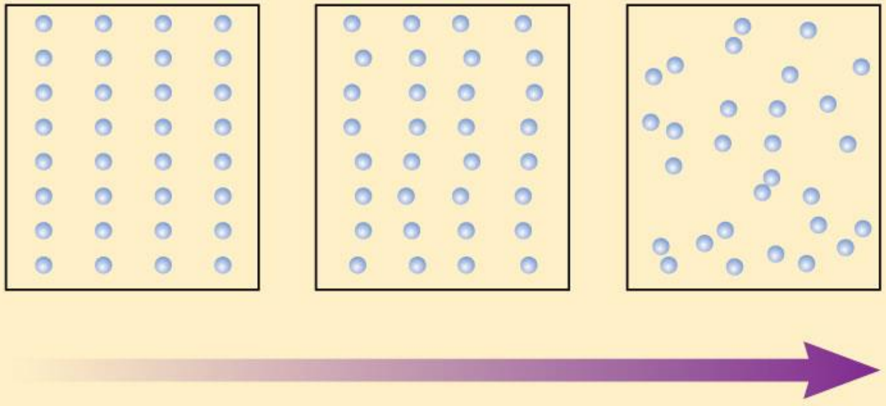
Summary: General Principles

Entropy and Irreversibility

Systems move toward more probable states. These states have higher **entropy**—more disorder. This change is irreversible. Changing other forms of energy to thermal energy is irreversible.



Increasing probability
Increasing entropy

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Summary: General Principles

The Laws of Thermodynamics

The **first law of thermodynamics** is a statement of conservation of energy for systems in which only thermal energy changes:

$$\Delta E_{\text{th}} = W + Q$$

The **second law of thermodynamics** specifies the way that isolated systems can evolve:

The entropy of an isolated system always increases.

This law has practical consequences:

- Heat energy spontaneously flows only from hot to cold.
- A transformation of energy into thermal energy is irreversible.
- No heat engine can be 100% efficient.

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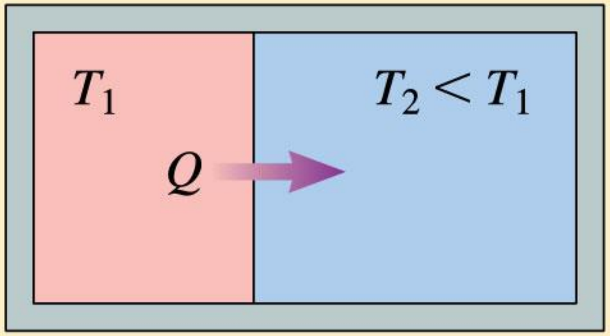
Summary: General Principles

Heat is energy transferred between two objects because they are at different temperatures. Energy will be transferred until thermal equilibrium is reached.



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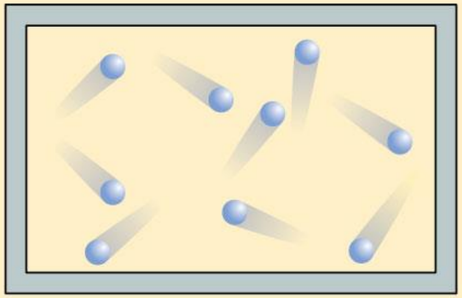
Summary: Important Concepts

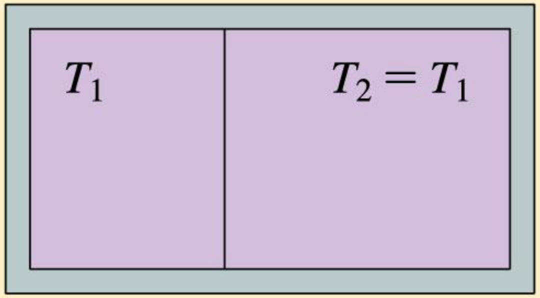
Thermal energy

- For a gas, the thermal energy is the **total kinetic energy** of motion of the atoms.
- Thermal energy is random kinetic energy and so is associated with entropy.



Temperature

- For a gas, temperature is related to the **average kinetic energy** of the motion of the atoms.
- Two systems are in **thermal equilibrium** if they are at the same temperature. No heat energy is transferred.



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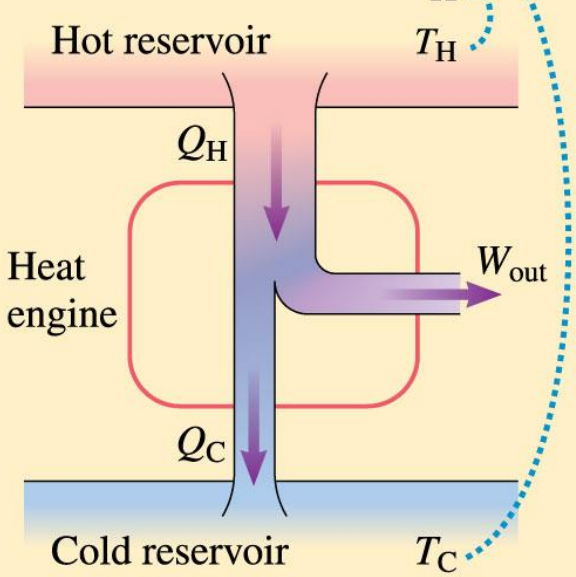
Summary: Important Concepts

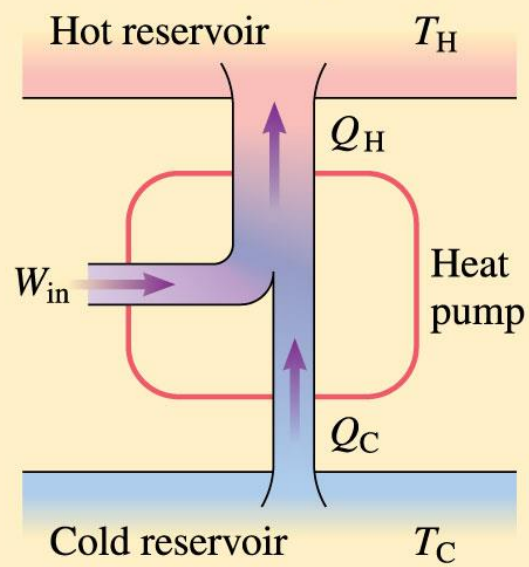
A **heat engine** converts thermal energy from a hot reservoir into useful work. Some heat is exhausted into a cold reservoir, limiting efficiency.

$$e_{max} = 1 - \frac{T_C}{T_H}$$



A **heat pump** uses an energy input to transfer heat from a cold side to a hot side. The **coefficient of performance** is analogous to efficiency. For cooling, its limit is

$$COP_{max} = \frac{T_C}{T_H - T_C}$$



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Summary: Applications

Efficiencies

Energy in the body
Cells in the body metabolize chemical energy in food. Efficiency for most actions is about 25%.

Energy used by body at rate of 480 W

Energy for forward propulsion at rate of 120 W

Power plants
A typical power plant converts about 1/3 of the energy input into useful work. The rest is exhausted as waste heat.

Chemical energy in

Waste heat

Useful work out

Text: p. 343

Summary: Applications

Temperature scales

Zero on the **Kelvin temperature scale** is the temperature at which the kinetic energy of atoms is zero. This is **absolute zero.** The conversion from °C to K is

$$T(\text{K}) = T(^\circ\text{C}) + 273$$

► All temperatures in equations must be in kelvin. ◄

Text: p. 343

Summary

GENERAL PRINCIPLES

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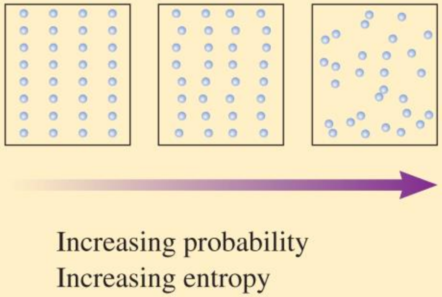

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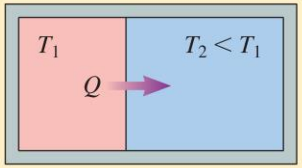

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Summary

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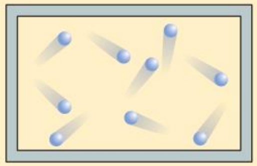

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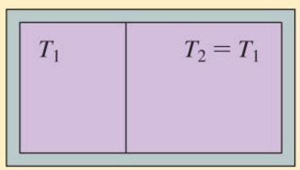

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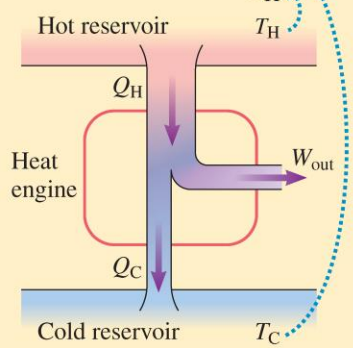

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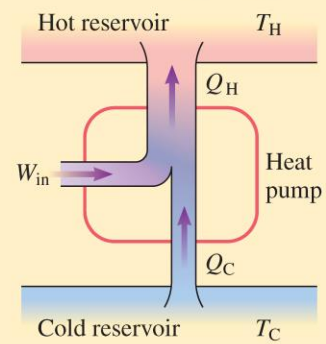

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Summary

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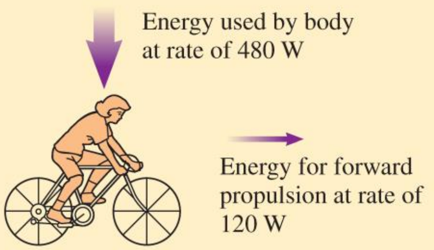

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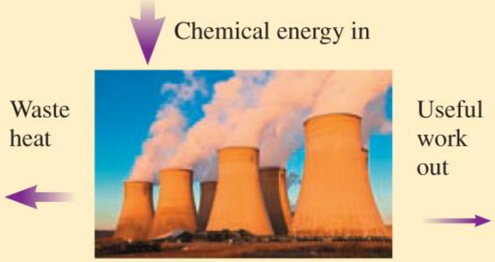

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