Chapter 18

Chapter 18 Key Words

Thermodynamics
Thermometer 温度计
Temperature
Triple point
Calibration 刻度
Thermal equilibrium
Vapor
Constant-volume gas thermometer
Mercury
Ideal gas temperature
Kelvin scale
Celsius scale
Fahrenheit scale
Thermal expansion
Linear expansion
Volume expansion
Calorie

Heat Capacity
Specific heat
Vaporize 蒸发
Melt
Heat of vaporization
Heat of fusion
Adiabatic processes
Constant-volume processes
Cyclical processes
Free expansions
Conduction
Thermal conductivity
Thermal insulator 绝热
Thermal Resistance 热阻
Convection
Thermal radiation

Chapter 18 Temperature Scales and Thermal Expansion

Temperature Scales:

$$\left.\begin{array}{l}\text{Kelvin scale: } T \\ \text{Celsius scale: } T_C \\ \text{Fahrenheit scale: } T_F\end{array}\right\} \quad T_C = T - 273.15°, \quad T_F = \frac{9}{5} T_C + 32°$$

Thermal Expansion :

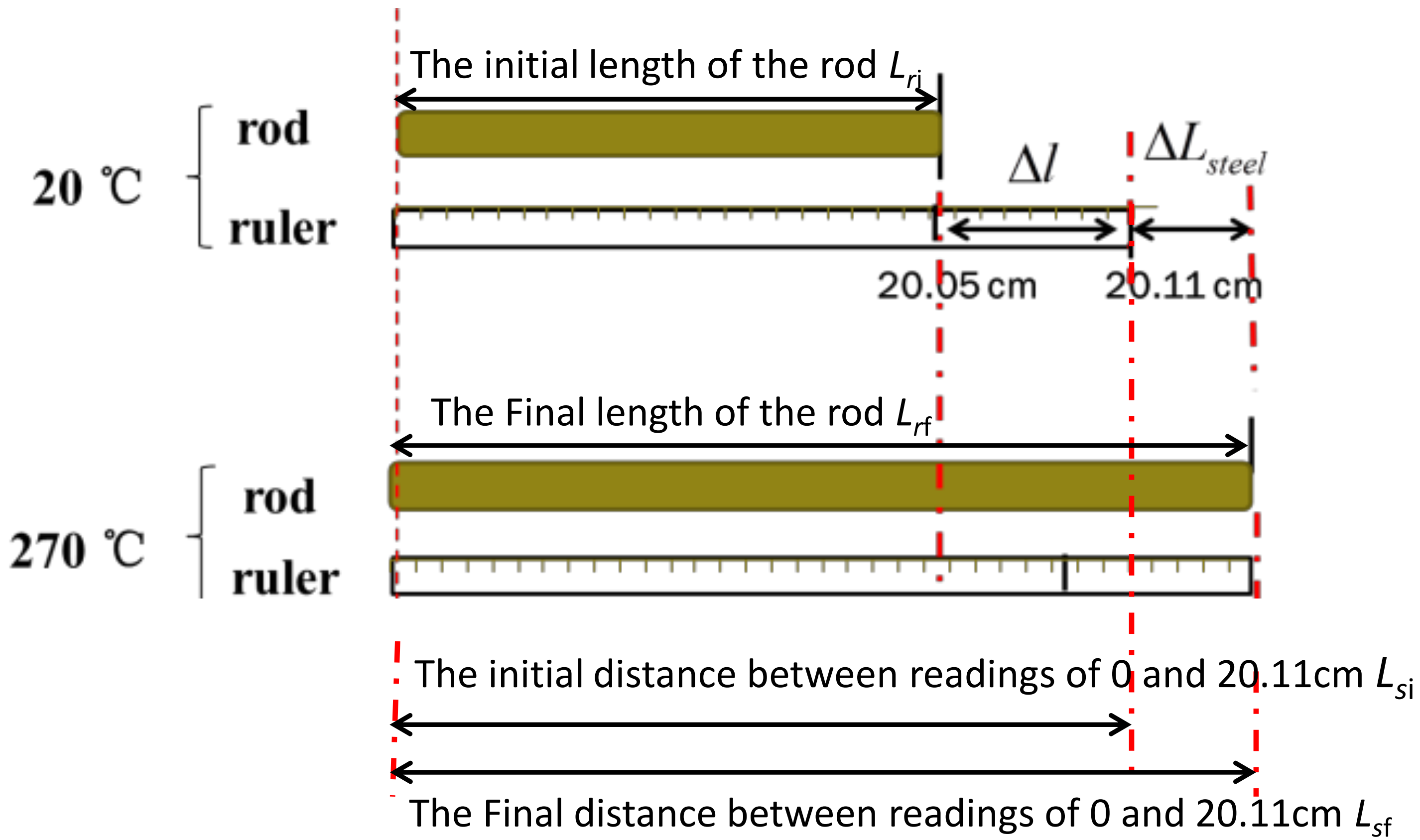
$$\left.\begin{array}{l}\text{Linear expansion: } \Delta L = L\alpha\Delta T \\ \text{Volume expansion: } \Delta V = V\beta\Delta T\end{array}\right\} \beta = 3\alpha$$

Chapter 18 Tutorial Problem 1

At 20°C, a rod is exactly 20.05 cm long on a steel ruler. Both the rod and the ruler are placed in an oven at 270 °C,where the rod now measures 20.11 cm on the same ruler. $\alpha_{steel} = 11\times 10^{-6}\ /\ {}^{\circ}C$

What is the coefficient of linear expansion for the material of which the rod is made?

Chapter 18 Tutorial Problem 1



$$L_{rod,f} - L_{rod,i} = \Delta L_{rod} = L_{rod,i}\alpha_r \Delta T \Rightarrow L_{rod,f} = L_{rod,i}(1+\alpha_r\Delta T) = L_{20.05}(1+\alpha_r\Delta T)$$

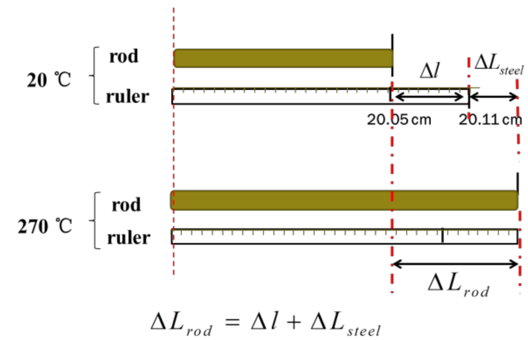
$$L_{20.11,f} - L_{20.11,i} = \Delta L_{20.11} = L_{20.11,i}\alpha_s \Delta T \Rightarrow L_{20.11,f} = L_{20.11,i}(1+\alpha_s\Delta T)$$

$$L_{rod,f} = L_{20.11,f} \Rightarrow L_{rod,i}(1+\alpha_r\Delta T) = L_{20.11,i}(1+\alpha_s\Delta T)$$

Chapter 18 Tutorial Problem 1

The change in length for the section of the steel ruler between its 0 cm mark and 20.11 cm mark is

$$\Delta L_{steel} = L_{steel}\alpha_{steel}\Delta T.$$



The actual change in length for the rod is

$$\Delta L_{rod} = \Delta l + \Delta L_{steel}$$

$$\Delta L_{rod} = L_{rod}\alpha_{rod}\Delta T$$

Then, $$\alpha_r = \frac{\Delta L_{rod}}{L_{rod}\Delta T} = \frac{\Delta l + \Delta L_{steel}}{L_{rod}\Delta T} = \frac{L_{steel} - L_{rod} + L_{steel}\alpha_{steel}\Delta T}{L_{rod}\Delta T}$$

Chapter 18 Tutorial Problem 1

Alternatively,
The actual length after expansion is given by

therefore $$L' = L + \Delta L = L(1 + \alpha \Delta T)$$

Then, $$L_{20.05}(1 + \alpha_{rod}\Delta T) = L_{20.11}(1 + \alpha_{steel}\Delta T)$$

$$\alpha_{rod} = \frac{L_{20.11} - L_{20.05} + L_{20.11}\alpha_{steel}\Delta T}{L_{20.05}\Delta T}$$

$$= \frac{0.06cm + 20.11cm \cdot 11 \times 10^{-6} /^0 C \cdot 250\ ^\circ C}{20.05cm \cdot 250^0 C}$$

$$= 2.25 \times 10^{-5} / ^\circ C$$

Chapter 18 Heat Absorption:

Without phase change:

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

- C: heat capacity with SI units **J/K**
- Specific heat c: heat capacity per unit mass.

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

phase change:

$$Q = Lm.$$

liquid ⟷ gas
heat of vaporization L_V

solid ⟷ liquid
heat of fusion L_F

Chapter 18 Tutorial Problem 2

water $25 \to 0\,^\circ C$ Q

Ice $-15 \to 0$ Q

Ice $\to$ water

A 50g Ice Cube drops into 200g of water in a thermally insulated container. Initially, water 25°C, ice −15°C

$$L_F = 333 \text{ kJ/kg}, \quad c_W = 4187\, J/kg \cdot K, \quad c_I = 2220\, J/kgK$$

What is the final temperature at thermal equilibrium?

Chapter 18 Tutorial Problem 2

The melting point is 0°C, and if the final temperature is below, at or above the melting point, *different processes shall occur.*

- First, we should check heat Q for different processes

$\mathcal{Q}_1$ ***: Warming 50g ice of -15 °C to 0 °C***

$\mathcal{Q}_2$ ***: Cooling 200g water of 25 °C to 0 °C***

$\mathcal{Q}_3$ ***: Melting the 0 °C ice to 0 °C water***

Chapter 18 Tutorial Problem 2

Warming the ice to 0 degree :

$$Q_1 = c_I m_I (T_f - T_i) = (2220)(50\times10^{-3})(0-(-15)) = 1665J$$

Cooling the water to 0 degree :

$$|Q_2| = c_W m_W (T_i - T_f) = (4186.8)(200\times10^{-3})(25-0) = 20934J$$

Melting the ice:

$$Q_3 = L_F m_I = (333\times10^{3})(50\times10^{-3}) = 16650J$$

Chapter 18 Tutorial Problem 2

Water, 200g, 25 °C

$$Q_2 = (4186.8)(200\times10^{-3})(0-25) = -20934J$$

Water, 200g, 0 °C

画状态阶段图

Water, 50g, 0 °C

$$Q_3(333\times10^{3})(50\times10^{-3}) = 16650J$$

Ice, 50g, 0 °C

$$Q_1 = (2220)(50\times10^{-3})(0-(-15)) = 1665J$$

Ice, 50g, -15°C

$$Q_3 + Q_1 = 18315J$$

Chapter 18 Tutorial Problem 2

- *If* $Q_2 < Q_1$ *, ice can't melting ,water freezes , Final state is solid (ice) or ice-water mixture .* 都是0°C 不再变 冰水融合
- *If* $Q_1 < Q_2 < Q_1 + Q_3$ *, part of ice melting ,Final state is a ice-water mixture.*
- *If* $Q_2 > Q_1 + Q_3$ *, ice melting completely ,Final state is liquid (water).*

And we find in this case $Q_2 > Q_1 + Q_3$ *, so the final state is liquid.*

Ice will be melt fully and the T_f>0°C

Chapter 18 Tutorial Problem 2

For the insulated system:

$$Q_1 + Q_3 + c_W m_I (T_f - 0) = c_W m_W (T_i - T_f)$$

$$\Rightarrow T_f = \frac{c_W m_W T_i - Q_1 - Q_3}{c_W (m_W + m_I)}$$

$$= \frac{(4186.8)(200\times10^{-3})(25) - 1665 - 16650}{(4186.8)(200+50)\times10^{-3}} = 2.5°C$$

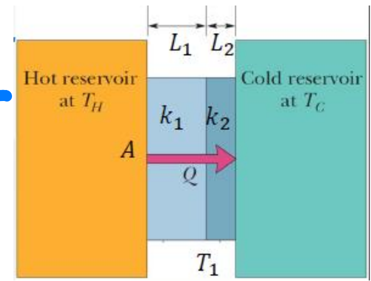
Chapter 18 Heat transfer

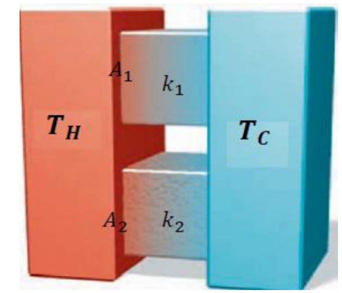
1, Heat conduction: Directly contact. Energy to be transferred, not particles

$$P_{cond} = \frac{Q}{t} = \frac{T_H - T_C}{R}, \quad R = L / \kappa A$$

$$\boxed{R_{tot} = \sum R_i = \sum \frac{L_i}{Ak_i}} \qquad \boxed{\frac{1}{R_{tot}} = \sum \frac{1}{L/A_i k_i} = \sum \frac{1}{R_i}}$$

$R = \frac{L}{kA}$





2, Convection: fluid motion

3, Radiation: does not depend on medium, no contact needed

Rate to absorb energy from environment through EM radiation:

$$P_{abs} = \sigma \varepsilon A T_{env}^4$$

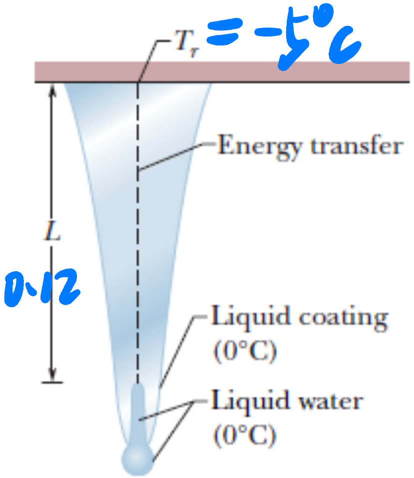
Net rate for a body's energy transferred through thermal radiation:

$$P_{net} = P_{abs} - P_{rad} = \sigma \varepsilon A (T_{env}^4 - T^4)$$

自身温度

Chapter 18 Tutorial Problem 3

Icicles. Liquid water coats an active (growing) icicle and extends up a short, narrow tube along the central axis. Because the water-ice interface must have a temperature of 0°C, the water in the tube cannot lose energy through the sides of the icicle or down through the tip because there is no temperature change in those directions. It can lose energy and freeze only by sending energy up (through distance L) to the top of the icicle, where the temperature T_r can be below 0°C. Take $\boldsymbol{L}$**= 0.12** m and $\boldsymbol{T_r}$**=– 5**°C. Assume that the central tube and the upward conduction path both have cross-sectional area A. The **thermal conductivity** of ice is **0.400 W/mK**, and the density of ice is **900 kg/m³**. In terms of A,



k

$R = \frac{L}{kA}$

P

$P = \frac{Q}{\Delta t} = \frac{\Delta T}{R}$

(a) what rate is energy conducted upward and

(b) the rate of mass converted from liquid to ice at the top of the central tube?

(c) At what rate does the top of the tube move downward because of water freezing there?

$\frac{dQ}{dt} = L_f \frac{dm}{dt}$

$\frac{dm}{dt} = \frac{d A L \rho}{dt}$

Chapter 18 Tutorial Problem 3

- (a) rate of energy conducted upward

$$P_{cond} = kA\frac{T_H - T_C}{L} = 0.400 \times A \times \frac{0-(-5)}{0.12} = 16.7A(\mathrm{W})$$

- (b)In this process, heat of fusion is termed as phase transition, namely $Q = L_F m$,

Thus,

$$P_{\mathrm{cond}} = \frac{dQ}{dt} = L_F \frac{dm}{dt}$$

Rate of Mass conversion from water to ice

$$\frac{dm}{dt} = \frac{P_{cond}}{L_F} = 5.0 \times 10^{-5} A\ (kg/s)$$

Chapter 18 Tutorial Problem 3

- (c) $$m = \rho V = \rho A h$$

$$\Rightarrow \quad \frac{dm}{dt} = \frac{d}{dt}(\rho A h) = \rho A \frac{dh}{dt}$$

So the rate of moving downward

$$\boldsymbol{v} = \frac{\boldsymbol{dh}}{\boldsymbol{dt}} = \frac{1}{\rho A}\frac{dm}{dt} = 5.6 \times 10^{-8}\,(\mathrm{m/s})$$

Chapter 18 Thermodynamic process

First Law of Thermodynamics:

$$\Delta E_{\text{int}} = E_{\text{int},f} - E_{\text{int},i} = Q - W_{\text{by}}$$

Special Cases of Thermodynamic Processes:

- Adiabatic processes ($Q = 0$):

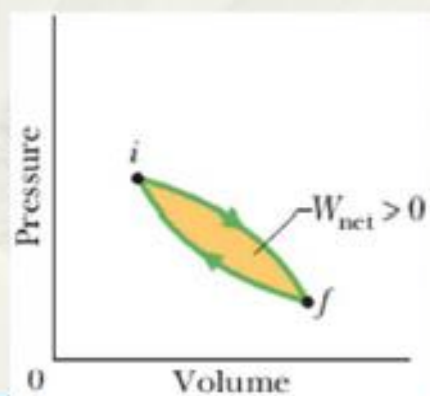
$$\Delta E_{\text{int}} = -W_{\text{by}}$$

- Constant-volume (isochoric) processes:

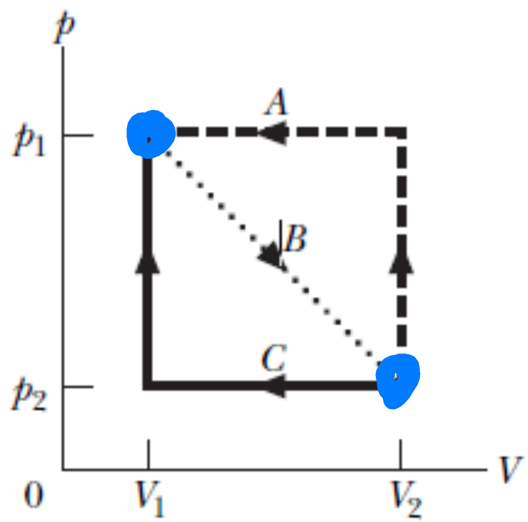
$$W = 0 \Rightarrow \Delta E_{\text{int}} = Q$$

- Cyclical processes (loop):

$$\Delta E_{\text{int}} = 0 \Rightarrow Q = W_{\text{net}}$$



Chapter 18 Tutorial Problem 4

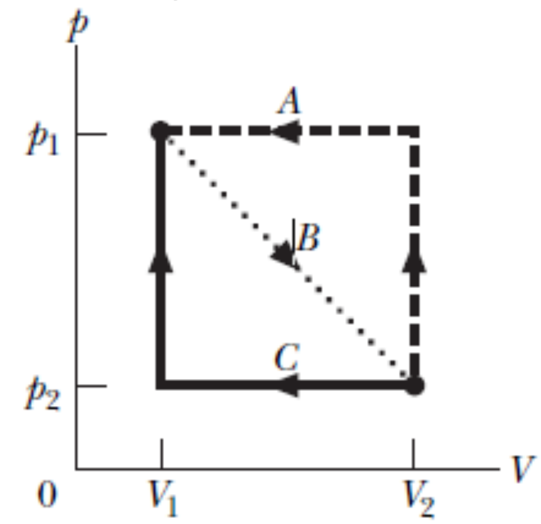


$\int pV$

A sample of gas expands from $V_1 = 1.0\ m^3$ and $p_1 = 40$ Pa to $V_2 = 4.0\ m^3$ and $p_2 = 10$ Pa along path B in the p-V diagram as shown in the figure. It is then compressed back to V_1 along either path A or path C. Compute the net work done by the gas and the net energy transferred as heats for the complete cycle along (a) path BA and (b) path BC.

Chapter 18 Tutorial Problem 4

The net work can be computed as a sum of works (for the individual process involved) or as the “area” (with appropriate $\pm$ sign) inside the figure.



For path B: $\mathrm{W}_B = \frac{p_i + p_f}{2}\Delta V = \frac{10+40}{2}\left(4.0\,\mathrm{m}^3 - 1.0\,\mathrm{m}^3\right) = 75\mathrm{J}$

For path A: $\mathrm{W}_A = p_1\left(1.0\,\mathrm{m}^3 - 4.0\,\mathrm{m}^3\right) = -120\mathrm{J}$

For path C: $\mathrm{W}_C = p_2(V_1 - V_2) = \left(10\,\mathrm{Pa}\right)\left(1.0\,\mathrm{m}^3 - 4.0\,\mathrm{m}^3\right) = -30\,\mathrm{J}$

Path BA: $\mathrm{W} = \mathrm{W_B+W_A} = 75\text{-}120 = \text{-}45\mathrm{J}$

$$\Delta E_{BA} = Q - W = 0 \Rightarrow Q = W = -45\mathrm{J}$$

Path BC: $\mathrm{W} = \mathrm{W_B+W_C} = 75\text{-}30 = 45\mathrm{J}$

$$\Delta E_{BA} = Q - W = 0 \Rightarrow Q = W = 45\mathrm{J}$$