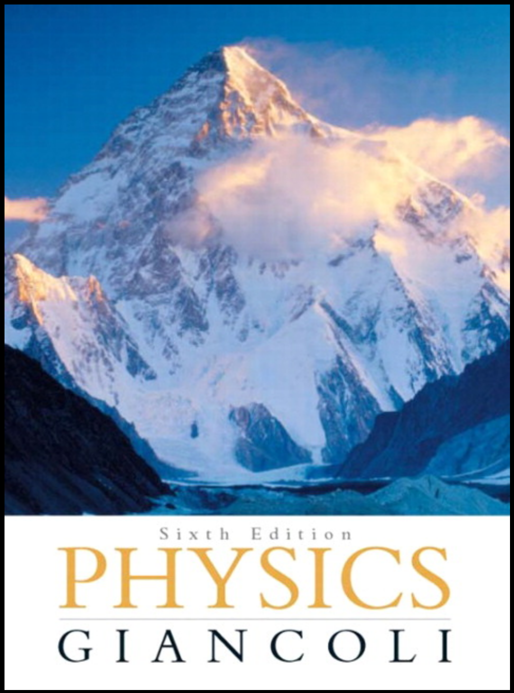


Lecture PowerPoints

Chapter 14

Physics: Principles with Applications, 6th edition

Giancoli

Chapter 14

Heat

Units of Chapter 14

- Heat As Energy Transfer
- Internal Energy
- Specific Heat
- Calorimetry – Solving Problems
- Latent Heat
- Heat Transfer: Conduction
- Heat Transfer: Convection
- Heat Transfer: Radiation

14-1 Heat As Energy Transfer

We often speak of **heat** as though it were a **material** that flows from one object to another; it is not. Rather, it is a form of **energy**.

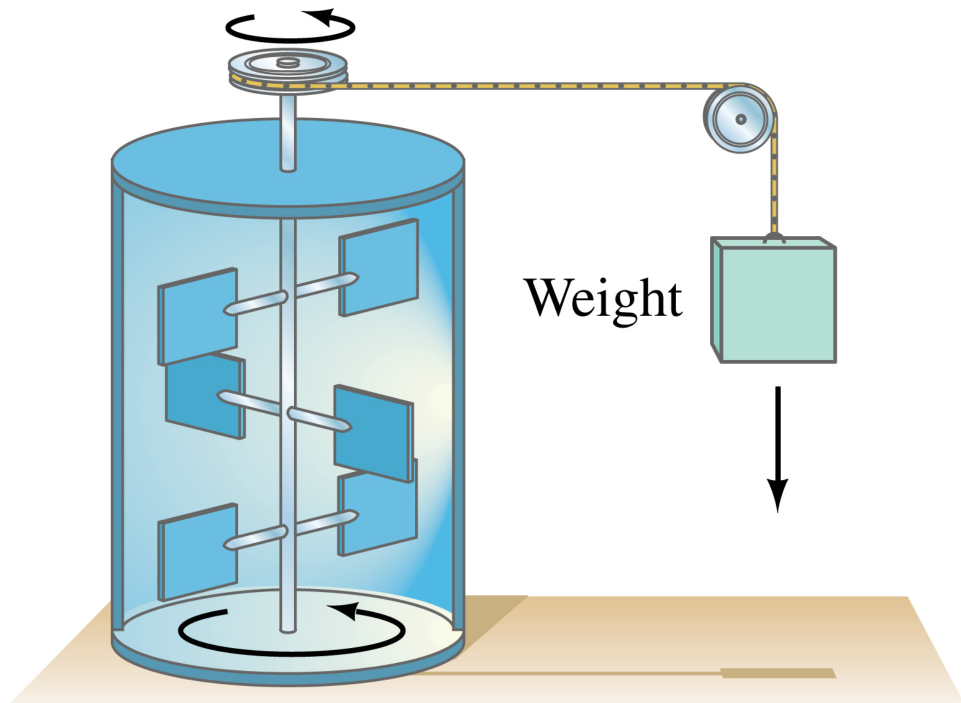
Unit of heat: **calorie** (cal)

1 **cal** is the amount of **heat** necessary to raise the **temperature** of 1 g of water by **1 Celsius degree**.

Don't be fooled – the calories on our food labels are really **kilocalories** (kcal or Calories), the heat necessary to raise 1 kg of water by 1 Celsius degree.

14-1 Heat As Energy Transfer

If **heat** is a form of **energy**, it ought to be possible to equate it to other forms. The experiment below found the **mechanical equivalent of heat** by using the falling weight to heat the water:



$$4.186\,\mathrm{J} = 1\,\mathrm{cal}$$

$$4.186\,\mathrm{kJ} = 1\,\mathrm{kcal}$$

14-1 Heat As Energy Transfer

Definition of heat:

Heat is energy transferred from one object to another because of a difference in temperature.

- **Remember that the temperature of a gas is a measure of the kinetic energy of its molecules.**

14-2 Internal Energy

The **sum total** of all the energy of all the molecules in a substance is its **internal** (or thermal) **energy**.

Temperature: measures molecules' average **kinetic energy**

Internal energy: **total** energy of all molecules

Heat: **transfer** of energy due to difference in temperature

14-2 Internal Energy

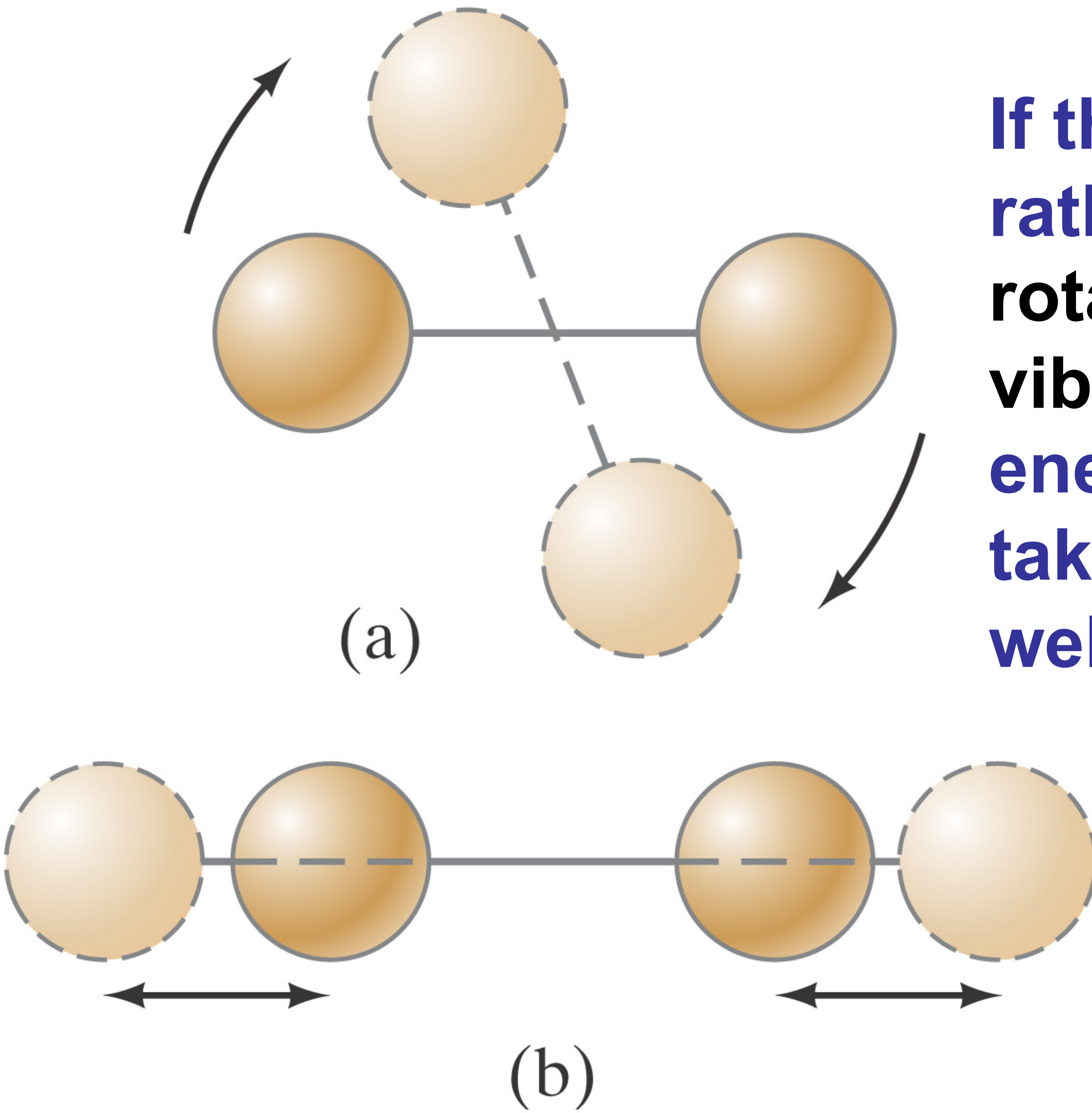
Internal energy of an **ideal** (atomic) gas:

$$U = N\left(\tfrac{1}{2} m\overline{v^2}\right)$$

But since we know the average kinetic energy in terms of the temperature, we can write:

$$U = \tfrac{3}{2} nRT \qquad \text{(14-1)}$$

14-2 Internal Energy



If the gas is **molecular** rather than **atomic**, **rotational** and **vibrational** kinetic energy needs to be taken into account as well.

14-3 Specific Heat

TABLE 14–1 Specific Heats
(at 1 atm constant pressure and 20°C unless otherwise stated)

Substance	Specific Heat, c: kcal/kg · C° (= cal/g · C°)	Specific Heat, c: J/kg · C°
Aluminum	0.22	900
Alcohol (ethyl)	0.58	2400
Copper	0.093	390
Glass	0.20	840
Iron or steel	0.11	450
Lead	0.031	130
Marble	0.21	860
Mercury	0.033	140
Silver	0.056	230
Wood	0.4	1700
Water		
Ice (−5°C)	0.50	2100
Liquid (15°C)	1.00	4186
Steam (110°C)	0.48	2010
Human body (average)	0.83	3470
Protein	0.4	1700

The amount of heat required to change the temperature of a material is proportional to the **mass** and to the **temperature change**:

$$Q = mc\,\Delta T \qquad \text{(14-2)}$$

The **specific heat**, c, is characteristic of the material. Some values are listed at left.

14-3 Specific Heat

Specific heats of **gases** are more complicated, and are generally measured at constant **pressure** (c_P) or constant **volume** (c_V).

Some sample values:

TABLE 14–2
Specific Heats of Gases
(kcal/kg · C°)

Gas	c_p (constant pressure)	c_v (constant volume)
Steam (100°C)	0.482	0.350
Oxygen	0.218	0.155
Helium	1.15	0.75
Carbon dioxide	0.199	0.153
Nitrogen	0.248	0.177

14-4 Calorimetry – Solving Problems

Closed system: **no mass** enters or leaves, but energy may be exchanged

Open system: mass may transfer as well

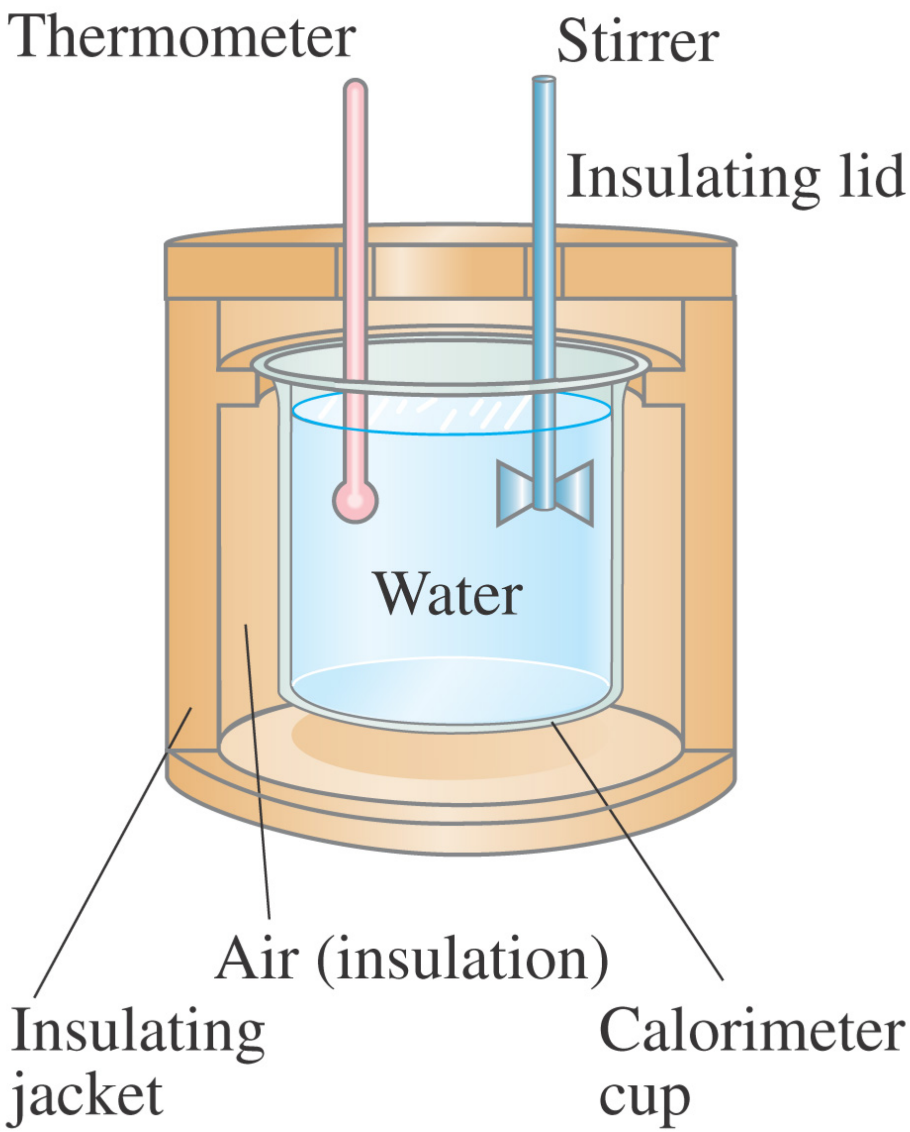
Isolated system: closed system where **no energy** in any form is transferred

For an isolated system,

Energy out of one part = energy into another part

Or: heat lost = heat gained

14-4 Calorimetry – Solving Problems



The instrument to the left is a calorimeter, which makes quantitative measurements of heat exchange. A sample is heated to a well-measured high temperature, plunged into the water, and the equilibrium temperature measured. This gives the specific heat of the sample.

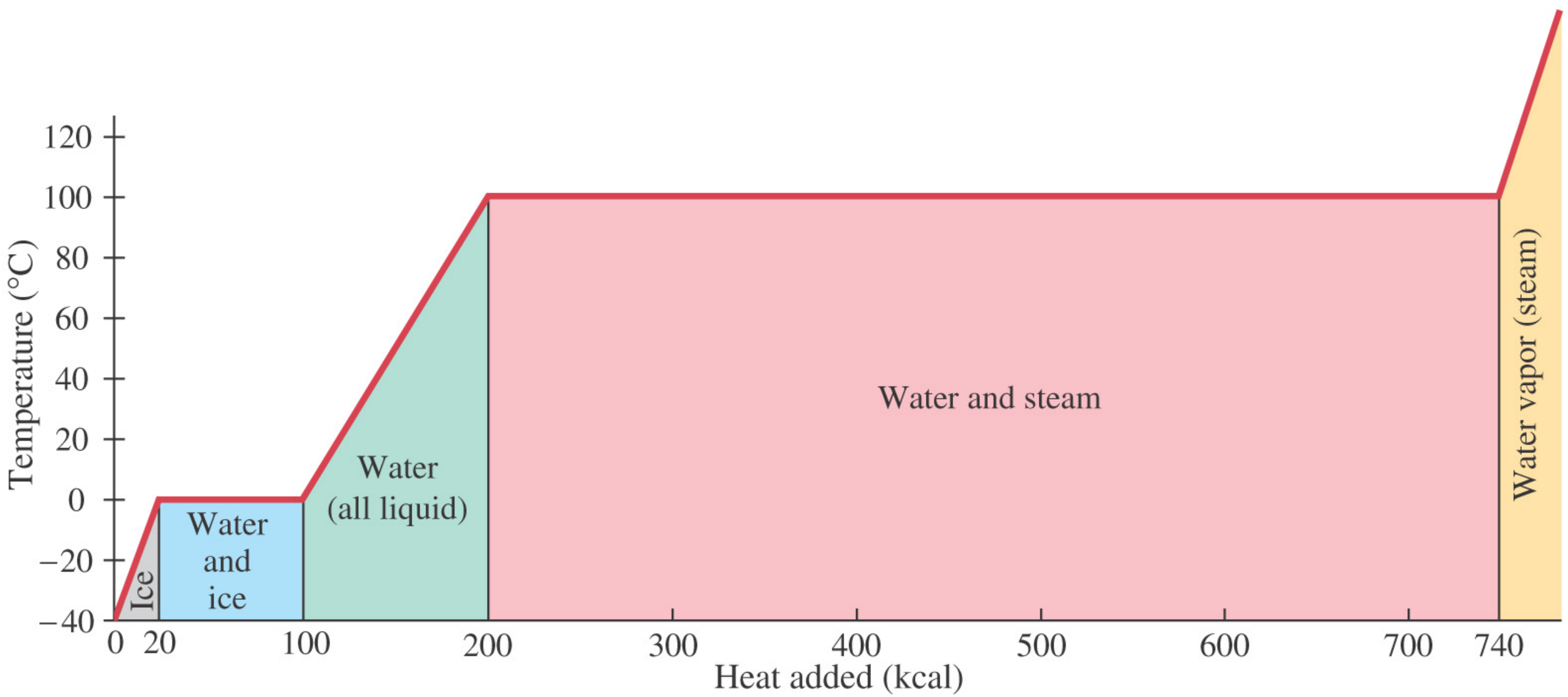
14-4 Calorimetry – Solving Problems

Another type of calorimeter is called a bomb calorimeter; it measures the thermal energy released when a substance burns.

This is the way the Caloric content of foods is measured.

14-5 Latent Heat

Energy is required for a material to change phase, even though its temperature is not changing.



14-5 Latent Heat

Heat of **fusion**, L_F: heat required to change 1.0 kg of material from solid to liquid

Heat of **vaporization**, L_V: heat required to change 1.0 kg of material from liquid to vapor

TABLE 14–3 Latent Heats (at 1 atm)

Substance	Melting Point (°C)	Heat of Fusion kcal/kg†	Heat of Fusion kJ/kg	Boiling Point (°C)	Heat of Vaporization kcal/kg†	Heat of Vaporization kJ/kg
Oxygen	−218.8	3.3	14	−183	51	210
Nitrogen	−210.0	6.1	26	−195.8	48	200
Ethyl alcohol	−114	25	104	78	204	850
Ammonia	−77.8	8.0	33	−33.4	33	137
Water	0	79.7	333	100	539	2260
Lead	327	5.9	25	1750	208	870
Silver	961	21	88	2193	558	2300
Iron	1808	69.1	289	3023	1520	6340
Tungsten	3410	44	184	5900	1150	4800

† Numerical values in kcal/kg are the same in cal/g.

14-5 Latent Heat

The **total** heat required for a phase change depends on the total **mass** and the **latent heat**:

$$Q = mL \qquad \text{(14-3)}$$

Problem Solving: Calorimetry

1. Is the system **isolated**? Are all significant sources of energy transfer **known** or **calculable**?

2. Apply **conservation** of energy.

3. If no phase changes occur, the heat transferred will depend on the **mass**, **specific heat**, and **temperature change**.

14-5 Latent Heat

4. If there are, or may be, phase changes, terms that depend on the mass and the latent heat may also be present. Determine or estimate what phase the final system will be in.

5. Make sure that each term is in the right place and that all the temperature changes are positive.

6. There is only one final temperature when the system reaches equilibrium.

7. Solve.

14-5 Latent Heat

The **latent heat of vaporization** is relevant for **evaporation** as well as **boiling**. The heat of vaporization of water rises slightly as the temperature decreases.

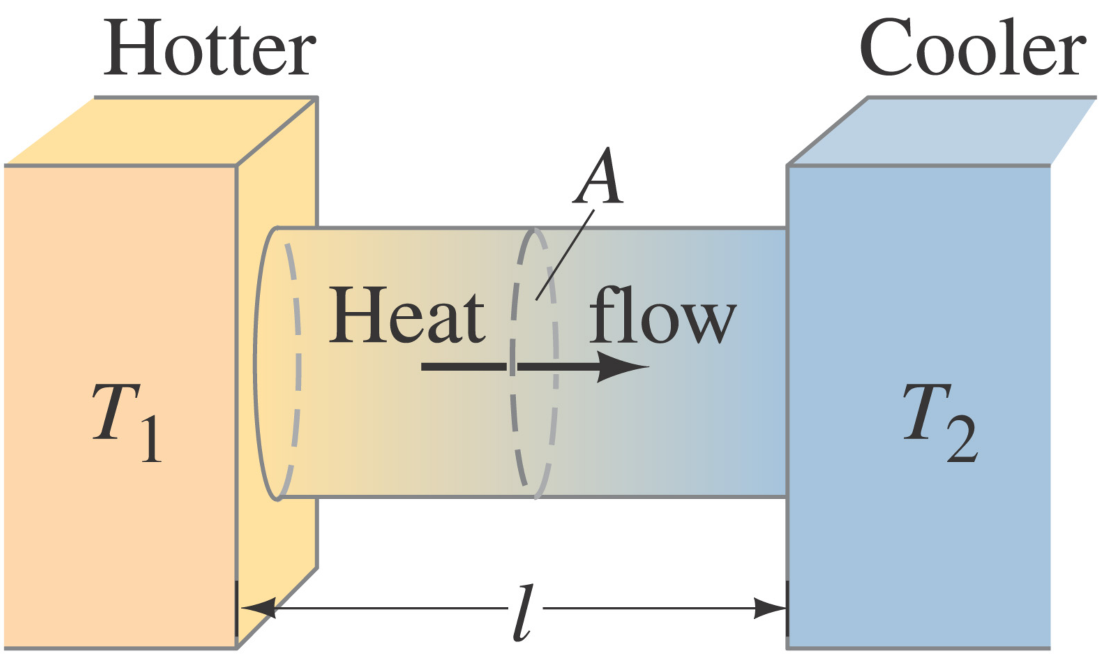
On a **molecular** level, the heat added during a change of state does not go to increasing the **kinetic energy** of individual molecules, but rather to break the close **bonds** between them so the next **phase** can occur.

14-6 Heat Transfer: Conduction

Heat **conduction** can be visualized as occurring through molecular **collisions**.

The **heat flow** per unit time is given by:

$$\frac{Q}{t} = kA\frac{T_1 - T_2}{l} \quad (14\text{-}4)$$



14-6 Heat Transfer: Conduction

TABLE 14–4
Thermal Conductivities

Substance	Thermal Conductivity, k $\frac{\text{kcal}}{(\text{s}\cdot\text{m}\cdot\text{C}^\circ)}$	Thermal Conductivity, k $\frac{\text{J}}{(\text{s}\cdot\text{m}\cdot\text{C}^\circ)}$
Silver	10×10^{-2}	420
Copper	9.2×10^{-2}	380
Aluminum	5.0×10^{-2}	200
Steel	1.1×10^{-2}	40
Ice	5×10^{-4}	2
Glass	2.0×10^{-4}	0.84
Brick	2.0×10^{-4}	0.84
Concrete	2.0×10^{-4}	0.84
Water	1.4×10^{-4}	0.56
Human tissue	0.5×10^{-4}	0.2
Wood	0.3×10^{-4}	0.1
Fiberglass	0.12×10^{-4}	0.048
Cork	0.1×10^{-4}	0.042
Wool	0.1×10^{-4}	0.040
Goose down	0.06×10^{-4}	0.025
Polyurethane	0.06×10^{-4}	0.024
Air	0.055×10^{-4}	0.023

The constant *k* is called the **thermal conductivity**.

Materials with large *k* are called **conductors**; those with small *k* are called **insulators**.

14-6 Heat Transfer: Conduction

Building materials are measured using *R* −values rather than thermal conductivity:

$$R = \frac{l}{k}$$

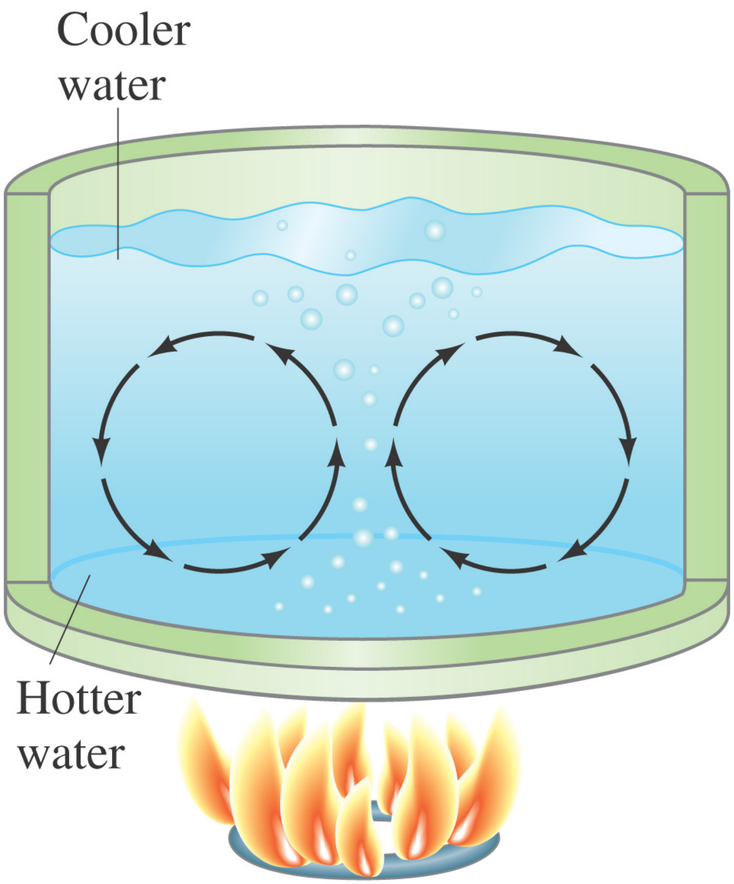
Here, *l* is the thickness of the material.

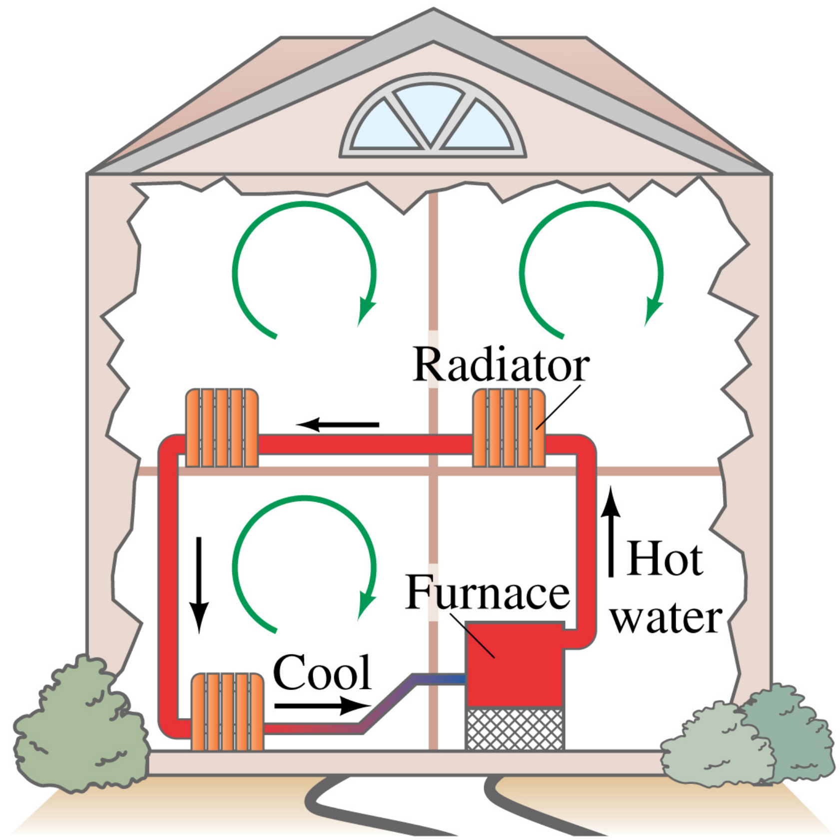
TABLE 14–5 *R*-values

Material	Thickness	*R*-value ($ft^2 \cdot h \cdot F°/Btu$)
Glass	$\frac{1}{8}$ inch	1
Brick	$3\frac{1}{2}$ inches	0.6–1
Plywood	$\frac{1}{2}$ inch	0.6
Fiberglass insulation	4 inches	12

14-7 Heat Transfer: Convection

Convection occurs when heat flows by the **mass movement** of molecules from one place to another. It may be **natural** or **forced**; both these examples are natural convection.





14-7 Heat Transfer: Convection

Many home heating systems are forced hot-air systems; these have a fan that blows the air out of registers, rather than relying completely on natural convection.

Our body temperature is regulated by the blood; it runs close to the surface of the skin and transfers heat. Once it reaches the surface of the skin, the heat is released through convection, evaporation, and radiation.

14-8 Heat Transfer: Radiation

The most familiar example of **radiation** is our own **Sun**, which radiates at a temperature of almost **6000 K**.

14-8 Heat Transfer: Radiation

The **energy** radiated has been found to be proportional to the **fourth** power of the temperature:

$$\frac{\Delta Q}{\Delta t} = e\sigma A T^4 \qquad (14\text{-}5)$$

The constant σ is called the **Stefan-Boltzmann** constant:

$$\sigma = 5.67 \times 10^{-8}\ \mathrm{W/m^2 \cdot K^4}$$

The **emissivity** e is a number between zero and one characterizing the surface; black objects have an emissivity near one, while shiny ones have an emissivity near zero.

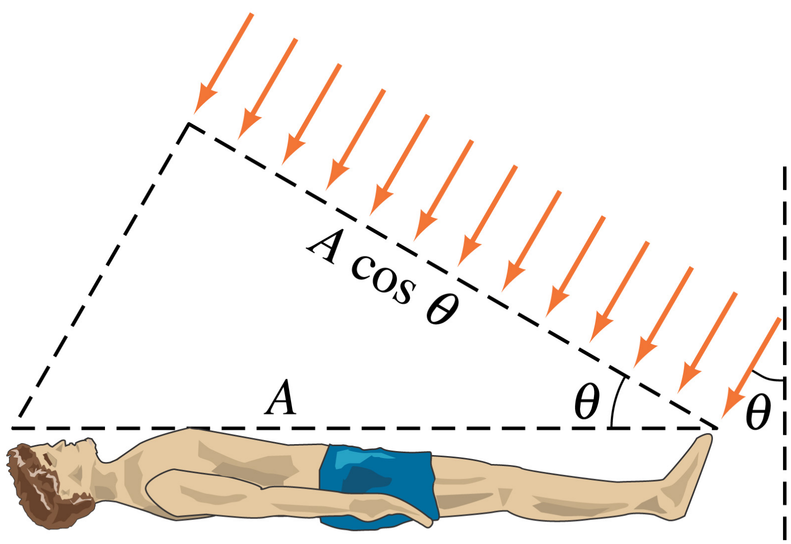
14-8 Heat Transfer: Radiation

If you are sitting in a place that is too **cold**, your body **radiates** more heat than it can produce. You will start **shivering** and your metabolic rate will **increase** unless you put on **warmer** clothing.

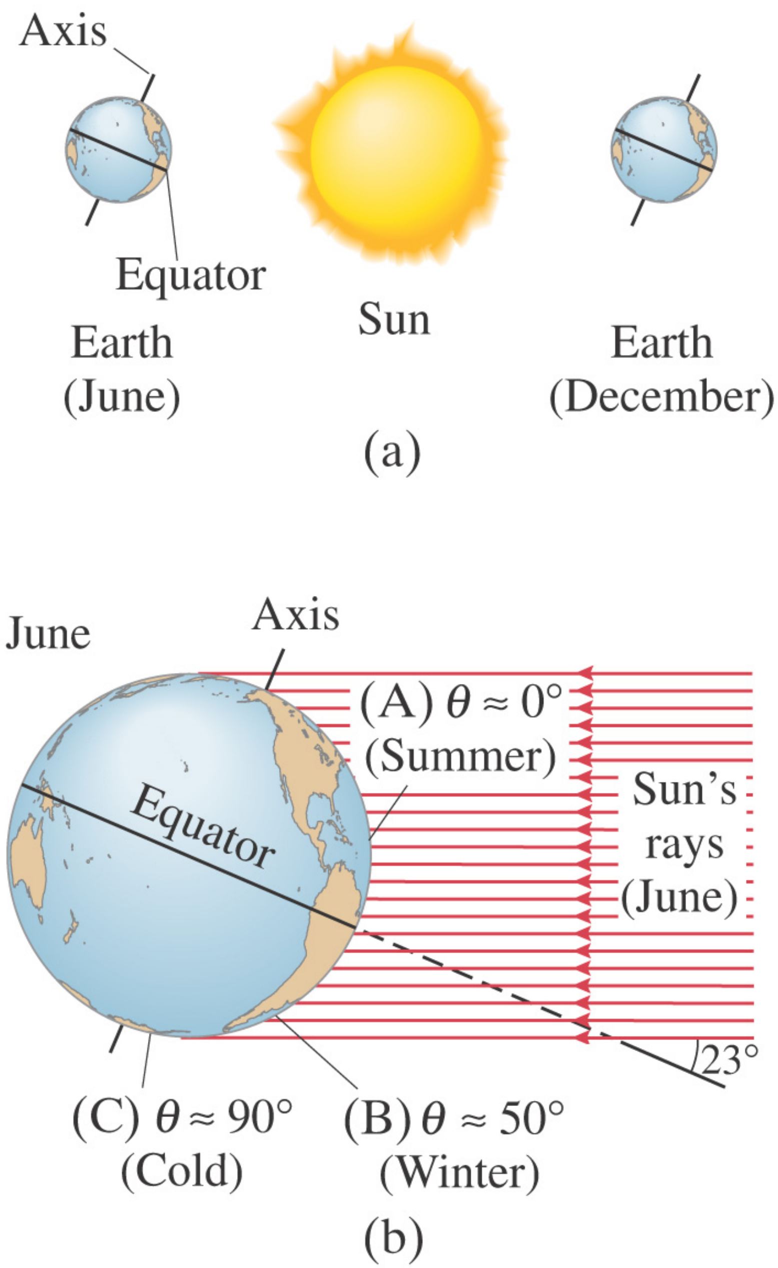
14-8 Heat Transfer: Radiation

If you are in the **sunlight**, the Sun's radiation will warm you. In general, you will not be perfectly perpendicular to the Sun's rays, and will absorb energy at the rate:

$$\frac{\Delta Q}{\Delta t} = \left(1000\ \mathrm{W/m^2}\right) e A \cos\theta \qquad \textbf{(14-6)}$$



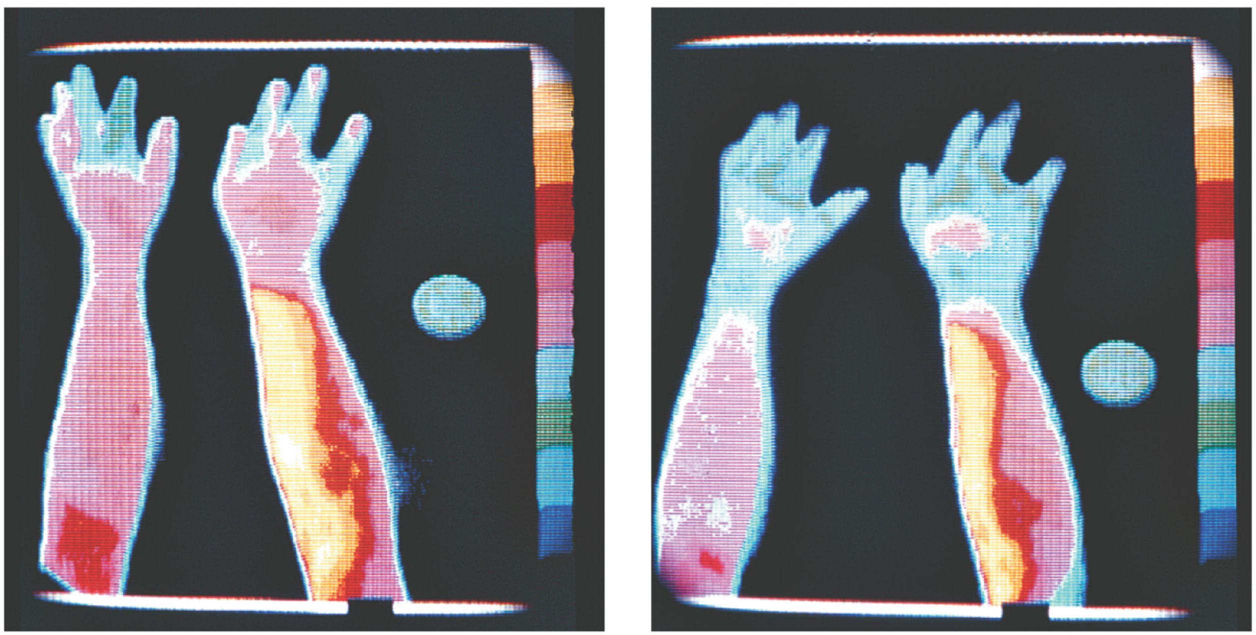
14-8 Heat Transfer: Radiation



This **cos θ** effect is also responsible for the **seasons**.

14-8 Heat Transfer: Radiation

Thermography – the detailed measurement of radiation from the body – can be used in medical imaging. Warmer areas may be a sign of **tumors** or **infection**; cooler areas on the skin may be a sign of **poor** circulation.



(a) (b)

Summary of Chapter 14

• Internal energy U refers to the total energy of all molecules in an object. For an ideal monatomic gas,

$$U = \frac{3}{2}NkT = \frac{3}{2}nRT$$

• Heat is the transfer of energy from one object to another due to a temperature difference. Heat can be measured in joules or in calories.

• Specific heat of a substance is the energy required to change the temperature of a fixed amount of matter by 1° C.

Summary of Chapter 14

- In an isolated system, heat gained by one part of the system must be lost by another.
- Calorimetry measures heat exchange quantitatively.
- Phase changes require energy even though the temperature does not change.
- Heat of fusion: amount of energy required to melt 1 kg of material.
- Heat of vaporization: amount of energy required to change 1 kg of material from liquid to vapor.

Summary of Chapter 14

- Heat transfer takes place by conduction, convection, and radiation.
- In conduction, energy is transferred through the collisions of molecules in the substance.
- In convection, bulk quantities of the substance flow to areas of different temperature.
- Radiation is the transfer of energy by electromagnetic waves.