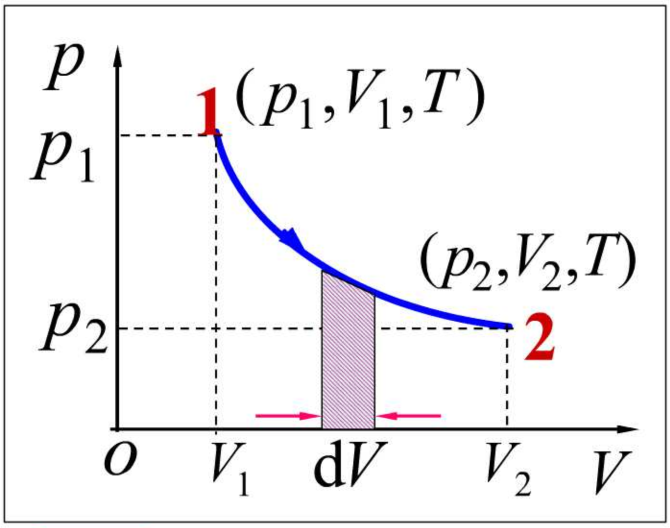
一 等温过程

特征 $T =$ 常量

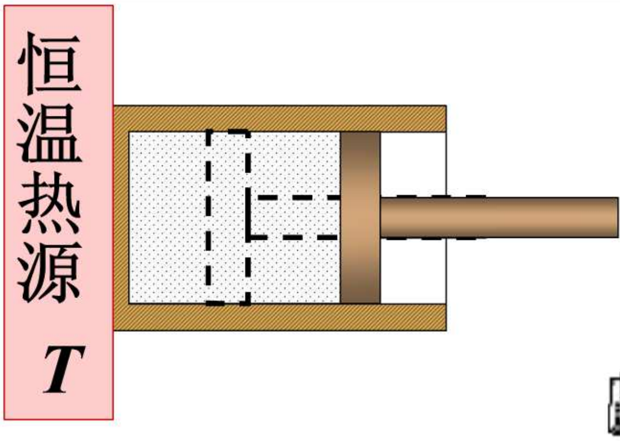
过程方程 $pV =$ 常量

$$\mathrm{d}E = 0$$



由热力学第一定律

$$\mathrm{d}Q_T = \mathrm{d}W = p\mathrm{d}V$$

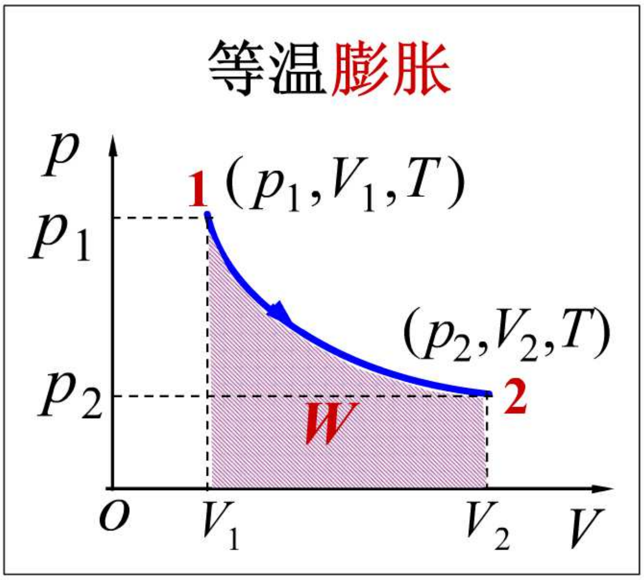


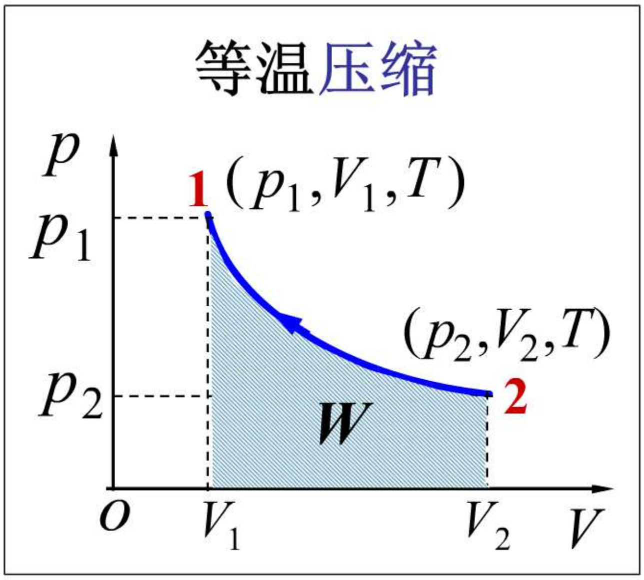
$$Q_T = W = \int_{V_1}^{V_2} p\,\mathrm{d}V$$

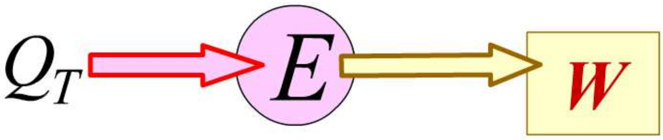
$$p = \nu \frac{RT}{V}$$

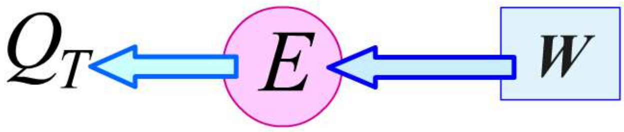
$$Q_T = W = \int_{V_1}^{V_2} \nu \frac{RT}{V}\mathrm{d}V = \nu RT \ln\frac{V_2}{V_1}$$

$$= \nu RT \ln\frac{p_1}{p_2}$$


等温膨胀
p
1 (p1,V1,T)
p1
(p2,V2,T)
p2
2
W
o
V1
V2
V


等温压缩
p
1 (p1,V1,T)
p1
(p2,V2,T)
p2
2
W
o
V1
V2
V


QT
E
W


QT
E
W

二　绝热过程

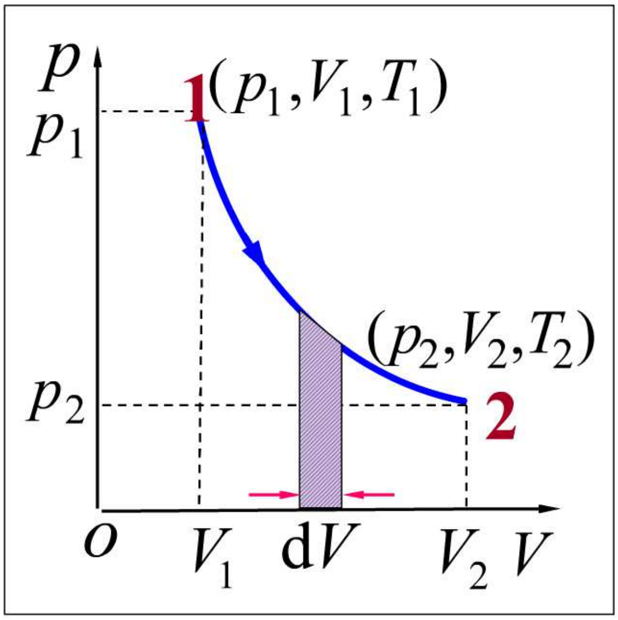
与外界无热量交换的过程

特征　$\mathrm{d}Q=0$

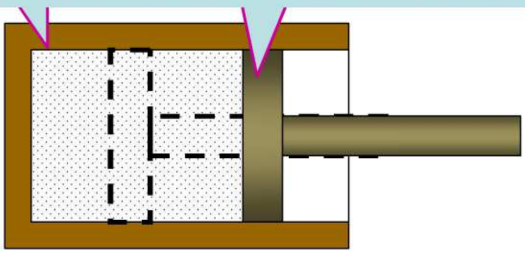
由热力学第一定律　$\mathrm{d}W+\mathrm{d}E=0$

$\mathrm{d}W=-\mathrm{d}E$

$$\mathrm{d}E=\nu C_{V,\mathrm{m}}\mathrm{d}T$$



绝热的汽缸壁和活塞



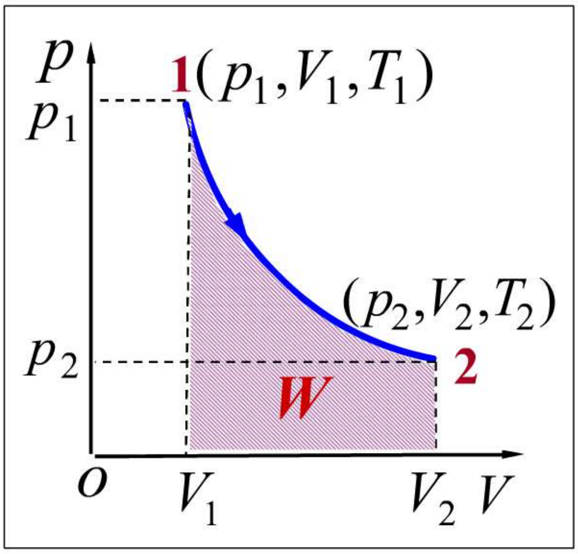
$$W=\int_{V_1}^{V_2}p\mathrm{d}V \quad =-\int_{T_1}^{T_2}\nu C_{V,\mathrm{m}}\mathrm{d}T$$

$$=-\nu C_{V,\mathrm{m}}(T_2-T_1)$$

由热力学第一定律有

$$W=-\Delta E$$

$$W=\nu C_{V,\mathrm{m}}(T_1-T_2)$$



若已知 p_1, V_1, p_2, V_2 及 γ

由 $pV = \nu RT$ 可得

$$W = C_{V,\mathrm{m}}\left(\frac{p_1V_1}{R} - \frac{p_2V_2}{R}\right)$$

$$= \frac{C_{V,\mathrm{m}}}{C_{p,\mathrm{m}} - C_{V,\mathrm{m}}}(p_1V_1 - p_2V_2)$$

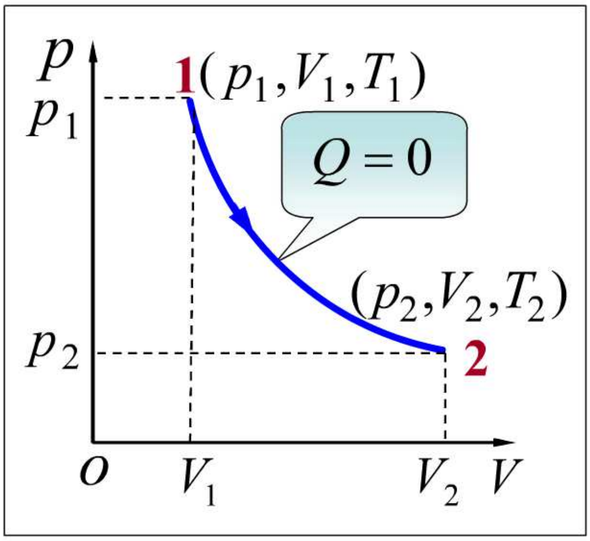
$$W = \frac{p_1V_1 - p_2V_2}{\gamma - 1}$$

◆ 绝热过程方程的推导

$\because \mathrm{d}Q = 0, \quad \therefore \mathrm{d}W = -\mathrm{d}E$

$$\begin{cases} p\mathrm{d}V = -\nu C_{V,\mathrm{m}}\mathrm{d}T \\ pV = \nu RT \end{cases}$$

$$\nu \frac{RT}{V}\mathrm{d}V = -\nu C_{V,\mathrm{m}}\mathrm{d}T$$

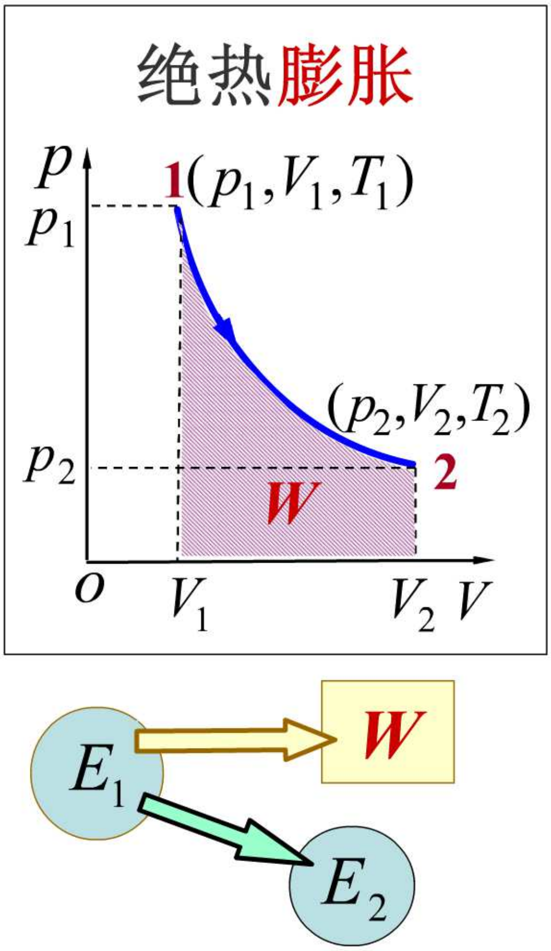


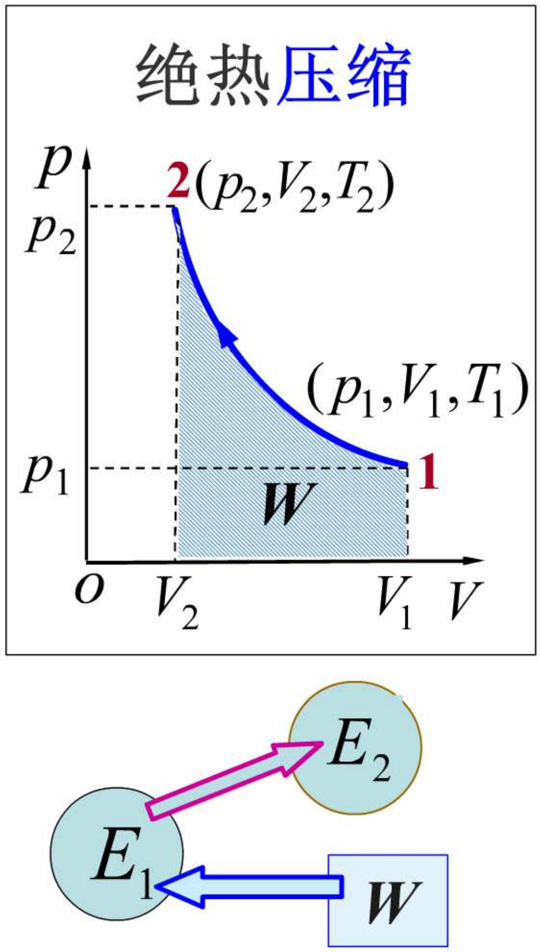
分离变量得 $\dfrac{dV}{V}=-\dfrac{C_{V,m}}{R}\dfrac{dT}{T}$

$$\int\frac{dV}{V}=-\int\frac{1}{\gamma-1}\frac{dT}{T}$$

$$V^{\gamma-1}T=\text{常量}$$

绝热方程	
	$V^{\gamma-1}T=\text{常量}$
	$pV^{\gamma}=\text{常量}$
	$p^{\gamma-1}T^{-\gamma}=\text{常量}$


绝热膨胀
p
1(p_1,V_1,T_1)
p_1
(p_2,V_2,T_2)
p_2
2
W
o
V_1
V_2
V
E_1
W
E_2


绝热压缩
p
2(p_2,V_2,T_2)
p_2
(p_1,V_1,T_1)
p_1
1
W
o
V_2
V_1
V
E_2
E_1
W

三 绝热线和等温线

绝热过程曲线的斜率

$$pV^{\gamma} = 常量$$

$$\gamma p V^{\gamma-1} \mathrm{d}V + V^{\gamma} \mathrm{d}p = 0$$

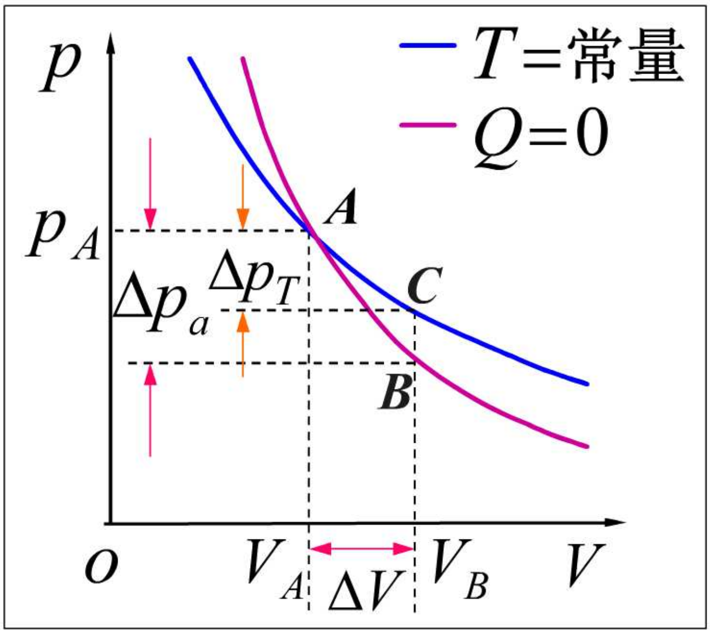
$$\left(\frac{\mathrm{d}p}{\mathrm{d}V}\right)_{a} = -\gamma \frac{p_A}{V_A}$$

等温过程曲线的斜率

$$pV = 常量$$

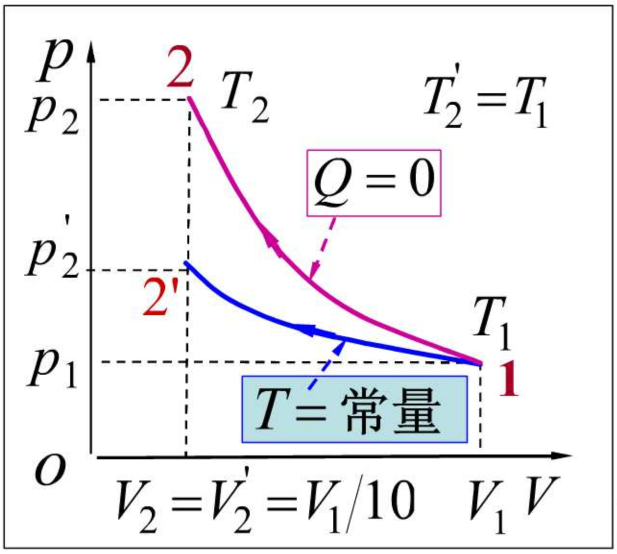
$$p\mathrm{d}V + V\mathrm{d}p = 0$$

$$\left(\frac{\mathrm{d}p}{\mathrm{d}V}\right)_T = -\frac{p_A}{V_A}$$



绝热线的斜率大于等温线的斜率.

例1 设有 5 mol 的氢气，最初温度 $20^\circ\mathrm{C}$，压强 $1.013\times10^5\,\mathrm{Pa}$，求下列过程中把氢气压缩为原体积的 1/10 需作的功：（1）等温过程（2）绝热过程（3）经这两过程后，气体的压强各为多少？



已知：$\nu = 5\,\text{mol} \quad T_0 = 293\,\text{K}$

$$P_0 = 1.013\times10^5\,\text{Pa} \quad V = 0.1V_0$$

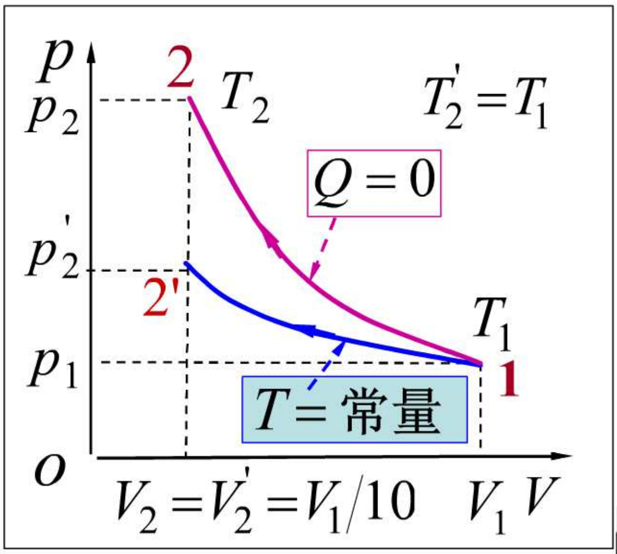
解 （1）等温过程

$$W'_{12} = \nu RT\ln\frac{V'_2}{V_1} = -2.80\times10^4\,\text{J}$$

（2）氢气为双原子气体

由表查得$\gamma = 1.41$ ，有

$$T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1} = 753\,\text{K}$$



$$W_{12}=-\nu C_{V,m}(T_2-T_1) \qquad C_{V,m}=20.44\,\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$$

$$W_{12}=-4.70\times10^{4}\,\mathrm{J}$$

（3） 对等温过程

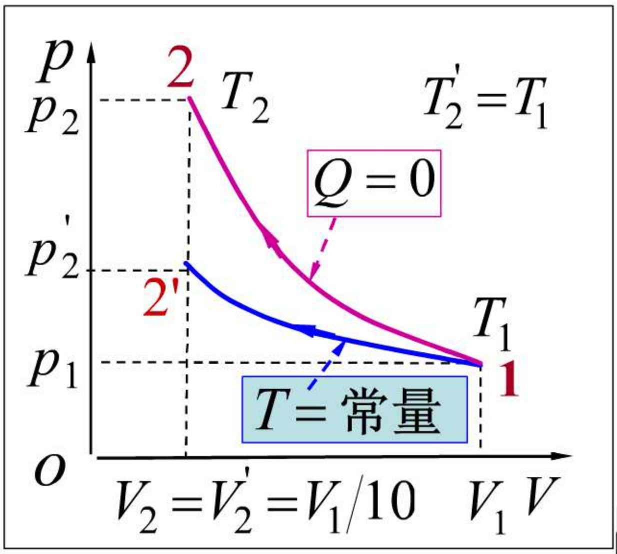
$$p_2' = p_1(\frac{V_1}{V_2})$$

$$=1.01\times10^{6}\ \mathrm{Pa}$$

对绝热过程， 有

$$p_2=p_1(\frac{V_1}{V_2})^{\gamma}$$

$$=2.55\times10^{6}\ \mathrm{Pa}$$



例2　氮气液化，　把氮气放在一个绝热的汽缸中.开始时,氮气的压强为50个标准大气压、温度为300K；　经急速膨胀后，其压强降至 1个标准大气压，从而使氮气液化.试问此时氮的温度为多少 ？

解 氮气可视为理想气体，其液化过程为绝热过程.

$$p_1 = 50\times1.01\times10^5\,\mathrm{Pa} \qquad T_1 = 300\mathrm{K}$$

$$p_2 = 1.01\times10^5\,\mathrm{Pa}$$

氮气为双原子气体由表查得 $\gamma = 1.40$

$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{(\gamma-1)/\gamma} = 98.0\mathrm{K}$$

例3 一汽缸内有一定的水，缸壁由良导热材料制成. 作用于活塞上的压强 $1.013\times10^{5}\ \mathrm{Pa}$ 摩擦不计. 开始时，活塞与水面接触. 若环境(热源) 温度非常缓慢地升高到 $100^{\circ}\mathrm{C}$. 求把单位质量的水汽化为水蒸气，内能改变多少?

已知 汽化热 $L=2.26\times10^{6}\ \mathrm{J\cdot kg^{-1}}$

密度 $\rho_{水}=1040\ \mathrm{kg\cdot m^{-3}}$

$\rho_{蒸气}=0.598\ \mathrm{kg\cdot m^{-3}}$

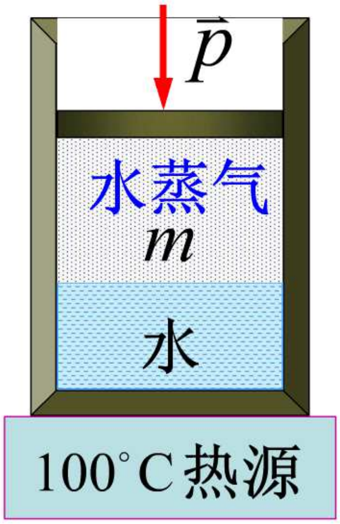
解 水汽化所需的热量 $Q = mL$

水汽化后体积膨胀为 $\Delta V = m\left(\frac{1}{\rho_{蒸气}} - \frac{1}{\rho_{水}}\right)$

$L = 2.26\times10^{6}\ \mathrm{J\cdot kg^{-1}}$

$\rho_{水} = 1040\ \mathrm{kg\cdot m^{-3}}$

$\rho_{蒸气} = 0.598\ \mathrm{kg\cdot m^{-3}}$



$$W=\int p\mathrm{d}V=p\Delta V=pm\left(\frac{1}{\rho_{蒸气}}-\frac{1}{\rho_{水}}\right)$$

$$\Delta E=Q-W=mL-pm\left(\frac{1}{\rho_{蒸气}}-\frac{1}{\rho_{水}}\right)$$

$$\frac{\Delta E}{m}=L-p\left(\frac{1}{\rho_{蒸气}}-\frac{1}{\rho_{水}}\right)=2.09\times10^{6}\ \mathrm{J\cdot kg^{-1}}$$