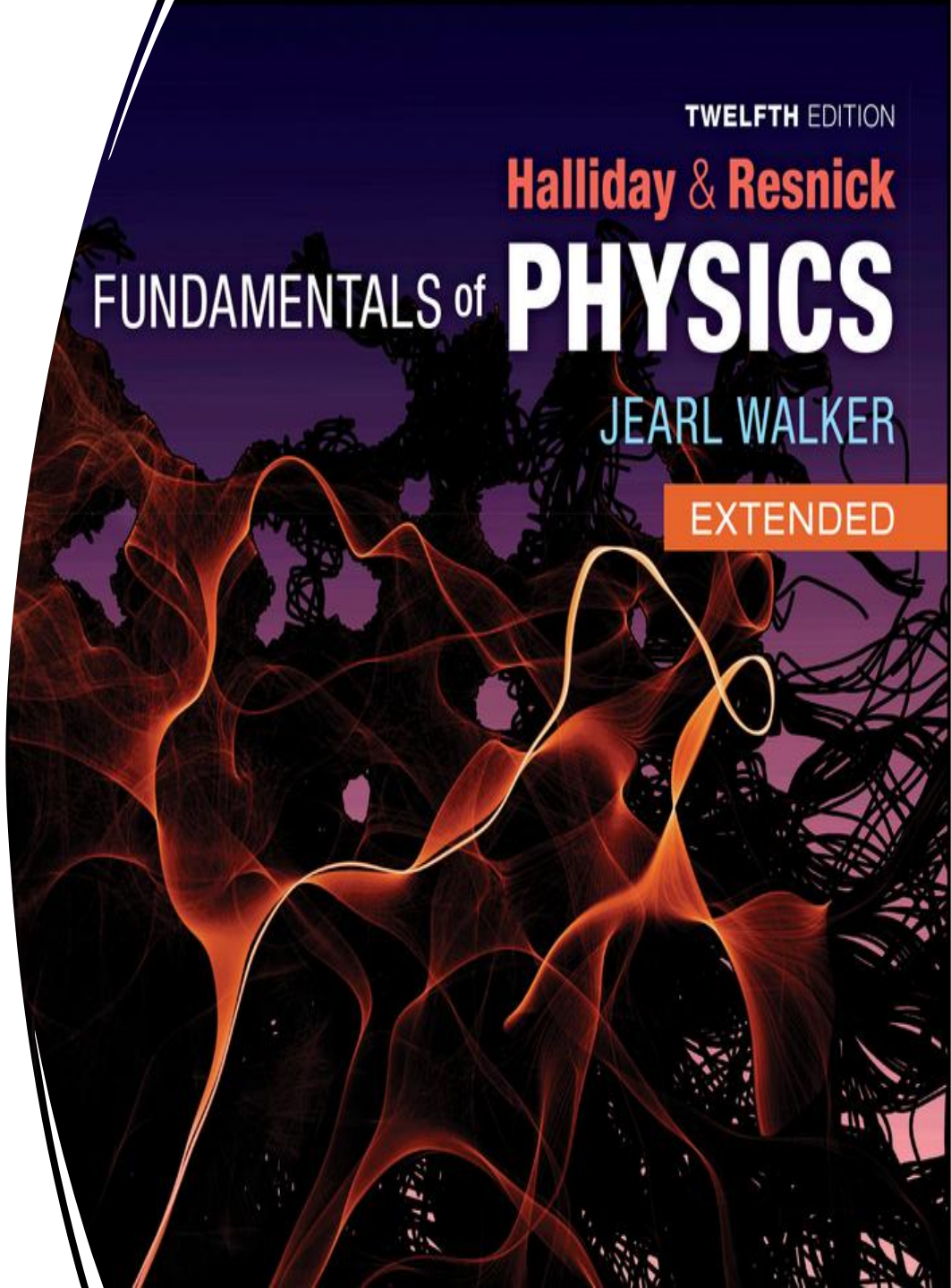
Chapter 18

Temperature, Heat, and the first Law of Thermodynamics



Units of Chapter 18

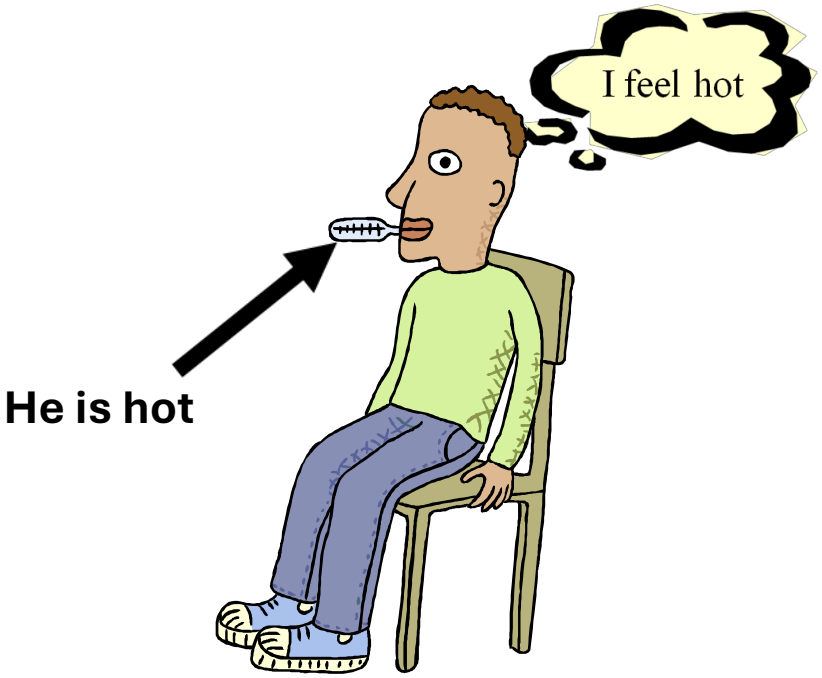
18.1. Temperature

18.2. The Celsius and Fahrenheit Scales

18.3 Thermal Expansion

18.1 Temperature





***Temperature*: it** is a quantity related to our sense of hot and cold. How hot or cold object is; hot or cold an object feels when we touch it.

Heat: is the energy transferred between objects because of temperature differences.

Thermal contact: objects in thermal contact if heat can flow between them.

Thermal equilibrium: Objects that are in thermal contact, but have no heat exchange between them, equilibrium with each other.

Temperature: is the quantity that determine whether two objects will be in thermal equilibrium.

18.2 The Celsius and Fahrenheit Scales

Celsius Scale:

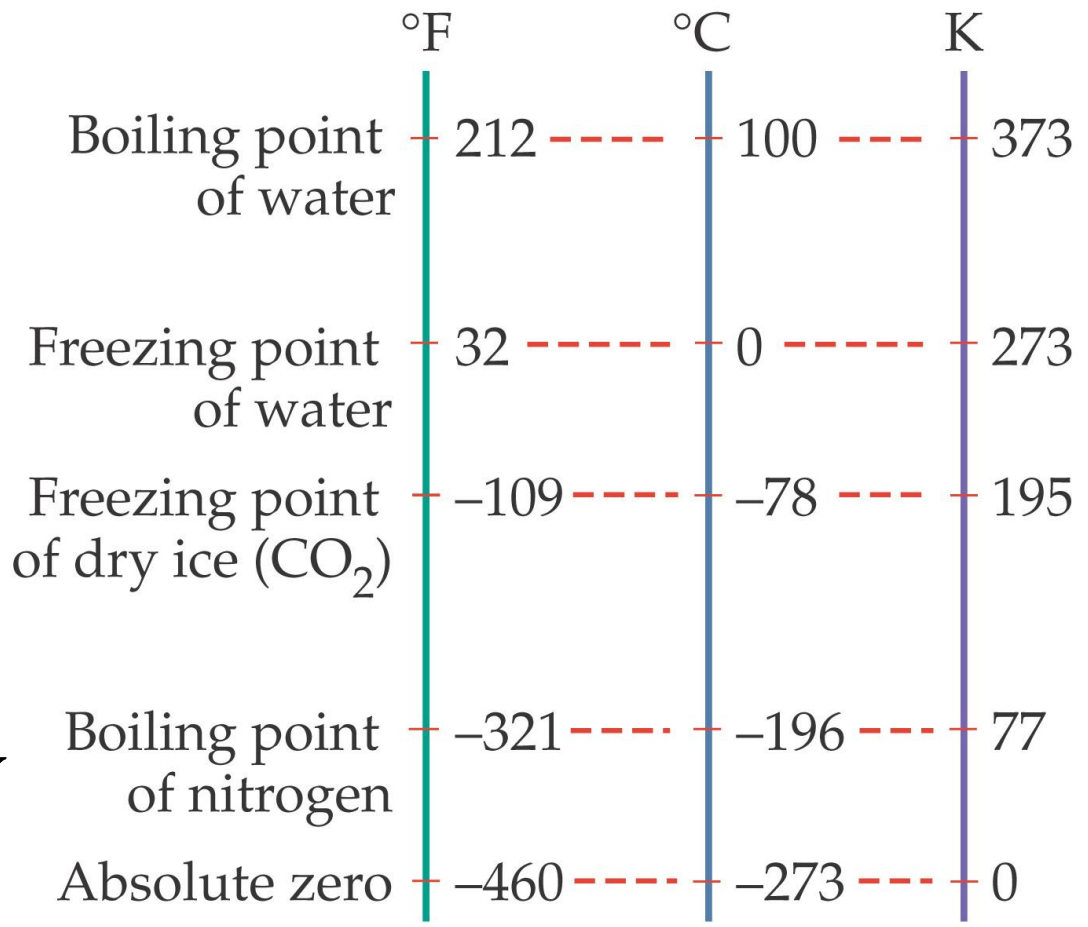
The water freezes at $\boldsymbol{0^oC}$ and boils at $\boldsymbol{100^oC}$

Fahrenheit Scale:

The water freezes at $\boldsymbol{32^oF}$ and boils at $\boldsymbol{212^oF}$

Kelvin Scale:

The water freezes at $\boldsymbol{273.15K}$ and boils at $\boldsymbol{373.15K}$



SI unit of absolute temperature is Kelvin (K)

Converting between Celsius and Fahrenheit:

$$T_{\mathrm{F}} = (\tfrac{9}{5}\mathrm{F}^\circ/\mathrm{C}^\circ)T_{\mathrm{C}} + 32\ ^\circ\mathrm{F}$$

Converting between Fahrenheit and Celsius :

$$T_{\mathrm{C}} = (\tfrac{5}{9}\mathrm{C}^\circ/\mathrm{F}^\circ)(T_{\mathrm{F}} - 32\ ^\circ\mathrm{F})$$

The 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:

$$T = T_{\mathrm{C}} + 273.15$$

EXAMPLE 1

1- On a fine spring day, you notice that the temperature is 75^0 F.
What is the corresponding temperature on the Celsius scale?

Answer : 24^0 C

Substitute $T_F = 75\ °F$ into Equation 16–2: $T_C = \frac{5}{9}(75 - 32) = 24\ °C$

2- If the temperature on the brisk winter morning is -2.00^oC, what is the corresponding Fahrenheit temperature?

Answer : 28^0 F

2. Substitute $T_C = -2.0\ °C$ in Equation 16–1: $T_F = \frac{9}{5}(-2.0) + 32 = 28\ °F$

3- Convert 55^0F to K ?

Answer: T= 286K

First, convert from °F to °C:

$$T_C = \frac{5}{9}(55 - 32) = 13\ °C$$

Next, convert °C to K:

$$T = 13 + 273.15 = 286\ K$$

18.3 Thermal Expansion

Most substances expand when heated; the change in length or volume is typically proportional to the change in temperature. For example: When the Concorde aircraft was built, the design had to allow for the thermal expansion of the fuselage during supersonic flight because of frictional heating by the passing air.



When a Concorde flew faster than the speed of sound, thermal expansion due to the rubbing by passing air increased the aircraft's length by about 12.5 cm. (The temperature increased to about 128°C at the aircraft nose and about 90°C at the tail, and cabin windows were noticeably warm to the touch.)

For example: power lines on a hot summer day hang low compared to their appearance on a cold day in winter.

The expansion of a liquid, such as mercury or alcohol



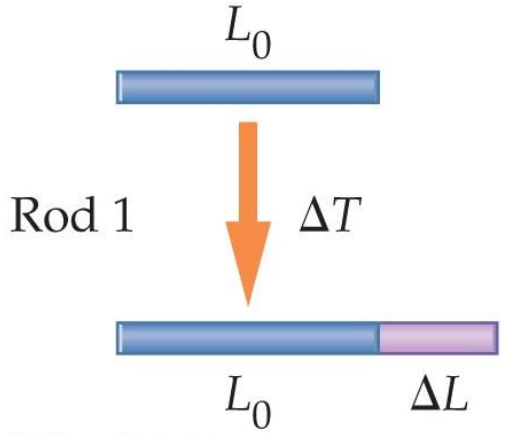


Linear Expansion

All objects change size with changes in temperature.

If the length of a rod is L_0 at Temperature T_0. For a temperature change ΔT, a change ΔL in any linear dimension L is given by

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



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in which α is the **coefficient of linear expansion**.

The coefficient α has the unit "per degree, $C°$" or "per kelvin, K" and depends on the material.

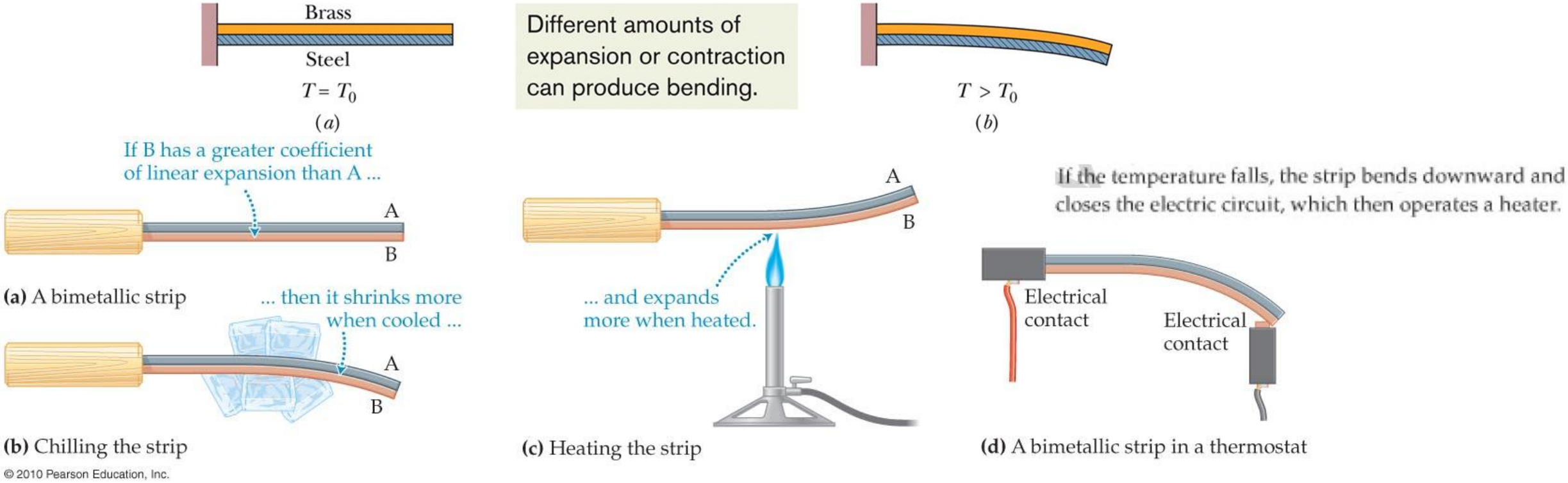
Some typical coefficients of thermal expansion:

Table 18.3.1 Some Coefficients of Linear Expansion[a]

Substance	α (10^{-6}/C°)
Ice (at 0°C)	51
Lead	29
Aluminum	23
Brass	19
Copper	17
Concrete	12
Steel	11
Glass (ordinary)	9
Glass (Pyrex)	3.2
Diamond	1.2
Invar[b]	0.7
Fused quartz	0.5

Bimetallic Strip Temperature Sensor

The strip bends as shown at temperatures above this reference temperature. Below the reference temperature the strip bends the other way. Many thermostats operate on this principle, making and breaking an electrical contact as the temperature rises and falls.

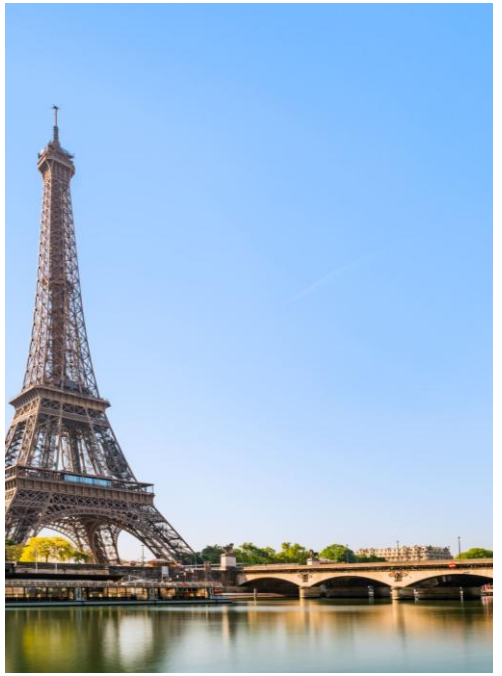


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it will shrink more when cooled

it will expand more when heated.

Example 2: The Eiffel tower constructed in 1889 by Alexandre Eiffel, is an impressive lattice work structure made of iron. If the tower is 301 m high on a 22^0C day, how much does its height decreases when the temperature cools to 0.0^0 C. Iron (12×10^{-6} K^{-1})



Answer: -7.9 cm

SOLUTION

We can calculate the change in height with Equation 16–4. Note that the coefficient of linear expansion for iron, given in Table 16–1, is $12 \times 10^{-6}\ \mathrm{K}^{-1}$ and the change in temperature is $\Delta T = -22\ \mathrm{C}^\circ = -22\ \mathrm{K}$:

$$\Delta L = \alpha L_0 \Delta T = (12 \times 10^{-6}\ \mathrm{K}^{-1})(301\ \mathrm{m})(-22\ \mathrm{K}) = -7.9\ \mathrm{cm}$$

Example 3: An aluminum flagpole is 33 m high. By how much does its length increase as the temperature increases by 15 C°? Aluminium (23×10^{-6} K^{-1})

The change in length for the aluminum pole is

$$\Delta \ell = \ell_0 \alpha_{Al} \Delta T = (33\ \mathrm{m})(23\times10^{-6}/\mathrm{C}^\circ)(15^\circ\mathrm{C}) = 0.011\ \mathrm{m}.$$

Volume Expansion

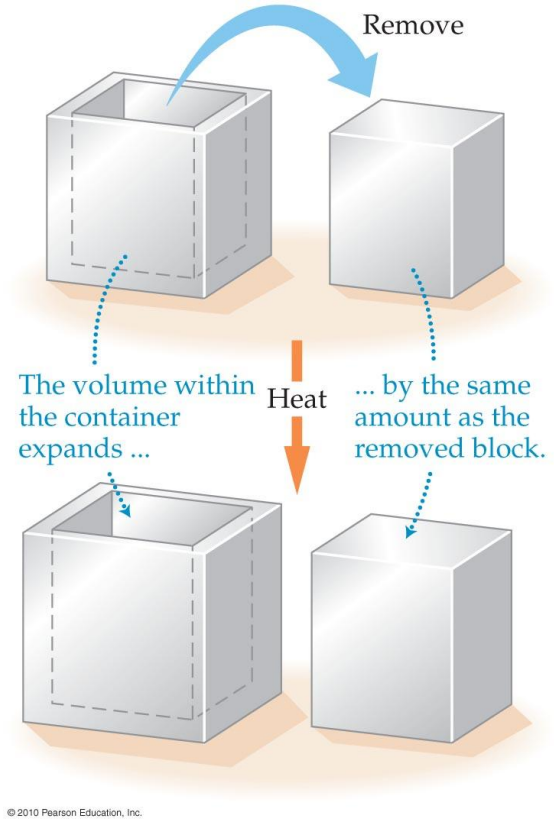
If the temperature of a solid or liquid whose volume is V is increased an amount ΔT, the increase in volume is found to be

$$\Delta V = \beta V_0 \Delta T$$

β is the **coefficient of volume expansion**

For the solids, coefficient of volume expansion three times the coefficient of linear expansion, in this way,

$$\beta = 3\alpha.$$



A portion of a cube is removed to create a container. When heated, the removed portion expands, just as the volume within the container expands.

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}

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}

Example 4: A copper flask with a volume of 150 cm^3 is filled to the brim with olive oil. If the temperature of the system is increased from 6°C to 31° C, how much oil spills from the flask in cm^3?

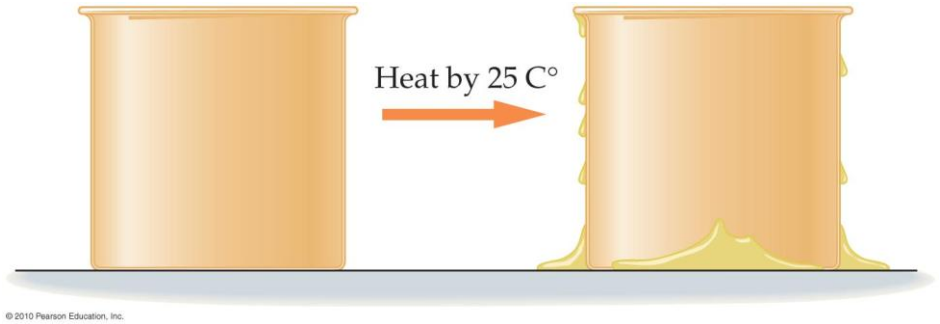
[$\beta_{oil} = 0.68 \times 10^{-3}\ K^{-1}$; $\alpha_{copper} = 17 \times 10^{-6}\ K^{-1}$]

Answers:

$\Delta V_{oil} = 2.6\ cm^3$

$\Delta V_{flask} = 0.19\ cm^3$

$\Delta V_{oil} - \Delta V_{flask} = 2.4\ cm^3$



SOLUTION

1. Calculate the change in volume of the olive oil:

$$\Delta V_{oil} = \beta V \Delta T$$
$$= (0.68 \times 10^{-3}\ K^{-1})(150\ cm^3)(25\ K) = 2.6\ cm^3$$

2. Calculate the change in volume of the flask:

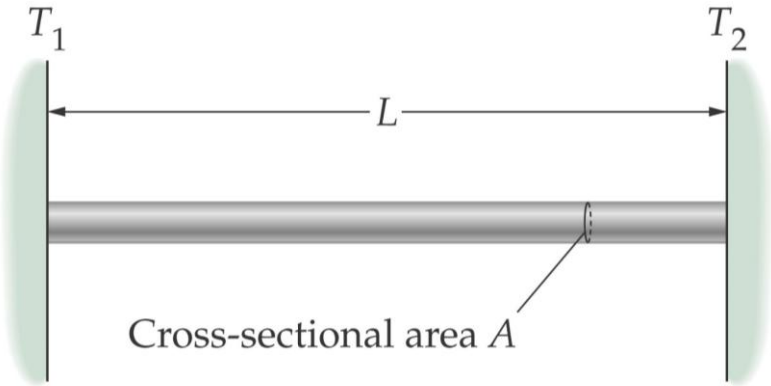
$$\Delta V_{flask} = 3\alpha V \Delta T$$
$$= 3(17 \times 10^{-6}\ K^{-1})(150\ cm^3)(25\ K) = 0.19\ cm^3$$

3. Find the difference in volume expansions. This is the volume of oil that spills out:

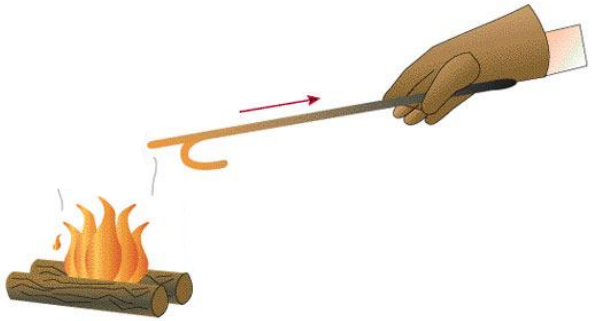
$$\Delta V_{oil} - \Delta V_{flask} = 2.6\ cm^3 - 0.19\ cm^3 = 2.4\ cm^3$$

Heat Transfer Mechanisms

Conduction

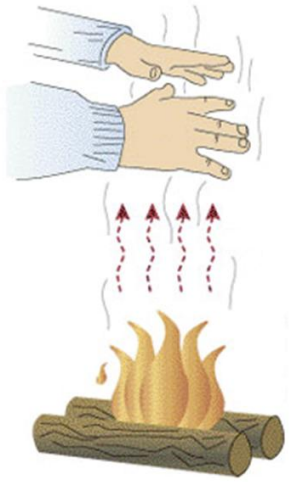


- ✓ Conduction is the flow of heat directly through a physical material.
- ✓ The transfer of heat on molecular/atomic level from one substance to another by direct contact.
- ✓ Conductors: conduct heat very well; such as metals
- ✓ Insulators: do not conduct heat (conduct heat poorly); such as wood, glass, ceramic, rubber
- ✓ The transfer is always from warmer to colder substances.
- ✓ A medium is necessary

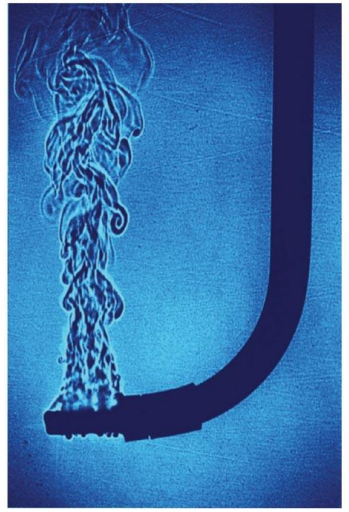


Convection

- ✓ Convection is the mass movement of molecules within fluids (i.e., liquids, gases).
- ✓ It cannot take place in solids.
- ✓ Needs a medium
- ✓ It 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.
- ✓Convection currents in (a) a gas (air) and (b) a liquid. Convection transfers heat vertically.



Example : We see this occurring when smoke from a fire rises and then settles off as it cools and its density matches that of the surrounding air.

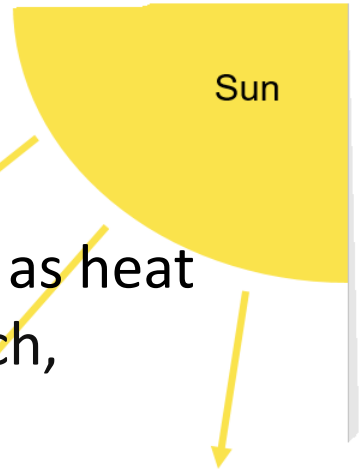


Example : The tip of a heater element submerged in water produces convection currents, which are revealed as shadows (caused by deflections of light in water of different temperatures).

Hot air travels upward by air convection. since air is a poor conductor, very little heat travels sideways to your fingers.



Radiation



- The third method by which an object and its environment can exchange energy as heat is via **electromagnetic waves** (infrared, visible light, ultraviolet) or photons which, unlike conduction and convection, can transport heat through a vacuum.
- Energy transferred in this way is often called **thermal radiation** to distinguish it from electromagnetic signals (as in, say, television broadcasts) and from nuclear radiation (energy and particles emitted by nuclei). (To "radiate" generally means to emit.)
- Energy that is radiated or transmitted in the form of rays or waves or particles.
- The energy transferred by radiation moves at the speed of light e.g., light, IR

- When you stand in front of a big fire, you are warmed by absorbing thermal radiation from the fire; that is, your thermal energy increases as the fire's thermal energy decreases.
- No medium is required for heat transfer via radiation—the radiation can travel through vacuum from, say, the Sun to you.

Chapter 18 Summary:

Celsius and Fahrenheit Scale

$$T_{\mathrm{C}} = T - 273.15^{\circ}$$

- The Celsius temperature scale is defined by
- The Fahrenheit temperature scale is defined by $T_{\mathrm{F}} = \frac{9}{5} T_{\mathrm{C}} + 32^{\circ}.$

Thermal Expansion

- Linear Expansion $\Delta L = L\alpha\ \Delta T,$

- Volume Expansion $\Delta V = V\beta\ \Delta T.$

Additional Exercises

- Lowest Temperature on Earth . The official record for the lowest temperature ever recorded on Earth was set at Vostok, Antarctica, on July 21,1983. The temperature on that day fell to -89.2 ^{o}C , well below the temperature of dry ice. What is this temperature in degrees Fahrenheit? Answer: –128.6 ^{o}F
- More than likely , there is a glowing incandescent lightbulb in your room at this moment. The filament of that bulb , with a temperature of about 4500 ^{o}F, is almost half as hot as the surface of the Sun. What is this temperature in degrees Celsius? Answer: 2500 ^{o}C
- Normal body temperature for humans is 98.6 oF. What is the corresponding temperature in
- **(a)** degrees Celsius and **(b)** kelvins Answer: 37 ^{o}C , 310.2 K
- What is the temperature 1.0 K on the Fahrenheit scale? Answer: – 458 ^{o}F
- The temperature at the surface of the Sun is about 6000 K. Convert this temperature to the:

(a) Celsius and **(b)** Fahrenheit scales. Answer: 5.7×10^{3} ^{o}C , 1×10^{4} ^{o}F

- Longest suspension Bridge . The World's longest suspension bridge is the Akashi Kaikyo Bridge in Japan . The bridge is 3910m long and is constructed of steel. How much longer is the bridge on a warm summer day (30 ^{o}C) than on a cold winter day (-5 ^{o}C) Answer: 1.6 m