Chapters 16

Temperature and Heat

Overview of Chapter 16

- Temperature and the Zeroth Law of Thermodynamics
- Temperature Scales
- Thermal Expansion
- Heat and Mechanical Work
- Specific Heat
- Conduction, Convection, and Radiation

16-1 Temperature and the Zeroth Law of Thermodynamics

Definition of heat:

Heat is the energy transferred between objects because of a temperature difference.

- Objects are in thermal contact if heat can flow between them…

- When the transfer of heat between objects in thermal contact ceases, they are in thermal equilibrium.

  - Have the same temperature…

16-1 Temperature and the Zeroth Law of Thermodynamics

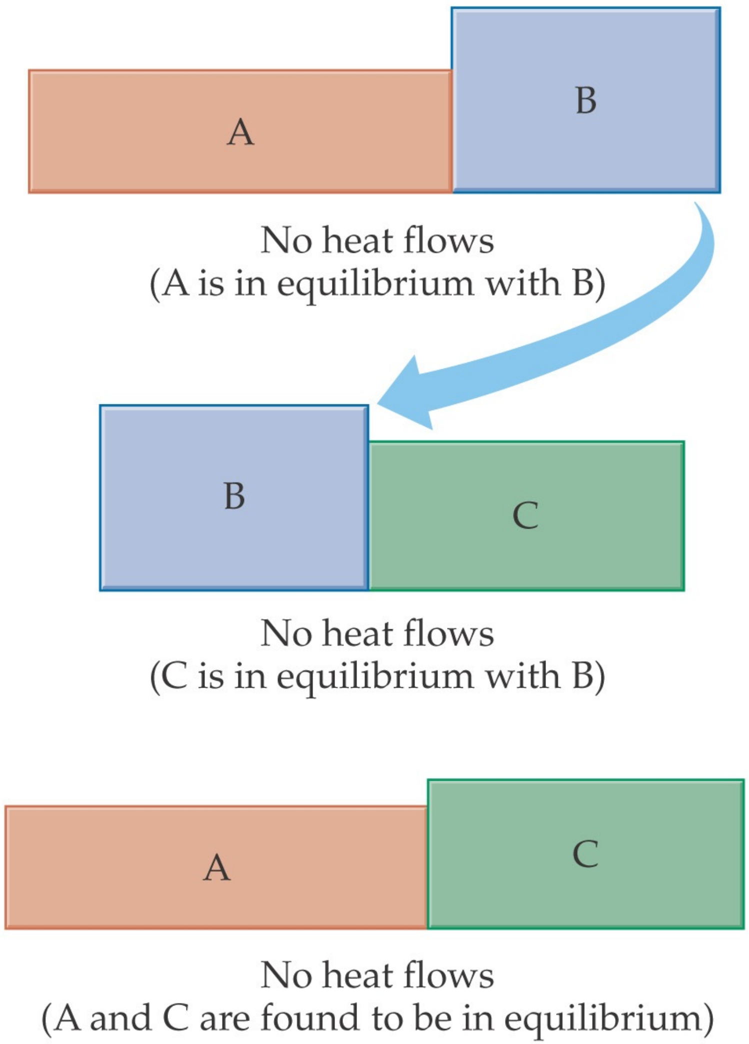
The zeroth law of thermodynamics:

- If object A is in thermal equilibrium with object B…
- Object C is also in thermal equilibrium with object B
- Objects A and C will be in thermal equilibrium if brought into thermal contact.

In short:

Temperature is the only factor that determines whether two objects are in thermal equilibrium…

16-1 Temperature and the Zeroth Law of Thermodynamics



All have the same Temperature!

16-2 Temperature Scales

The Celsius scale:

Water freezes at 0° Celsius.

Water boils at 100° Celsius.

The Fahrenheit scale:

Water freezes at 32° Fahrenheit…

Water boils at 212° Fahrenheit

16-2 Temperature Scales

Converting between Celsius and Fahrenheit:

$$T_F = \left(\tfrac{9}{5}\,\mathrm{F}^\circ/\mathrm{C}^\circ\right)T_C + 32\ ^\circ\mathrm{F}$$

Converting between Fahrenheit and Celsius :

$$T_C = \left(\tfrac{5}{9}\,\mathrm{C}^\circ/\mathrm{F}^\circ\right)\left(T_F - 32\ ^\circ\mathrm{F}\right)$$

16-2 Temperature Scales

- Kelvin scale is similar to the Celsius scale, except that the Kelvin scale has its zero at absolute zero.

- Conversion between a Celsius temperature and a Kelvin temperature:

$$T = T_C + 273.15$$

16-3 Thermal Expansion

Most substances expand when heated; the change in length or volume is typically proportional to the change in temperature.

The proportionality constant is called the coefficient of linear expansion.

Definition of Coefficient of Linear Expansion, α

$$\Delta L = \alpha L_0 \Delta T$$

SI unit for α: $K^{-1} = (C°)^{-1}$

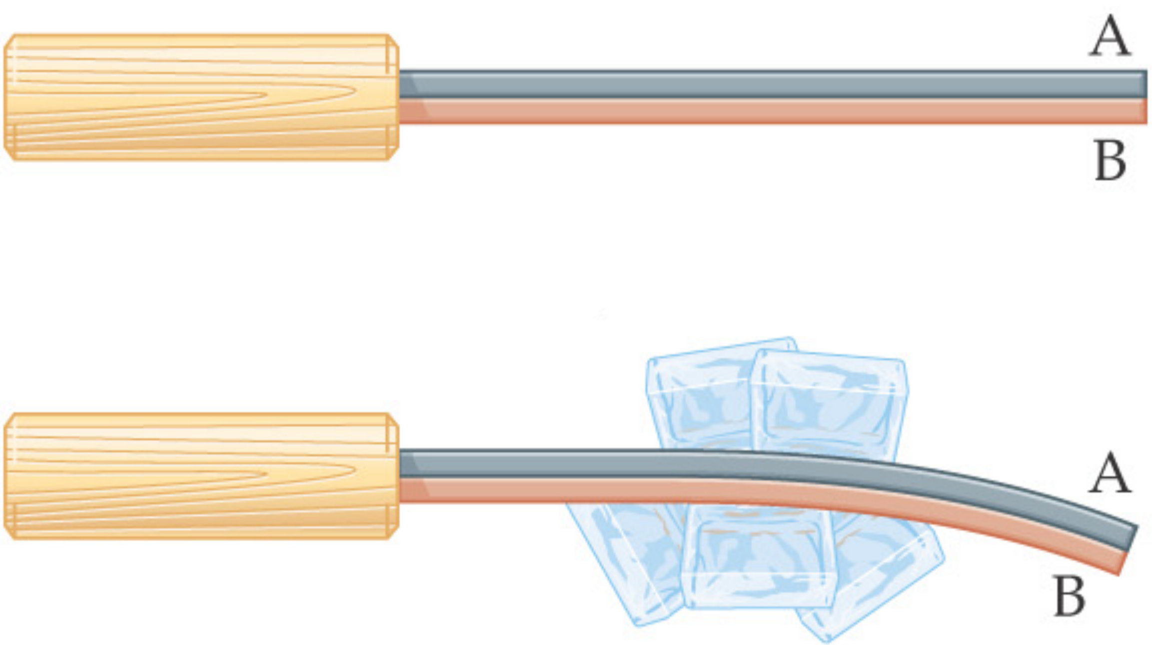
16-3 Thermal Expansion

Some typical coefficients of thermal expansion:

Substance	Coefficient of linear expansion, $\alpha (K^{-1})$
Lead	29×10^{-6}
Aluminum	24×10^{-6}
Brass	19×10^{-6}
Copper	17×10^{-6}
Iron (steel)	12×10^{-6}
Concrete	12×10^{-6}
Window glass	11×10^{-6}
Pyrex glass	3.3×10^{-6}
Quartz	0.50×10^{-6}

16-3 Thermal Expansion

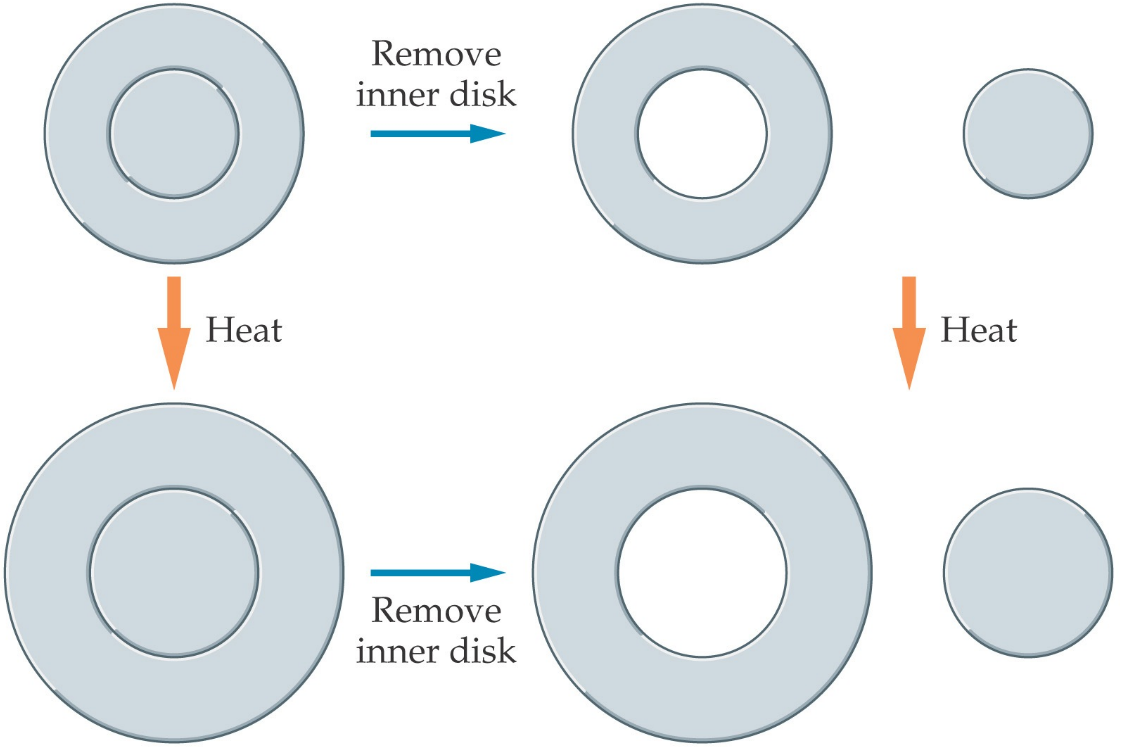
A bimetallic strip consists of two metals of different coefficients of thermal expansion, A and B in the figure. It will bend when heated or cooled.



16-3 Thermal Expansion

The expansion of an area of a flat substance is derived from the linear expansion in both directions:

$$\Delta A \approx 2\alpha A \Delta T$$



16-3 Thermal Expansion

The change in volume of a solid is also derived from the linear expansion:

$$\Delta V \approx 3\alpha V \Delta T$$

For liquids and gases, only the coefficient of volume expansion is defined:

Definition of Coefficient of Volume Expansion, β

$$\Delta V = \beta V \Delta T$$

SI unit for β: $K^{-1} = (C^{\circ})^{-1}$

16-3 Thermal Expansion

Some typical coefficients of volume expansion:

Substance	Coefficient of volume expansion, $\beta (K^{-1})$
Ether	1.51×10^{-3}
Carbon tetrachloride	1.18×10^{-3}
Alcohol	1.01×10^{-3}
Gasoline	0.95×10^{-3}
Olive oil	0.68×10^{-3}
Water	0.21×10^{-3}
Mercury	0.18×10^{-3}

16-4 Heat and Mechanical Work

- Experimental work has shown that heat is another form of energy.
- One kilocalorie (kcal) is defined as the amount of heat needed to raise the temperature of 1 kg of water from 14.5° C to 15.5° C.
- Mechanical equivalent is:

The Mechanical Equivalent of Heat

$$1 \text{ cal} = 4.186 \text{ J}$$

SI unit: J

16-5 Specific Heats

Heat capacity of an object is the amount of heat added to it divided by its rise in temperature:

Definition of Heat Capacity, *C*

$$C = \frac{Q}{\Delta T}$$

SI unit: $J/K = J/C°$

- Q is positive if ΔT is positive
  - Heat is added to a system.
- Q is negative if ΔT is negative
  - Heat is removed from a system.

16-5 Specific Heats

Heat capacity of an object depends on its mass. A quantity which is a property only of the material is the specific heat:

Definition of Specific Heat, *c*

$$c = \frac{Q}{m\Delta T}$$

SI unit: J/(kg · K) = J/(kg · C°)

16-5 Specific Heats

Here are some specific heats of various materials:

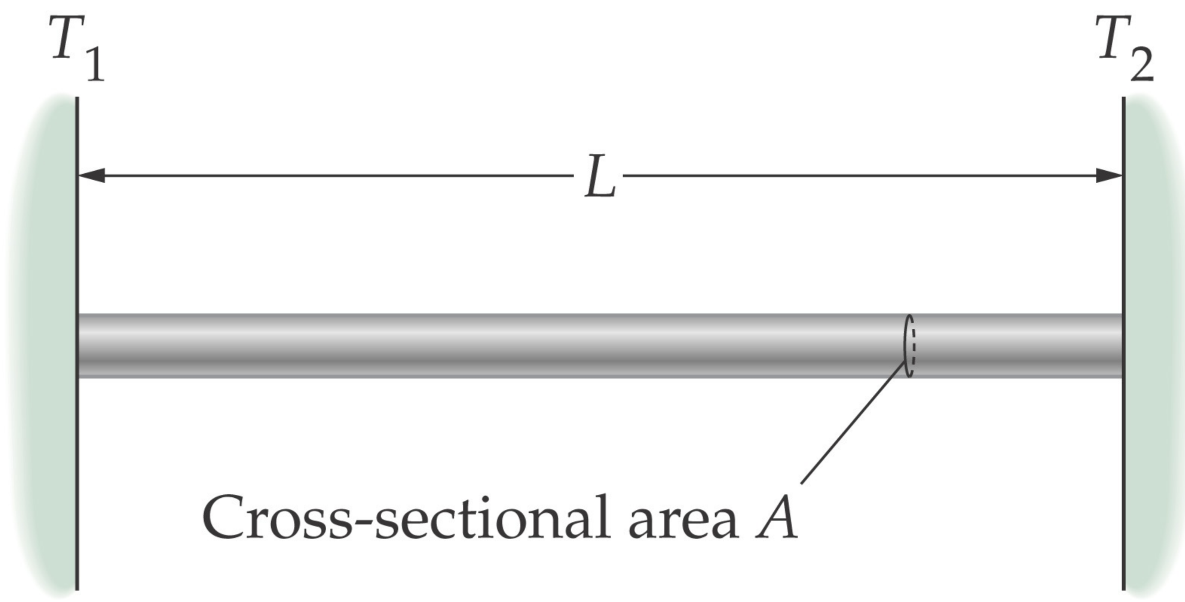
TABLE 16–2
Specific Heats at Atmospheric Pressure

Substance	Specific heat, $c\,[J/(kg \cdot K)]$
Water	4186
Ice	2090
Steam	2010
Beryllium	1820
Air	1004
Aluminum	900
Glass	837
Silicon	703
Iron (steel)	448
Copper	387
Silver	234
Gold	129
Lead	128

16-6 Conduction, Convection, and Radiation

Conduction, convection, and radiation are three ways that heat can be exchanged.

Conduction is the flow of heat directly through a physical material…



16-6 Conduction, Convection, and Radiation

Combining, we find:

Heat Flow by Conduction

$$Q = kA\left(\frac{\Delta T}{L}\right)t$$

The constant k is called the thermal conductivity of the rod.

16-6 Conduction, Convection, and Radiation

- Substances with high thermal conductivities are good conductors of heat…

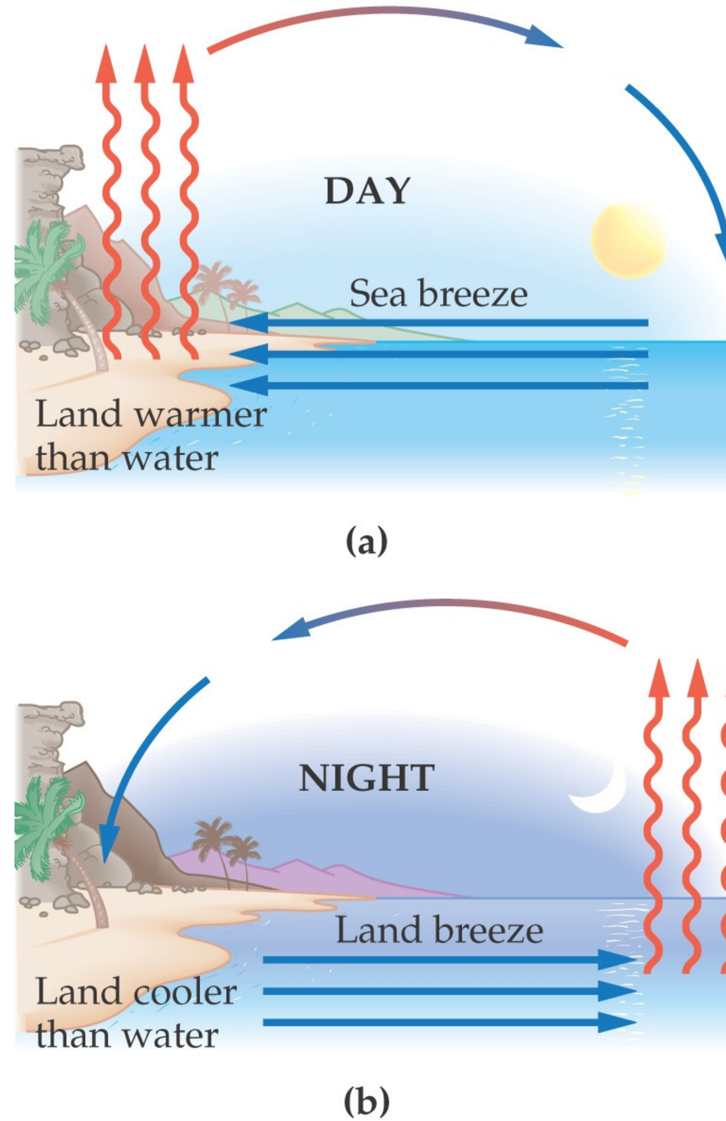
- Those with low thermal conductivities are good insulators…

TABLE 16–3 Thermal Conductivities

Substance	Thermal conductivity, $k[W/(m \cdot k)]$
Silver	417
Copper	395
Gold	291
Aluminum	217
Steel, low carbon	66.9
Lead	34.3
Stainless steel—alloy 302	16.3
Ice	1.6
Concrete	1.3
Glass	0.84
Water	0.60
Asbestos	0.25
Wood	0.10
Wool	0.040
Air	0.0234

16-6 Conduction, Convection, and Radiation

Convection is the flow of fluid due to a difference in temperatures, such as warm air rising. The fluid "carries" the heat with it as it moves….



16-6 Conduction, Convection, and Radiation

- All objects give off energy in the form of radiation, as electromagnetic waves
  - Infrared, visible light, ultraviolet…
  - Unlike conduction and convection, can transport heat through a vacuum.

- Amount of energy radiated by an object due to its temperature is proportional to:
  - Surface area
  - Fourth of temperature I.e. T^4

16-6 Conduction, Convection, and Radiation

Behavior is described by:

Stefan-Boltzmann Law for Radiated Power, *P*

$$P = e\sigma A T^4$$

SI unit: W

e is emissivity, and σ is Stefan-Boltzmann constant:

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

3. • Normal body temperature for humans is 98.6 °F. What is the corresponding temperature in **(a)** degrees Celsius and **(b)** kelvins?

Answer: a) 37 C

Answer: b) 310.2 K

22. •• Some cookware has a stainless steel interior ($\alpha = 17.3 \times 10^{-6}\ \text{K}^{-1}$) and a copper bottom ($\alpha = 17.0 \times 10^{-6}\ \text{K}^{-1}$) for better heat distribution. Suppose an 8.0-in. pot of this construction is heated to 610 °C on the stove. If the initial temperature of the pot is 22 °C, what is the difference in diameter change for the copper and the steel?

Answer: 0.0014 in

39. •• If 2200 J of heat are added to a 190-g object, its temperature increases by 12 C°. **(a)** What is the heat capacity of this object? **(b)** What is the object's specific heat?

Answer: 0.18 kJ/K

Answer: 0.96 kJ/(kg K)

40. •• An 97.6-g lead ball is dropped from rest from a height of 4.57 m. The collision between the ball and the ground is totally inelastic. Assuming all the ball's kinetic energy goes into heating the ball, find its change in temperature.

Answer: 0.35 K

49. • A glass window 0.35 cm thick measures 84 cm by 36 cm. How much heat flows through this window per minute if the inside and outside temperatures differ by 15 C°?

Answer: 653 J