第十四章 热力学第一定律

14-1 解: $Q = \Delta U + A$

$A = Q - \Delta U$

$= 2.7\times10^5 - 4.2\times10^5$

$= -1.5\times10^5$ J

$\because$ $A < 0$ $\therefore$ 外界对系统做功 1.5×10^5 J

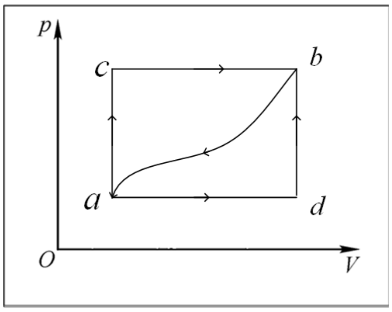


图14.2

14-2 解: $\Delta U_{ab} = Q_{acb} - A_{acb}$

$= 80\times4.18 - 126$

$= 208.4$ J

(1) 经 adb $A_{adb} = 42$ J

$Q_{adb} = \Delta U_{adb} + A_{adb}$

$= 208.4 + 42$

$= 250.4$ J 系统吸热

(2) 经 ba $\Delta U_{ba} = -\Delta U_{ab} = -208.4$ J

$A_{ba} = -84$ J

$Q_{ba} = \Delta U_{ba} + A_{ba} = -208.4 + (-84) = -293.4$ J

系统吸热

(3) $\Delta U_{ad} = 167$ J

$\Delta U_{db} = \Delta U_{ab} - \Delta U_{ad} = 208.4 - 167 = 41.4$ J

经 db $\mathrm{d}V = 0$ $A_{db} = \int p\mathrm{d}V = 0$

$\therefore$ $Q_{db} = \Delta U_{db} = 41.4$ J 系统吸热

经 ad $Q_{ad} = Q_{adb} - Q_{db} = 250.4 - 41.4 = 209$ J 系统吸热

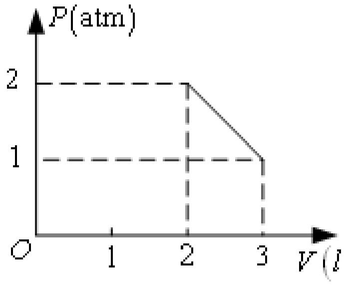


图14.3

14-3 解: 气体对外界做的功等于曲线下面积

$$A=1\times1\times1.013\times10^{5}\times10^{-3}+\frac{1}{2}\times1\times10^{-3}\times1.013\times10^{5}$$

$=151.95$ J

$=152$ J

14-4 解:总平均动能 $=\frac{3}{2}RT=\frac{3}{2}\times8.31\times300.15$

$=3.74\times10^{3}$ J

∵ 氢分子是刚性双原子分子 ∴ 转动自由度 $r=2$

∴ 总转动动能 $=RT=8.31\times300.15=2.49\times10^{3}$ J

14-5 解：非刚性双原子分子

$t=3 \quad r=2 \quad s=1$

∴ $\overline{\varepsilon}=\frac{1}{2}(t+r+2s)kT=\frac{7}{2}kT$

$U=\nu N_A\overline{\varepsilon}=\nu N_A\frac{7}{2}kT$

$=\frac{7}{2}\nu RT$

∵ $PV=\nu RT$

∴ $U=\frac{7}{2}PV$

$=\frac{7}{2}\times3.039\times10^{5}\times5\times10^{-3}$

$=5.32\times10^{3}$ J

14-6 解: 氢气和氮气都是刚性双原子分子

1 mol 氢气和1 mol 氮气的内能均为

$$U=\nu\frac{5}{2}kT=\frac{5}{2}RT$$

$$=\frac{5}{2}\times 8.31\times 300$$

$$=6.23\times 10^{3}\quad \text{J}$$

1 g 氢气内能为

$$U=\frac{M}{\mu_{氢}}\frac{5}{2}RT$$

$$=\frac{1}{2}\frac{5}{2}RT$$

$$=\frac{1}{2}\times\frac{5}{2}\times 8.31\times 300$$

$$=3.12\times 10^{3}\quad \text{J}$$

1 g 氮气内能为

$$U=\frac{M}{\mu_{氮}}\frac{5}{2}RT$$

$$=\frac{1}{28}\times\frac{5}{2}\times 8.31\times 300$$

$$=2.23\times 10^{2}\quad \text{J}$$

14-7 解: 对于非线型多原子分子气体,一般认为 $C_V=3R$

$$\Delta U=\nu C_V\Delta T$$

$$=\frac{4.27}{17}\times 3R\Delta T$$

$$=\frac{4.27}{17}\times 3\times 8.31\times(21-0)$$

$$=124.65\quad \text{J}$$

$=125 \quad \text{J}$

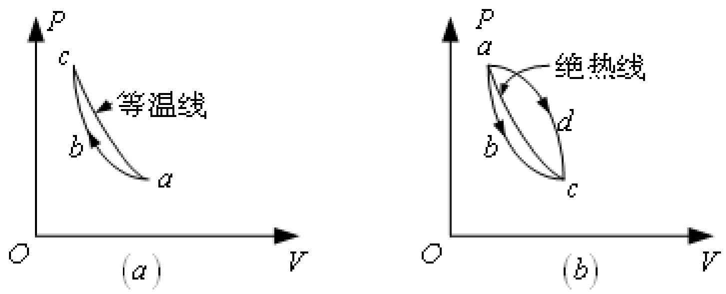


图14.8

14-8 解: (1) a,c 两点的温度相同

$\therefore \ \Delta U_{ac}=0 \qquad \Delta T=0$

$Q=A=\int_{V_a}^{V_c} p\mathrm{d}V<0$

(2) abc 过程,由于 a,c 两点由绝热线相连

$Q_{ac}=0 \quad \therefore \ \Delta U_{ac}=-\nu C_V\left(T_c-T_a\right)$

$\because \ TV^{\gamma-1}=C \qquad \therefore \ T_c<T_a$

$\therefore \ \Delta T=T_c-T_a<0$

$\therefore \ \Delta U_{ac}<0$

$A_{ac}>A_{abc}>0 \qquad Q_{abc}=\Delta U_{ac}+A_{abc}$

$\because \ \Delta U_{ac}+A_{ac}=0$

$\therefore \ Q_{abc}<0$

adc 过程

$\Delta U_{ac}<0 \qquad \Delta T<0$

$A_{adc}>A_{ac}>0$

$Q_{adc}=\Delta U_{ac}+A_{adc}$

$\because \Delta U_{ac}+A_{ac}=0$

$\therefore \ Q_{adc}>0$

14-9 解: 刚性双原子分子 $C_P=\frac{7}{2}R$

等压过程 $Q=\nu C_P\left(T_2-T_1\right)$

$=\frac{200}{28}\times\frac{7}{2}\times 8.31\times(100-20)$

$=1.662\times 10^4$ J

$\Delta U=\nu C_V\left(T_2-T_1\right)$

$=\frac{200}{28}\times\frac{5}{2}\times 8.31\times(100-20)$

$=1.187\times 10^4$ J

$A=Q-\Delta U$

$=1.662\times 10^4-1.187\times 10^4$

$=4.75\times 10^4$ J

14-10 解: (1) 等容过程 $\left(C_V=\frac{5}{2}R\right)$

$Q=\Delta U=\nu C_V\left(T_2-T_1\right)$

$=\frac{1}{22.4}\times\frac{5}{2}\times 8.31\times(100-0)$

$=92.7$ J

或 $PV=\nu RT$

$\nu R=\frac{PV}{T}=\frac{1.013\times 10^5\times 10^{-3}}{273.15}=\frac{101.3}{273.15}$

$Q=\nu R\frac{5}{2}\left(T_2-T_1\right)$

$=\frac{101.3}{273.15}\times\frac{5}{2}\times 100$

$= 92.7 \quad \mathrm{J}$

$A = 0$

(2) 等压过程 $\left(C_P = \frac{7}{2}R\right)$

$Q = \nu C_P\left(T_2 - T_1\right)$

$= \frac{1}{22.4} \times \frac{7}{2} \times 8.31 \times (100 - 0)$

$= 129.8 \quad \mathrm{J}$

$\Delta U = \nu C_V\left(T_2 - T_1\right)$

$= 92.7 \ \mathrm{J}$

$A = Q - \Delta U = 129.8 - 92.7 = 37.1 \quad \mathrm{J}$

14-12 解: 绝热压缩 $Q = 0$

$\Delta U = -A = -\int P\mathrm{d}V$

$= -\int_{V_1}^{V_2} \frac{P_1 V_1^{\gamma}}{V^{\gamma}} \mathrm{d}V$

$= \frac{-P_1 V_1^{\gamma}}{1-\gamma}\left(V_2^{-\gamma+1} - V_1^{-\gamma+1}\right)$

双原子分子 $\gamma = \frac{C_P}{C_V} = \frac{7}{5}$

$\therefore \Delta U = -A$

$$= \frac{1 \times 1.013 \times 10^5 \times \left(0.1 \times 10^{-3}\right)^{\frac{7}{5}}}{\frac{7}{5} - 1} \times \left[\left(0.02 \times 10^{-3}\right)^{-\frac{2}{5}} - \left(0.1 \times 10^{-3}\right)^{-\frac{2}{5}}\right]$$

$= 22.89 \quad \mathrm{J}$

14-13 解:（1）绝热过程 $Q = 0$

$$T_1V_1^{\gamma-1}=T_2V_2^{\gamma-1} \qquad \gamma=\frac{\frac{7}{2}R}{\frac{5}{2}R}=\frac{7}{5}$$

$$T_2=T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1}=300\times\left(\frac{0.41}{4.1}\right)^{\frac{7}{5}-1}=119.4\ \text{K}$$

$$A=-\Delta U=\nu C_V\left(T_2-T_1\right)$$

$$=\frac{16}{32}\times\frac{5}{2}\times8.31\times(300-119.4)$$

$$=1.875\times10^3\ \text{J}$$

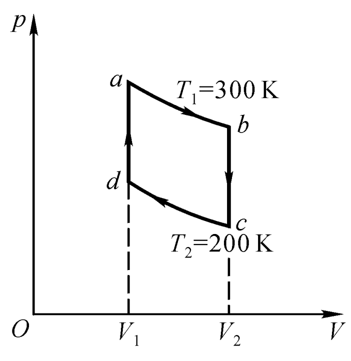
(2) 等容过程 $A=0$

等温膨胀 $A=\int P\mathrm{d}V=\int_{V_1}^{V_2}\nu RT\frac{\mathrm{d}V}{V}$

$$=\nu RT\ln\frac{V_2}{V_1}$$

$$=\frac{16}{32}\times8.31\times300\times\ln\frac{4.1}{0.41}$$

$$=2.87\times10^3\quad \text{J}$$



14-14 解: $a\to b$ 等温过程 $\Delta U=0$

$$Q_{ab}=A_{ab}=\nu RT\ln\frac{V_b}{V_a}$$

$$=\nu RT\ln2=207.9\nu R$$

$b\to c$ 等容过程

$$Q_{bc}=\Delta U_{bc}=\nu C_V\left(T_c-T_b\right)$$

$$=\frac{5}{2}\nu R(200-300)$$

$$=-250\nu R$$

$c\to b$ 等温过程

$$Q_{cd}=A_{cd}=\nu RT\ln\frac{V_d}{V_c}$$

$$=-\nu RT\ln 2=-139\nu R$$

$d\rightarrow a$ 等容过程

$$Q_{da}=\Delta U_{da}=\nu C_V\left(T_a-T_d\right)$$

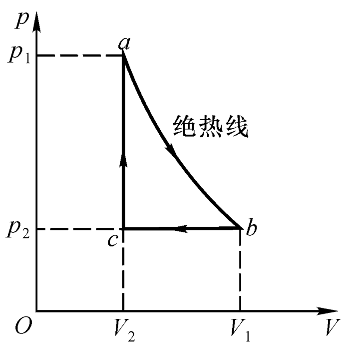
$$=\frac{5}{2}\nu R\left(300-200\right)$$

$$=250\nu R$$

$$Q_1=Q_{吸}=\left|Q_{ab}\right|+\left|Q_{da}\right|=250\nu R+207.9\nu R=458\nu R$$

$$Q_2=Q_{放}=\left|Q_{bc}\right|+\left|Q_{cd}\right|=250\nu R+139\nu R=389\nu R$$

$$\eta=\frac{Q_1-Q_2}{Q_1}=\frac{69\nu R}{458\nu R}=15.1\%$$



14-15 证: $b\rightarrow c$ 等压过程

$$Q_{bc}=\nu C_P\left(T_c-T_b\right)<0$$

$c\rightarrow a$ 等容过程

$$Q_{ca}=\nu C_V\left(T_a-T_c\right)>0$$

$$Q_1=\left|Q_{ca}\right|=\nu C_V\left(T_a-T_c\right)$$

$$Q_2=\left|Q_{bc}\right|=\nu C_P\left(T_b-T_c\right)$$

$$\eta=1-\frac{Q_2}{Q_1}$$

$$=1-\frac{\nu C_P\left(T_b-T_c\right)}{\nu C_V\left(T_a-T_c\right)}$$

$$=1-\gamma\frac{T_b-T_c}{T_a-T_c}$$

$\because \dfrac{P_2V_1}{T_b}=\dfrac{P_2V_2}{T_c} \qquad T_b=\dfrac{V_1}{V_2}T_c$

$\dfrac{P_1V_2}{T_a}=\dfrac{P_2V_2}{T_c} \qquad T_a=\dfrac{P_1}{P_2}T_c$

$$\therefore \quad \eta=1-\gamma\frac{\frac{V_1}{V_2}T_c-T_c}{\frac{P_1}{P_2}T_c-T_c}$$

$$=1-\gamma\frac{\frac{V_1}{V_2}-1}{\frac{P_1}{P_2}-1}$$

14-16 解: $\eta=1-\dfrac{T_2}{T_1}$

$1-\dfrac{280}{T_1}=0.4 \qquad T_1=\dfrac{280}{0.6}$

$1-\dfrac{280}{T_1'}=0.5 \qquad T_1'=\dfrac{280}{0.5}$

$T_1'-T_1=\dfrac{280}{0.5}-\dfrac{280}{0.6}=93.3\,\mathrm{K}$

高温热源需提高 $93.3\ ^\circ\mathrm{C}$ 或 $93.3\,\mathrm{K}$

14-17 解: $T_1=273+11=284 \quad \mathrm{K}$

$T_2=273-10=263 \quad \mathrm{K}$

$\dfrac{Q_2}{Q_1-Q_2}=\dfrac{T_2}{T_1-T_2}$

$\dfrac{Q_2}{1000}=\dfrac{263}{284-263}$

$Q_2=1.25\times10^4 \quad \mathrm{J}$

14-18 解: $\begin{cases} Q_1 - Q_2 = 8000 \\ \dfrac{Q_2}{Q_1} = \dfrac{T_2}{T_1} = \dfrac{273}{373} \end{cases} \Rightarrow \begin{cases} Q_1 = 2.984\times10^4 \text{ J} \\ Q_2 = 2.184\times10^4 \text{ J} \end{cases}$

$$T_2' = T_2 = 273$$

$$Q_1' - Q_2' = 10000$$

$$Q_2' = Q_2 = 2.184\times10^4$$

$$\therefore \quad Q_1' = Q_2' + 10000 = 2.184\times10^4 + 1\times10^4$$

$$= 3.184\times10^4 \quad \text{J}$$

$$\frac{Q_2'}{Q_1'} = \frac{T_2'}{T_1'}$$

$$T_1' = \frac{Q_1'}{Q_2'} T_2' = \frac{3.184\times10^4}{2.184\times10^4}\times273 = 398\ \text{K} = 125^\circ\text{C}$$

$$\eta = 1 - \frac{T_2'}{T_1'} = 1 - \frac{273}{398} = 31.4\%$$

高温热源温度为 125°C ,效率为 31.4%