# 大学物理笔记

## 多普勒效应

source:$v_s$, observer:$v_O$,distance $L$

issued at $t=0,x=0$, recieved at $t_1',L+v_Ot_1'$

issued at $t=T,x=v_ST$, received at $t_2',L+v_Ot_2'$

由运动学:

$$v_Pt_1'=L+v_Ot_1'$$
$$v_P(t_2'-T)=L+v_Ot_2'-v_ST$$

于是

$$t_1'=\frac{L}{v_P-v_O}$$
$$t_2'=\frac{L}{v_P-v_O}+\frac{v_P-v_S}{v_P-v_O}T$$
$$T'=t_2'-t_1'=\frac{v_P-v_S}{v_P-v_O}T$$
$$\nu'=\frac{v_P-v_O}{v_P-v_S}\nu$$

Discussion:

$v_O>v_S$(including $v_S\le 0$):separating, $\nu'<\nu$, Doppler redshift

$v_S>v_O$(including $v_O\le 0$):approaching, $\nu'>\nu$, Doppler blueshift

靠近:频率变高;远离:频率变低

考虑波源的运动与波振面的运动(supersonic speed $v_S>v_p$)

马赫锥:$sin\theta=\frac{v_P}{v_S}$

## 驻波(stationary wave)

- 推导

由$kx-\omega t-\phi=const$,求导得 $v=\frac{\omega}{k}$

$$\begin{aligned}u_1&=Acos(kx-\omega t-\phi)\\u_2&=Acos(kx+\omega t)\\&=Acos(k(x+\frac{\omega}{k}t))\end{aligned}\tag{1}$$

$$\text{从而}u_1+u_2=2Acos(kx-\frac{\phi}{2})cos(wt+\frac{\phi}{2})$$

令 $(u_1+u_2)_{x=0}=0$,得 $\phi=\pi$; 令 $(u_1+u_2)_{x=L}=0$,得 $L=\frac{n\pi}{k}=\frac{n\lambda}{2}$

注意 $\lambda=T\cdot v_P=\frac{2\pi}{\omega}\cdot\frac{\omega}{k}=\frac{2\pi}{k}, k=\frac{2\pi}{\lambda}, \omega=vk$,有

$$\begin{aligned} f &= \frac{\omega}{2\pi}=\frac{kv}{2\pi}=n\frac{v}{2L} \\ &= f_n \\ &= nf_1 \end{aligned}$$

波节(node),波腹(antinode)的定义

- 半波损失

fixed hard boundary; from high spped to low speed

由$(1)$式,令 $(u_1+u_2)_{x=0}=0$,得 $\phi=\pi$,即为在固定端的相差

# 第9章 Relativistic Mechanics 相对论力学

## 9.1 伽利略变换

- 观测者:一套矫正好的时钟,可记录 $x,y,z,t$
- 结果 $t'_A-t'_B=t_A-t_B$,$x'_A-x'_B=x_A-x_B-u(t_A-t_B)$

  同时测量:$x'_A-x'_B=x_A-x_B$

  速度直接叠加,加速度不变
- Galileo's relativity: 力学定律在不同惯性参考系中相同
- 电学:不满足麦克斯韦方程组

## 9.2 洛伦兹变换 Lorentz Transformation

- Two basic principles of Special Theory of Relativity
  - 所有惯性参考系中物理定律相同(力学,电学等)
  - 光速不变
- 推导

假定变换为线性变换(考虑匀速直线运动);

待定系数:

$$\begin{aligned} x' &= a_{11}x+a_{12}y+a_{13}z+a_{14}t \\ y' &= y \\ z' &= z \end{aligned}$$

For arbitrary y,z if $x'=0$,$x=ut$;则

$$x'=a_{11}(u)(x-ut), a_{11}(0)=1 \tag{1.1}$$

By the priciple of relativity, we have

$$x = a_{11}(-u)(x' + ut'),\text{带入}(1.1),\text{有}$$
$$t' = f(x, x'(u,t)) = a_{44}t + a_{41}x$$

从而

$$\begin{aligned} x' &= a(x - ut) \\ t' &= b(t - ex) \end{aligned} \tag{1.2}$$

解得 $x = \frac{1}{\Delta}(bx' + aut')$

与 $x = a_{11}(-u)(x' + ut')$比较,得 $a = b$

考虑光速不变:假设 $t = t' = 0$时在原点发出光信号,有

$$x^2 + y^2 + z^2 = c^2t^2$$
$$x'^2 + y'^2 + z'^2 = c^2t'^2$$

代入 (1.2)式,有

$$e = \frac{u}{c^2}$$
$$a = \frac{1}{\sqrt{1-\beta^2}} = \gamma = \sqrt{1 - \frac{v^2}{c^2}}$$
$$\text{其中}\beta = \frac{u}{c}$$

完整的变换关系为

$$\begin{aligned} x' &= \gamma(x - ut) \\ y' &= y \\ z' &= z \\ t' &= \gamma(t - \frac{u}{c^2}x) \end{aligned}$$

考虑事件对 $(x'_1, t'_1), (x'_2, t'_2)$,洛伦兹变换是

$$\begin{aligned} \Delta x' &= \gamma(\Delta x - u\Delta t) \\ \Delta y' &= \Delta y \\ \Delta z' &= \Delta z \\ \Delta t' &= \gamma(\Delta t - \frac{u}{c^2}\Delta x) \end{aligned} \tag{1.3}$$

- 讨论
  - 逆变换: $u \to -u$ 直接根据相对性原理
  - Invariance of spacetime interval 时空间隔不变:$(\Delta s)^2 = (c\Delta t)^2 - (\Delta x)^2 - (\Delta y)^2 - (\Delta z)^2 = (\Delta s')^2$
  - 伽利略变换:时间归时间 空间归空间 时间空间分别不变
- 事件对
  - 光信号联系: $(c\Delta t)^2 = (\Delta x)^2, \Delta s = 0$
  - 固有时间间隔与固有空间间隔

- Simultaneous measurement $\Delta x' = \ell_0$ in $S'(\Delta t' = 0)$ 形成一个事件

  the same pair of events in S:

$$\begin{aligned}\Delta x &= \gamma(\Delta x' + u\Delta t') = \gamma\Delta x' = \gamma\ell_0 \\ \Delta t &= \gamma(\Delta t + \frac{u}{c^2}\Delta x') \neq 0\end{aligned} \quad \text{同时的相对性}$$

也即 $\ell = \ell_0\sqrt{1-\frac{v^2}{c^2}} = \frac{\ell_0}{\gamma}$

- 用光速不变推出钟慢:

$$\begin{aligned}\Delta t' &= \frac{2L_0}{c} \\ (\frac{u\Delta t}{2})^2 + L_0^2 &= (\frac{c\Delta t}{2})^2 (\text{用到光速不变}) \\ \Delta t = \frac{2L_0}{\sqrt{c^2-u^2}} &= \frac{2L_0/c}{\sqrt{1-\beta^2}} = \gamma\Delta t'\end{aligned}$$

- 用光速不变推出尺缩:

$$\begin{aligned}c\Delta t_1 = L + u\Delta t_1, c\Delta t_2 &= L - u\Delta t_2 \\ \Delta t = \Delta t_1 + \Delta t_2 &= \frac{L}{c+u} + \frac{L}{c-u} = \frac{2L}{c}\frac{1}{1-\beta^2} \\ \Delta t' &= \frac{2L_0}{c} = \gamma\Delta t \\ \frac{2L_0}{c\gamma} &= \frac{2L}{c}\frac{1}{1-\beta^2} \\ \text{于是} L &= \frac{L_0}{\gamma}\end{aligned}$$

- 因果律及信号传播(Causality and signal speed)

  - An event $P(x_P, t_P)$ causes an event $Q(x_Q, t_Q)$. 信号传输速度

$$v_S = \frac{x_Q - x_P}{t_Q - t_P} = \frac{\Delta x}{\Delta t}$$

  在 $S'(u)$系中时间间隔为

$$\Delta t' = \gamma\Delta t(1 - \frac{uv_S}{c^2})$$

  为保证先后次序,必须有

$$\begin{gathered}1 - \frac{uv_S}{c^2} < 0 \\ \text{则} v_S < c\end{gathered}$$

- 光多普勒效应

  - 由$(1.3), \Delta t = \sqrt{\frac{1+\beta}{1-\beta}}\Delta t'$
  - redshift: $\nu_0 = \sqrt{\frac{1-\beta}{1+\beta}}\nu_e$

- 波动方程: 用洛伦兹变换恰好符合(洛伦兹不变)

## 9.3 时空图和孪生paradox

- Minkowski Space
    - 洛伦兹变换在时空图中的体现
- Twin paradox: 在宇宙飞船加速,减速的过程中经历了非惯性系
- Pole-barn Paradox: 火车进隧道;火车系:隧道收缩;地面系:火车收缩
    - 涉及同时的相对性:看能否在地面系同时关上前门和后门(火车系觉得没有同时)
    - 地面系的观测者觉得能关进去,在火车系的观测者看来后门早就关起来了
- Visual Apperance
    - 球不变 立方体转过一个角度

## 9.4 相对论运动学

- 速度变换公式(求导可得)

$$v'_x = \frac{v_x - u}{1 - v_x\frac{u}{c^2}}$$
$$v'_y = \frac{v_y}{\gamma(1 - v_x\frac{u}{c^2})}$$
$$v'_z = \frac{v_z}{\gamma(1 - v_x\frac{u}{c^2})}$$

## 9.5 相对论动力学(Relativistic Dynamics)

- 广义相对论: 引力场,非惯性系
- 讨论$m, p, F, E_k, a$
- Discuss a completely inelastic collision(保持动量守恒)
    - In $S'(-u) : u, -u \to 0, 0$
    - In $S : v_x, 0 \to u, u$; $v_x = \frac{u+u}{1+u\frac{u}{c^2}}(9.5.1)$
    - 而 $m\frac{u+u}{1+\frac{uu}{c^2}} + m \times \cancel{0} = 2mu$,动量守恒不成立.
    - 假定 $m \equiv m(v), m_0 \equiv m(0)$,有

$$\begin{aligned} m(v_x) + m_0 &= m_{total}(u) \\ m(v_x) \cdot v_x + m_0 \cdot 0 &= m_t(u)u \\ &= [m(v_x) + m_0]u \\ \text{求得} m(v_x) &= \frac{m_0}{\frac{v_x}{u} - 1} \end{aligned}$$

由 $(9.5.1)$,$\frac{v_x}{u} - 1 = \sqrt{1-\beta^2}$,则 $m(v) = \gamma m_0$. 于是

$$
\begin{aligned}
p &= \gamma m_0 v \\
E_k &= \int F \cdot dx = \int \frac{d}{dt}(mv) \cdot dx = \int v \cdot d(mv) \\
\text{而} d(mv) &= vdm + mdv \\
\text{则} E_k &= \int (v^2 dm + mvdv)
\end{aligned}
$$

考虑 $m^2(1-\frac{v^2}{c^2}) = m_0^2, m^2(c^2-v^2) = m_0^2 c^2$,两边微分得

$$
c^2 2mdm - v^2 2mdm - m^2 2vdv = 0, \\
c^2 dm - v^2 dm - mdv = 0, c^2 dm = v^2 dm + mdv
$$

于是

$$
\begin{aligned}
E_k &= \int c^2 dm = mc^2 - m_0 c^2 \\
&= m_0 c^2 \Big[\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} - 1\Big] \\
&= (\gamma - 1) m_0 c^2
\end{aligned}
$$

- 讨论
  - 牛顿力学中

$$
E_k = \int v \cdot d(mv) = \int mv \cdot dv = \frac{1}{2} mv^2
$$

- - 相对论中,mass-energy $\quad E = mc^2 = E_k + m_0 c^2$
- - 已知动能求速度: $\gamma = \dfrac{E_k}{m_0 c^2} + 1$
- 相对论能量-动量关系
  - $E = \sqrt{c^2 p^2 + m_0^2 c^4}$
  - 若 $m_0 = 0, E = cp, p = \dfrac{E}{c}$
  - 若 $cp << m_0 c^2$,泰勒展开后得到牛顿力学.

# 期末考试大致内容

- 相对论运动学: 速度的变换
- 理想气体(或给定气体的状态方程) 等温膨胀,绝热等过程, 功和热, 内能等
- 理想气体的性质: 速度,平均动能等
- 过程中温度的变化,熵的变化
- 过程中 **亥姆霍兹自由能变**, 求平衡态(可能有数学上求导等)
- 比热容, 温度.
- 相变 三相点.

# Project Proposal

- structure
  - Template

- Guideline
- how and where
- basics of thesis writing
- deadline

# 第十章 温度

## 10.1 Equilibruim state

- | System | exchange |
  | --- | --- |
  | isolated | $\times$ |
  | closed | energy |
  | open | energy&matter |
- Thermodynamic Equilibruim state: 宏观状态不随时间改变,除非外界条件发生变化.
- description of equilibruim state: state variables
  - extensive quantity: $F(n\ systems) = nF(1\ system)$
  - intensive quantity: $F(n\ systems) = F(1\ system)$
- relaxation time $\tau$: 恢复平衡所用时间
- Quasi-static process 准静态过程: $t >> \tau$, 每一点都是平衡态, 可以在状态图上画出.
- No-dissipative, quasi-static process is reversible. (无耗散准静态过程是可逆的); All natural process(自发过程) is irreversible.
  - 系统和外界同时恢复初态

## 10.2 Thermal equilibruim and temperature

- The zeroth law of thermodynamics: 热平衡的传递性(热平衡的系统有共同性质)
- 温度: 衡量热平衡的一种物理性质
- 各种温标

## 10.4 物态方程

- 微分的常见写法 $(\frac{\partial U}{\partial V})_T$ , $(\frac{\partial U}{\partial V})_P$ . 保持右下标不变
- $P, V, T 不独立, f(P, V, T) = 0 \to U(T, P) = U(T, V(P, T)) = U(T, V) = 0$
- 等压线膨胀系数 $a_\ell = \frac{1}{L}\frac{\partial L}{\partial T}_p$ ; $\alpha_V = \frac{1}{V}(\frac{\partial V}{\partial T})_P = \frac{1}{L^3}(\frac{\partial L^3}{\partial T})_P = 3\alpha_\ell$
- 等温线膨胀系数 $\kappa_T = -\frac{1}{V}\frac{\partial V}{\partial p}_T$
- 体积变化方程

$$
\begin{aligned}
\frac{dV}{V} &= \frac{1}{V}(\frac{\partial V}{\partial T})_p dT + \frac{1}{V}(\frac{\partial V}{\partial p})_T dp = \alpha_V(T)dT - \kappa_T(p)dp \\
&(全微分) \\
ln\frac{V}{V_0} &= \alpha_V\Delta T - \kappa_T\Delta p \\
V &= V_0(1 + \alpha_V\Delta T - \kappa_T\Delta p)
\end{aligned}
$$

- Van der Waal's equation

$$\left[p + a(\frac{n}{V})^2\right](V - nb) = nRT$$

推导: 对1mol理想气体:

$$p = \frac{RT}{V_m} \leftarrow \frac{RT}{V_m - b}(\text{相互作用, 体积减小})$$
$$\leftarrow \frac{RT}{V_m - b} - \frac{a}{V^2}(\text{相互作用, 压强减小, 体积越小作用力越大})$$

# 第十一章 热力学第一定律

## 11.1 功,内能和热力学第一定律

- 准静态过程压活塞 $\bar{d}W = -p\bar{d}V$, $W = -\int_{V_i}^{V_f} pdV$ (依赖于 $P - V$图上的路径,不是全微分)
- 绝热功: Internal energy function $\Delta U = U_B - U_A \equiv W_{BA} \equiv -W_{AB}$(用与路径无关的绝热功定义内能变化)
- 非绝热功: $\Delta U = W + Q$外界做的功和外界传给内部的热量; 微分 $dU = \bar{d}Q + \bar{d}W$(功和热不是全微分,与路径有关)

## 11.3 热容和比热容(Heat capacity and specific heat capacity)

- $C = \lim_{\Delta T \to 0} \frac{\Delta Q}{\Delta T}$; specific: $C_m = \frac{C}{n}$
  - $C = 0$: 绝热(adiabatic)过程, $\Delta Q = 0$
  - $C = \infty$: 等温(isothermal)过程,$\Delta T = 0$
- $C_V = \lim_{\Delta T \to 0}(\frac{\Delta Q}{\Delta T})_V = \lim_{\Delta T \to 0}(\frac{\Delta U}{\Delta T})_V = \left(\frac{\partial U}{\partial T}\right)_V$
- $C_P = \lim_{\Delta T \to 0}(\frac{\Delta Q}{\Delta T})_p = \lim_{\Delta T \to 0}(\frac{\Delta U + p\Delta V}{\Delta T})_p = \left(\frac{\partial(U + pV)}{\partial T}\right)_p \equiv \left(\frac{\partial H}{\partial T}\right)_{p'}$, $H = U + pV$: enthalpy, 焓
- ratio of specific heat: $\gamma = \frac{C_p}{C_V}$
- heat capacity of ideal gases

| **monatomic ideal gas** | $C_V = \frac{3}{2}nR$ |
| --- | --- |
| 双原子 ideal gas | $C_V = \frac{5}{2}nR$ |
| 三原子 ideal gas | $C_V = \frac{6}{2}nR$ |

## 11.4 Free expansion and internal energy of gas

- Case of free expansion

$$\begin{aligned}
U &= U(T,V) \\
dU &= (\frac{\partial U}{\partial T})_V dT + (\frac{\partial U}{\partial V})_T dV \\
T &= T(U,V) \\
dU &= (\frac{\partial U}{\partial T})_V [(\frac{\partial T}{\partial U})_V dU + (\frac{\partial T}{\partial V})_U dV] + (\frac{\partial U}{\partial V})_T dV \\
&\text{对照左右, 得} \\
(\frac{\partial U}{\partial T})_V (\frac{\partial T}{\partial U})_V &= 1 \\
(\frac{\partial U}{\partial V})_T &= -(\frac{\partial U}{\partial T})_V (\frac{\partial T}{\partial V})_U = -C_V (\frac{\partial T}{\partial V})_U \to \text{焦耳系数} = 0(\text{理想气体}) \\
\text{故} U &= U(T)
\end{aligned}$$

- 焦耳的实验非常不严谨
- 理想气体:

$$\begin{aligned}
dU(T) &= \frac{dU}{dT} dT = C_V dT \\
U &= U_0 + C_V T \\
dQ &= dU - dW = C_V dT + pdV \\
\text{理想气体}: d(pV) &= d(nRT) \\
pdV + Vdp &= nRdT, pdV = nRdT - Vdp \\
dQ &= (C_V + nR)dT - Vdp \\
C_p &= C_V + nR \to C_V = \frac{nR}{\gamma - 1}, C_p = \frac{\gamma nR}{\gamma - 1}
\end{aligned}$$

## 11.5 Adiabatic equation

$$\begin{aligned}
dQ &= dU - dW, \\
&= C_V dT + pdV \\
C_V dT + pdV &= 0 \\
\text{又} Vdp + pdV &= nRdT = (\gamma - 1) C_V dT
\end{aligned}$$

消去 $dT$,得

$$\begin{aligned}
Vdp + \gamma pdV &= 0 \\
\frac{dp}{p} + \gamma \frac{dV}{V} &= 0 \\
lnp + \gamma lnV &= C \\
pV^\gamma &= C
\end{aligned}$$

由 $\gamma > 1$, 绝热线比等温线陡峭

- adiabatic work

$$
\begin{aligned}
W_S &= -\int_{V_1}^{V_2} pdV = -C\int_{V_1}^{V_2}\frac{dV}{V^\gamma} = \frac{C}{\gamma-1}(\frac{V_2}{V_2^\gamma}-\frac{V_1}{V_1^\gamma}) \\
&= \frac{1}{\gamma-1}(p_2V_2-p_1V_1) \\
&= \frac{nR}{\gamma-1}(T_2-T_1) \\
&= C_V(T_2-T_1) = \Delta U
\end{aligned}
$$

- 声音的传播: 绝热

## 11.6 卡诺循环

- 高温热源 $T_1$等温膨胀→绝热膨胀→低温热源 $T_2$等温压缩→绝热压缩
- $T_1, U = U(T_1) = const$ 热机吸热,做功
- $T_2$ 热机放热
- 整个循环: $\Delta U = 0, \Delta Q_{12} + \Delta Q_{34} - \Delta W = 0$

$$
\begin{gathered}
\text{效率}\eta = \frac{\Delta W}{\Delta Q_{12}} = \frac{\Delta Q_{12}+\Delta Q_{34}}{\Delta Q_{12}} = \frac{Q_1-Q_2}{Q_1} \\
(\text{考察做功过程中的放热}Q_2\text{，放热越多效率越低})
\end{gathered}
$$

$$
\begin{aligned}
\text{等温过程}: Q_1 = \Delta W_{12} &= \int_{V_1}^{V_2} pdV = \int_{V_1}^{V_2}\frac{nRT_1}{V}dV = nRT_1 ln\frac{V_2}{V_1} \\
Q_2 &= -\Delta Q_{34} = nRT_2 ln\frac{V_3}{V_4} \\
\eta &= 1 - \frac{T_2 ln\frac{V_3}{V_4}}{T_1 ln\frac{V_2}{V_1}} \\
2\to 3: &T_1V_2^{\gamma-1} = T_2V_3^{\gamma-1} \\
4\to 1: &T_1V_1^{\gamma-1} = T_2V_4^{\gamma-1} \\
\eta &= 1-\frac{T_2}{T_1}
\end{aligned}
$$

要学会将此推导推广到其他热机上

- 可逆过程: 外界不可逆
- 逆卡诺循环: 从低温热源吸热 到高温热源被做功,放热

# 第十二章 热力学第二定律

## 12.1 内容

- No process is possible whose sole result is the absorption of heat from a reservoir and the conversion of this heat into work.
- No process is possible whose sole result is the transfer of heat from a cooler to a hotter body.
- 自发过程具有方向性

## 12.2 卡诺定理

- 任何热机效率不超过可逆热机

- 证明: 任意热机做功驱动可逆热机的逆过程, 反证法与热二矛盾

## 12.3 熵与熵原理

- 熵的引入

假设$Q_2 < 0$为放热:

$$\text{效率不大于卡诺热机}: \eta_A = 1 + \frac{Q_2}{Q_1} \leq 1 - \frac{T_2}{T_1}$$
$$\sum_{i=1}^{2} \frac{Q_i}{T_i} \leq 0$$
$$\text{一般过程}: \sum_{i=1}^{n} \frac{Q_i}{T_i} \leq 0 (\text{系统与很多热源接触})$$
$$\oint \frac{dQ}{T} \leq 0$$
$$(\text{取等}: \text{可逆过程}, \text{考虑} Q_i \to -Q_i)$$
$$(\text{环路积分})$$
$$\text{写作全微分}: \frac{\bar{d}Q}{T} \equiv dS$$
$$S_B - S_A = \int_A^B \left(\frac{dQ}{T}\right)_R$$

若环路中包含不可逆过程:

$$\oint \left(\frac{dQ}{T}\right) < 0$$
$$\int_A^B \left(\frac{dQ}{T}\right)_{IR} + \int_A^B \left(\frac{dQ}{T}\right)_R < 0$$
$$\int_A^B \left(\frac{dQ}{T}\right)_{IR} - \int_B^A \left(\frac{dQ}{T}\right)_R < 0$$
$$S_B - S_A > \int_A^B \left(\frac{dQ}{T}\right)_{IR}$$
$$\int_A^B dS > \int_A^B \left(\frac{dQ}{T}\right)_{IR}$$
$$dS > \left(\frac{dQ}{T}\right)_{IR}$$

- 熵原理: 任何过程: $dS \geq \dfrac{dQ}{T}$
  - 绝热过程: $dQ = 0$; 可逆: $dS = 0$, isentropic 等熵过程
  - 孤立系统: $dS \geq 0$; 非平衡趋于平衡: 熵增加; 平衡态: 宏观特征不变,熵最大
- 热二的另一种形式: The entropy of an isolated system never decreases.
  - 从单一热源吸热的熵变: $\Delta S = \dfrac{\Delta Q}{T} = \dfrac{-Q}{T} < 0$,矛盾!
  - 两热源 $T_1 > T_2$, $T_1$吸热, $T_2$放热: $\Delta S = \dfrac{Q}{T_1} - \dfrac{Q}{T_2} < 0$, 矛盾!

- 克劳修斯不等式的证明: 考虑多热源与单一热源 $T_0$由多个卡诺机联合:
  - 系统作循环过程,分别与热源 $T_i$交换 $Q_i$的热量
  - $T_0 \rightarrow T_i$之间加上卡诺热机
  - $T_0 \rightarrow Q_{0i}$
  - Carnot engines: $\frac{Q_{0i}}{T_0} = \frac{Q_i}{T_i}$
  - 对整个辅助系统: $T_i$,系统,热机不变, 热源 $T_0$ 放热,对外做功. 第一定律: $\sum_{n=1}^{n} Q_{0i} = \sum_{n=1}^{n} W_i$
  - 第二定律: 没有真正做功 $\sum_{n=1}^{n} Q_{0i} = T_0 \sum_{n=1}^{n} \frac{Q_i}{T_i} = \sum_{n=1}^{n} W_i \leq 0$

- 求熵变
  - 理想气体

$$
\begin{aligned}
dS &= \frac{1}{T}(dU + pdV)(\text{第一定律}) \\
&= C_V \frac{dT}{T} + nR\frac{dV}{V}(\text{第二类曲线积分}) \\
S_f - S_i &= C_v ln\frac{T_f}{T_i} + nRln\frac{V_f}{V_i} \\
S &= C_v lnT + nRlnV + S_0 \\
\text{状态函数}: S(T,V) &= C_v lnT + nRlnV + S_0
\end{aligned}
$$

- 
  - 
    - Free expansion from $V \rightarrow 2V(T = const)$:用熵作为状态函数来求: $\Delta S = nRln2 > 0$, irreversible
  - 热库reservior $\Delta S = \int \frac{dQ}{T} = \frac{\Delta Q}{T}$吸热熵增,放热熵减
  - 由准静态过程连接的状态: $\Delta S = \int_i^f \frac{dQ}{T}, dQ = C_p dT \ / \ C_V dT$
  - 由不可逆过程联系的: 找到相应的可逆过程(如不可逆的自由膨胀转化为等温过程) $\Delta S = \frac{1}{T}\int pdV = nRln\frac{V_f}{V_i}$
  - 混合: $\Delta S = \int_{T_1}^{T_f} \frac{m_1 c_1 dT}{T} + \int_{T_2}^{T_f} \frac{m_2 c_2 dT}{T}$
    - 吉布斯佯谬: 相同气体混合

- 再探功与热
  - 做功: 有广义距离: 电热丝,搅拌,微波炉等;
  - 但这些功只能转化为热,熵也就增加了⇒耗散功; 只要有耗散,就不可逆

- 熵的微观解释: $S = k_B lnW, W$: 微观状态数
  - 自由膨胀到两倍体积: $N$个粒子, $W = 2^N W_0,\ \Delta S = k_B N ln2$
  - 熵: 广延量: 微观状态用乘法原理计算, $lnW$可加
  - 习题 $(12.9)$:棋盘密度最大:平衡状态