Homework: 2, 3, 5, 6 (page 500)

2. (page 500) Two constant-volume gas thermometers are assembled, one with nitrogen and the other with hydrogen. Both contain enough gas so that p_3=80 kPa. (a) What is the difference between the pressures in the two thermometers if both bulbs are in boiling water? (b) Which gas is at higher pressure?

$$\frac{T}{p} = \frac{T_3}{p_3} \Rightarrow p = p_3 \times \frac{T}{T_3}$$

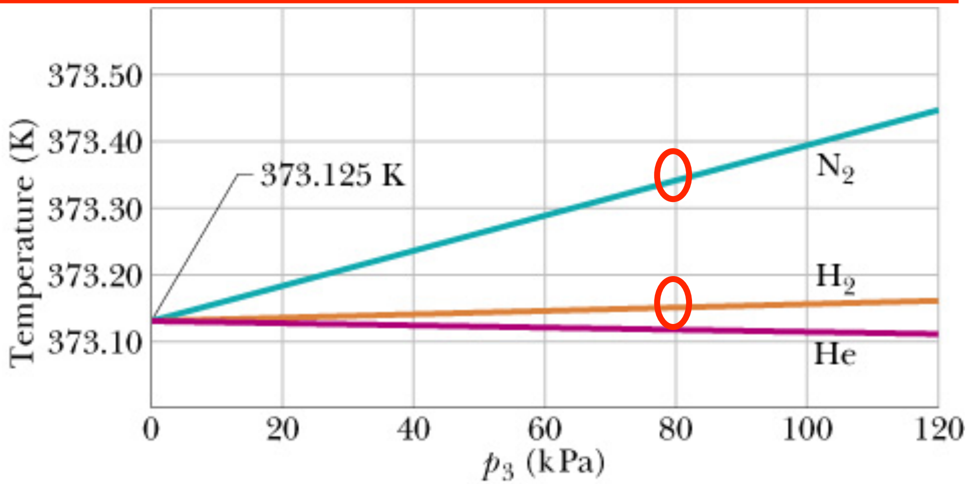


Fig. 18-6 (page 480)

(a) For the nitrogen thermometer:
$T_N \approx 373.35$ (K)

$$p_N = 80 \times \frac{373.35}{273.16} = 109.343 \text{ (kPa)}$$

For the hydrogen thermometer:
$T_H \approx 373.15$ (K)

$$p_H = 80 \times \frac{373.15}{273.16} = 109.284 \text{ (kPa)}$$

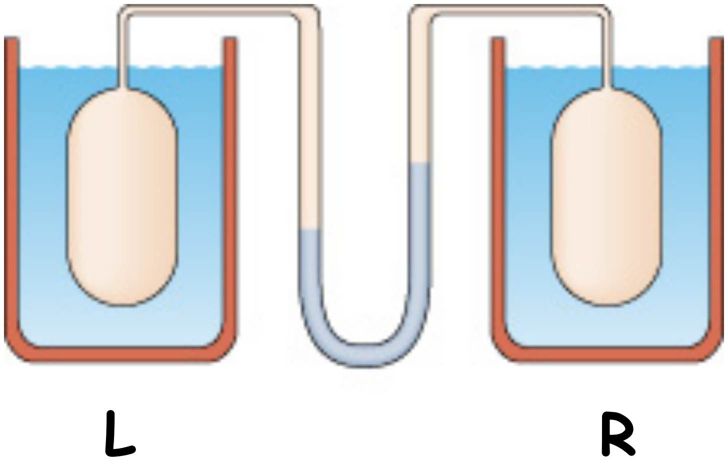
$$\Delta p = 0.059 \text{ kPa or } \Delta p = 59 \text{ Pa}$$

(b) $P_N > P_H$

3. A gas thermometer is constructed of two gas-containing bulbs, each in a water bath, as shown in the figure below. The pressure difference between the two bulbs is measured by a mercury manometer as shown. Appropriate reservoirs, not shown in the diagram, maintain constant gas volume in the two bulbs. There is no difference in pressure when both baths are at the triple point of water. The pressure difference is 120 torr when one bath is at the triple point and the other is at the boiling point of water. It is 90.0 torr when one bath is at the triple point and the other is at an unknown temperature to be measured. What is the unknown temperature?

$$\frac{T}{p} = \frac{T_3}{p_3} \Rightarrow p = p_3 \times \frac{T}{T_3}$$

$$p_L = p_3 \times \frac{T_L}{T_3}; \qquad p_R = p_3 \times \frac{T_R}{T_3}$$



- When one bath (L) is at the triple point and the other (R) is at the boiling point of water:

$$T_L = T_3 = 273.16\,(\mathrm{K}) \text{ and } p_L = p_3$$

$$T_R = T_{boiling} = 373.125\,(K)$$

$$p_R - p_L = p_3\left(\frac{T_R}{T_3} - 1\right)$$

• **When one bath (L) is at the triple point and the other (R) is at an unknown temperature X=T'$_R$:**

$$p_R^{'} - p_L = p_3\left(\frac{T_R^{'}}{T_3} - 1\right)$$

$$\Rightarrow \frac{p_R - p_L}{p_R^{'} - p_L} = \frac{T_R - T_3}{X - T_3} = \frac{120}{90}$$

$$\frac{373.125 - 273.16}{X - 273.16} = \frac{4}{3}$$

$$\boxed{X \approx 348\,(K)}$$

5. At what temperature is the Fahrenheit scale reading equal to (a) twice that of the Celsius scale and (b) half that of the Celsius scale?

$$\boxed{T_F = \frac{9}{5} T_C + 32^0}$$

$$T_F = 2T_C :$$

$$T_C = 160^0 C; T_F = 320^0 F$$

$$T_F = \frac{1}{2} T_C :$$

$$T_C \approx -24.6^0 C; T_F = -12.3^0 F$$

6. On a linear X temperature scale, water freezes at -125.0^0X and boils at 360.0^0X. On a linear Y temperature scale, water freezes at -70.0^0Y and boils at -30.0^0Y. A temperature of 50.0^0Y corresponds to what temperature on the X scale?

For linear scales, the relationship between X and Y can be written by:

$$y = ax + b$$

$$-70 = -125a + b$$

$$-30 = 360a + b$$

$$\Rightarrow a, b$$

$$x = \frac{y - b}{a} = 1330^0 X$$

Chapter 2 Heat, Temperature and the First Law of Thermodynamics

2.1. Temperature and the Zeroth Law of Thermodynamics

2.2. Thermal Expansion

2.3. Heat and the Absorption of Heat by Solids and Liquids

2.4. Work and Heat in Thermodynamic Processes

2.5. The First Law of Thermodynamics and Some Special Cases

2.6. Heat Transfer Mechanisms

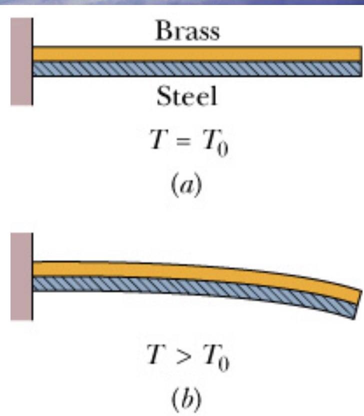
2.2. Thermal Expansion

The change in volume of materials in response to a change in temperature is called thermal expansion. Under the microscopic view as the temperature increases, the particles (atoms and molecules) jiggle more rapidly, atoms are pushed away from each other, leading to an expansion.

There are three types of thermal expansion:

128^0C

90^0C



A bimetal strip

- Linear expansion: (solids)

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

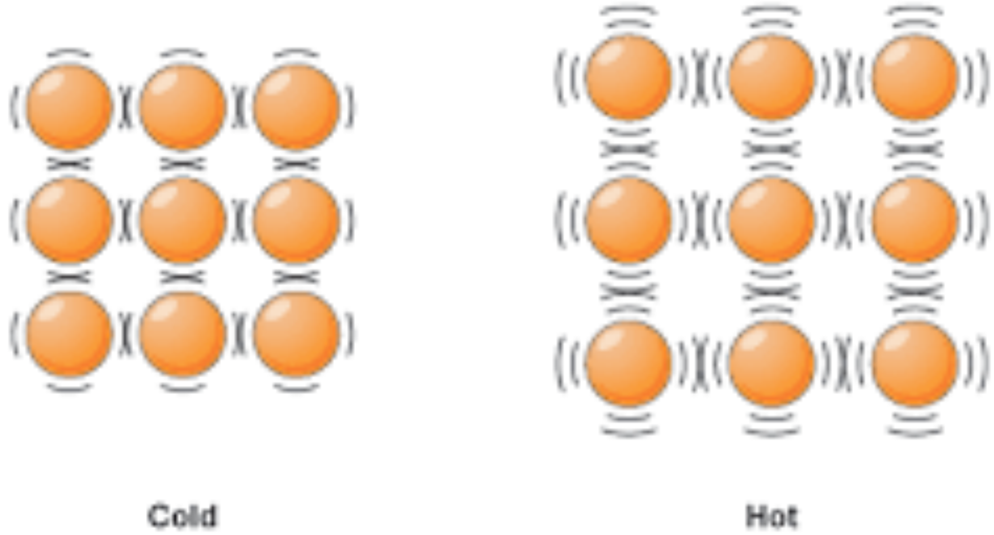
α: the coefficient of linear expansion
unit: $1/C^0$ or $1/K$

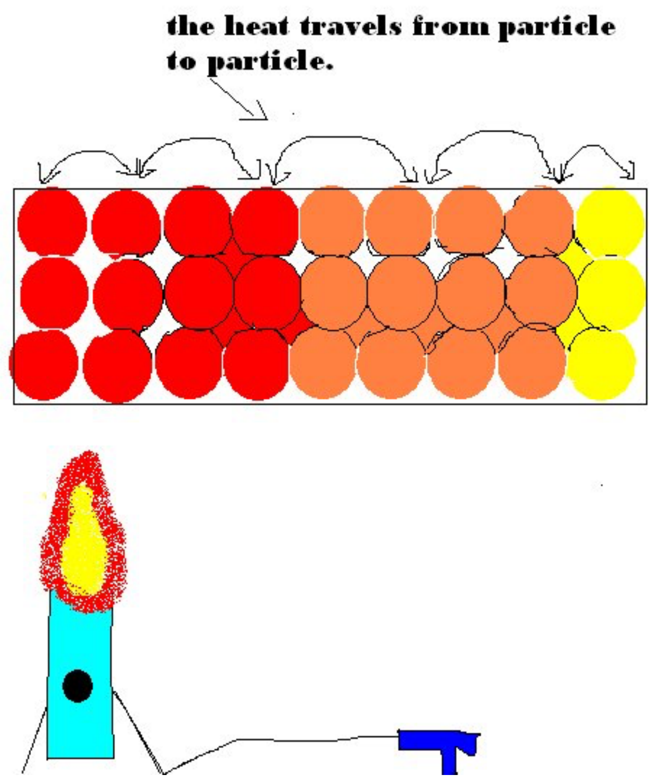
- Area expansion: (solids)

$$\Delta A = A\alpha_A\Delta T$$

α_A: the coefficient of area expansion

For isotropic materials: $\alpha_A = 2\,\alpha$


Cold
Hot


the heat travels from particle to particle.

- Volume expansion: (solids and liquids) → liquid has 3 dimensions

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

β: the coefficient of volume expansion

For isotropic materials: $\beta = 3\alpha$

$$\beta = \frac{1}{V}\frac{\partial V}{\partial T} = \frac{1}{L^3}\frac{\partial L^3}{\partial T} = \frac{1}{L^3}\frac{\partial L^3}{\partial L}\frac{\partial L}{\partial T} = 3\frac{1}{L}\frac{\partial L}{\partial T} = 3\alpha$$

- Special case of water:

+ $0^0C < T < 4^0C$: water contracts as the temperature increases.

+ $T > 4^0C$: water expands with increasing temperature.

+ The density of water is highest at about 4^0C.

- **Question:** The initial length L, change in temperature ΔL of four rods are given in the following table. Rank the rods according to their coefficients of thermal expansion, greatest first.

Rod	L (m)	ΔT (^0C)	ΔL (10^{-4}m)
a	2	10	4
b	1	20	4
c	2	10	8
d	4	5	4

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

$$\alpha = \frac{\Delta L}{L\Delta T}$$

- $L \times \Delta T$ is the same for all the 4 rods, in $10^{-5}/C^0$:

c: 4; a: 2; b: 2; d: 2

$$\Delta L^{\,m} = L^{\,m}\,\alpha^{\,1/C^0}\,\Delta T^{\,^0C}$$

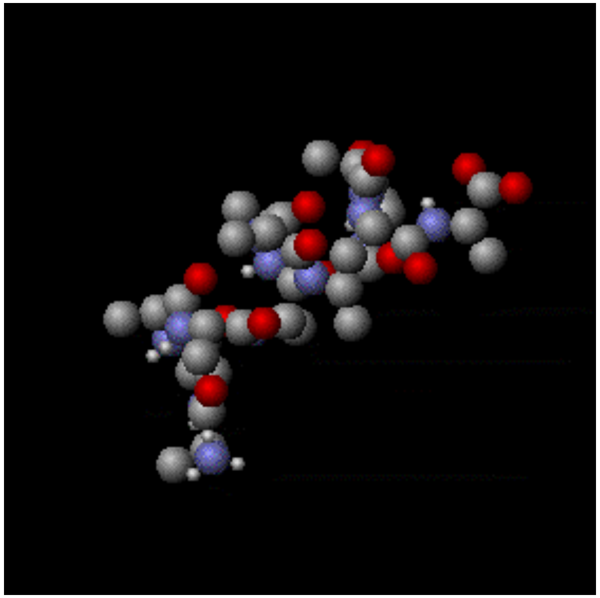
the change in length

initial length

2.3. Heat and the Absorption of Heat by Solids and Liquids

A. Temperature and Heat

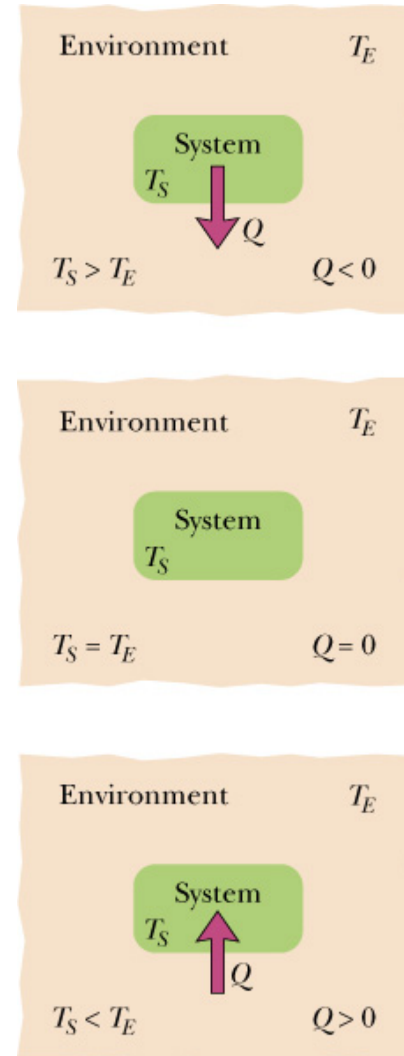
Recall: Thermal energy is an internal energy that consists of the kinetic and potential energies associated with the random motions of the atoms, molecules, and other microscopic bodies within an object.



Thermal motion of a segment of protein alpha helix.

Experiment: Leave a cup of hot coffee in a cool room → the temperature of the cup will fall until it reaches the room temperature.

- Heat (symbolized Q) is the energy transferred between a system and its environment because of a temperature difference that exists between them.



(a) (b) (c)

- $T_S > T_E$: energy transferred from the system to the environment, $Q<0$.

  $T_S < T_E$: system ← environment, $Q>0$.

  $T_S = T_E$: no transferred energy, $Q=0$.

<u>Unit:</u> -SI: joule (J); CGS: erg, 1 erg=1 $g.cm^2/s^2$

10^7 ergs = 1 joule

-calorie (cal): the amount of heat is needed to raise the temperature of 1 g of water from 14.5^0C 15.5^0C.

1 cal = 4.1868 J

1 food calorie = 1 kcal

B. The Absorption of Heat by Solids and Liquids

B1. Heat capacity: The heat capacity C of an object is the amount of energy needed to raise the temperature of the object by 1 degree.

$$Q = C\,\Delta T = C\,(T_f - T_i)$$

T_f and T_i are the final and initial temperatures of the object, respectively.
Unit: J/K or J/C^0; or cal/K or cal/C^0

B2. Specific Heat: The specific heat c of a material is the heat capacity of the material per unit mass.

$$Q = cm\,\Delta T = cm\,(T_f - T_i)$$

m: the mass of the object

Unit: $\dfrac{\text{cal}}{\text{g C}^0}$ or $\dfrac{\text{J}}{\text{kg K}}$

B3. Molar Specific Heat:

Why do we need to use the mole? In many instances, the mole is the most convenient unit for specifying the amount of a substance:

$$\boxed{1 \text{ mol} = 6.02 \times 10^{23} \text{ elementary units}}$$

- Elementary unit: atom or molecule

  Examples:

  1 mol of aluminum (Al) means 6.02×10^{23} atoms

  1 mol of aluminum oxide (Al_2O_3) means 6.02×10^{23} molecules

→ The molar specific heat is the heat capacity per mole.

B3. Heats of transformation:

- Phase change: When heat is absorbed or released by a solid, liquid, or gas, the temperature of the sample does not change but the sample may change from one phase (or state) to another.

- Three common states of matter: solid, liquid, gas (vapor).

- **melting**: solid → liquid; freezing is the reverse of melting
- **vaporizing**: liquid → gas (vapor); condensing is the reverse of vaporizing

The amount of energy per unit mass that is transferred as heat when a sample of mass m completely undergoes a phase change is called the heat of transformation L:

$$\boxed{Q = Lm}$$

Q is also called "latent heat"; L: specific latent heat
Latent means "hidden"

- Phase change from liquid to gas: the ***heat of vaporization*** L_V (or specific latent heat of vaporization)

- Phase change from solid to liquid: the ***heat of fusion*** L_F (or specific latent heat of fusion)

Sample Problem 18-8 (page 488):
(a) How much heat must be absorbed by ice of mass m=720 g at -10^{0}C to take it to liquid state at 15^{0}C?

•**Key idea:** heating process from -10^{0}C to 0^{0}C, then melting of all the ice, and finally heating of water from 0^{0}C to 15^{0}C.

•First, we compute the heat Q_1 needed to increase the ice temperature from -10^{0}C to the melting point of water (0^{0}C):

$$Q_1 = c_{ice} m (T_f - T_{init})$$

c_{ice}: the specific heat of ice, 2220 J kg^{-1} K^{-1} (see Table 18-3)

$$Q_1 \approx 15.98 \text{ kJ}$$

•Second, the heat Q_2 is needed to completely melt the ice:

$$Q_2 = L_F m$$

L_F: the heat of fusion of ice, 333 kJ kg^{-1} (see Table 18-4)

$$Q_2 \approx 239.8 \text{ kJ}$$

•Finally, the heat Q_3 is needed to increase the liquid water of 0^0C to 15^0C:

$$Q_3 = c_{liquid} m (T_f^{'} - T_{init})$$

c_{liquid}: the specific heat of water, 4190 J kg^{-1} K^{-1} (see Table 18-3)

$$Q_3 \approx 45.25 \text{ kJ}$$

(b) If we supply the ice with a total energy of only 210 kJ (as heat), what then are the final state and temperature of the water?

$$Q_1 < Q_{supply} < Q_1 + Q_2$$

→The final state is a mixture of ice and liquid, the mass of water m_{water} (=the mass of melted ice) is:

$$m_{water} = \frac{Q_{supply} - Q_1}{L_F}$$

$$m_{water} \approx 583 \text{ g}$$

→The mass of remaining ice: 137 g

→The temperature of the mixture is 0^0C

Homework: 10, 11, 15, 19, 21 (pages 500-501)

25, 29, 30, 32 (page 501)