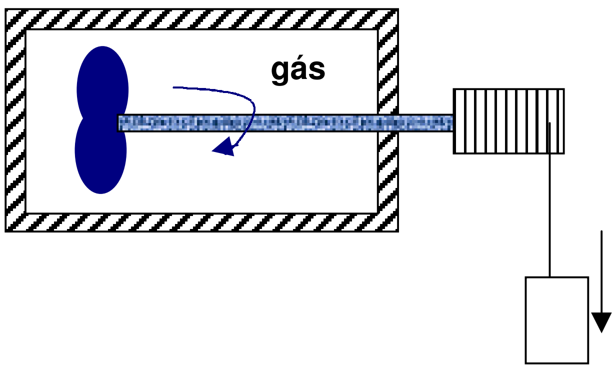
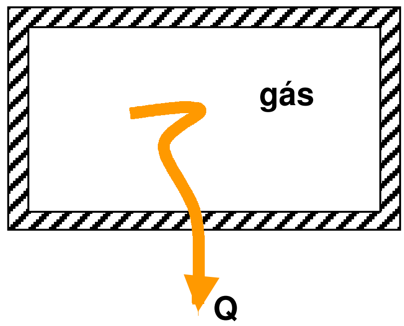
PRIMEIRA LEI DA TERMODINÂMICA

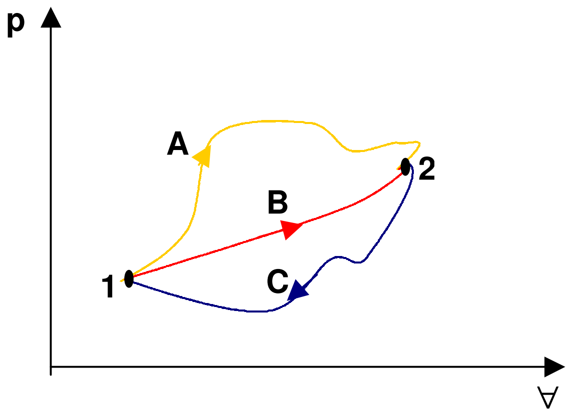
a)Primeira Lei para um Sistema percorrendo um ciclo





$$\oint \delta Q = \oint \delta W$$

b) Primeira Lei para Mudança de Estado de um Sistema



$$\oint \delta Q = \oint \delta W$$

$$\int_{1A}^{2A} \delta Q + \int_{2B}^{1B} \delta Q = \int_{1A}^{2A} \delta W + \int_{2B}^{1B} \delta W$$

$$\int_{1A}^{2A} \delta Q + \int_{2C}^{1C} \delta Q = \int_{1A}^{2A} \delta W + \int_{2C}^{1C} \delta W$$

$$\int_{2B}^{1B} \delta Q - \int_{2C}^{1C} \delta Q = \int_{2B}^{1B} \delta W - \int_{2C}^{1C} \delta W \longrightarrow \int_{2B}^{1B} (\delta Q - \delta W) =$$

$$= \int_{2C}^{1C} (\delta Q - \delta W)$$

$\therefore (\delta Q - \delta W)$ **independe do caminho**

função de ponto

$$\delta Q = \delta W = dE$$

$$\delta Q = dE + \delta W$$

$$_1Q_2 = E_2 - E_1 + {}_1W_2$$

$E = \textit{energia total do sistema}$

$$E = E_c + E_p + U$$

U → energia interna (estado termodinâmico do sistema

1ª Lei:

$$\delta Q = dE_c + dE_p + dU + \delta W$$

c) Energia Interna = Propriedade Termodinâmica

U = propriedade extensiva

$u = \dfrac{U}{m} =$ propriedade intensiva

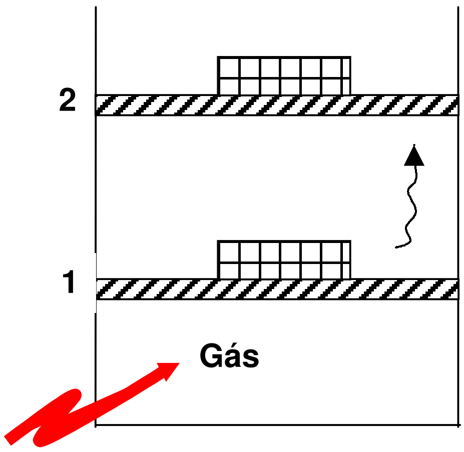
S.P.S.C → **u pode ser considerada uma das propriedades independentes para definir um estado termodinâmico**

<u>Na saturação</u>: $u = u_\ell + x\left(u_V - u_\ell\right)$

$$u = u_\ell + x u_{lv}$$

d) Entalpia

J. Gibbs (séc. 19)



Processo Quase-estático isobárico

$$ {}_1Q_2 = \Delta E + {}_1W_2 $$

$$ {}_1Q_2 = \Delta E + \int_1^2 p\,d\forall $$

Fazendo $\Delta E = U_2 - U_1$, isto é, $\Delta E_p = \Delta E_c = 0$

$$ {}_1Q_2 = U_2 - U_1 + p\left(\forall_2 - \forall_1\right) $$

$$ {}_1Q_2 = U_2 - U_1 + p\forall_2 - p\forall_1 $$

$$ {}_1Q_2 = \left(U_2 + p_2\forall_2\right) - \left(U_1 + p_1\forall_1\right) $$

$H = U + p\forall$ → **entalpia (propriedade termodinâmica)**

$$ {}_1Q_2 = H_2 - H_1 \left(\text{processo quase estático e } p = cte\right) $$

Na região de saturação

$$h = h_\ell + x h_{\ell v}$$

com

$$h_{\ell v} = h_v - h_\ell$$

e)Calores Específicos

$C_p \equiv$ *calor específico à pressão cte*

$C_v \equiv$ *calor específico a volume cte*

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v \qquad C_p = \left(\frac{\partial h}{\partial T}\right)_p$$

$$\left\{\begin{array}{l} \delta Q = du + \delta W \\ \delta Q = du + pd\forall \\ c_v = \dfrac{1}{m}\left(\dfrac{\delta Q}{\delta T}\right)_v = \dfrac{1}{m}\left(\dfrac{\delta U}{\delta T}\right)_v \\ c_p = \dfrac{1}{m}\left(\dfrac{\partial Q}{\partial T}\right)_p = \dfrac{1}{m}\left(\dfrac{\partial H}{\partial T}\right)_p \end{array}\right.$$

Gás Perfeito

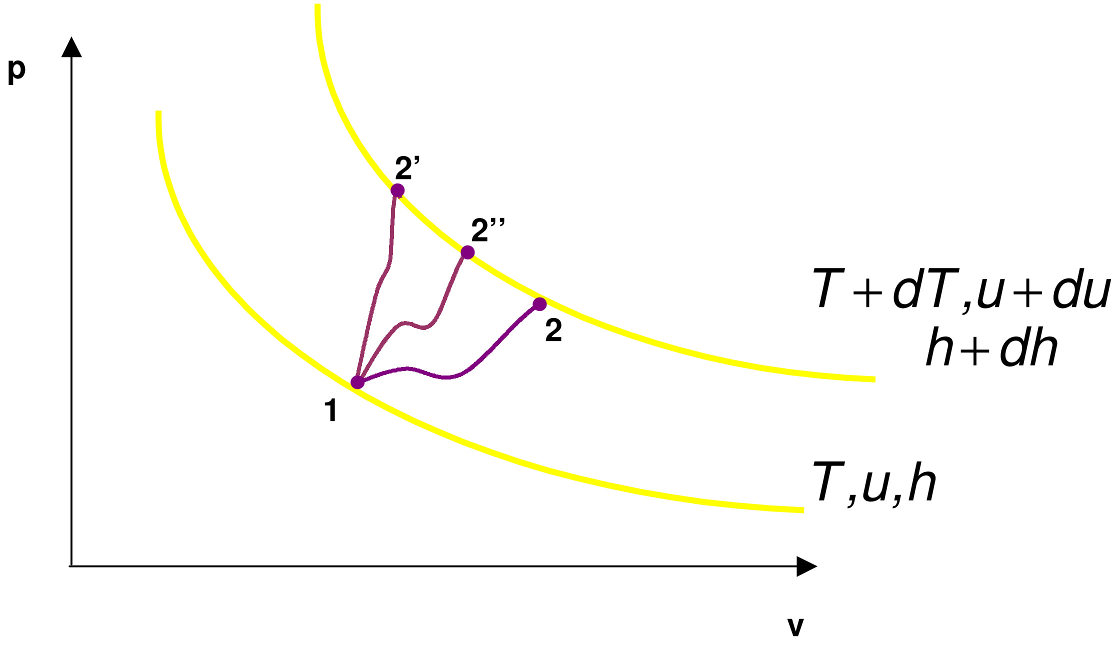
$$p = \rho R T$$

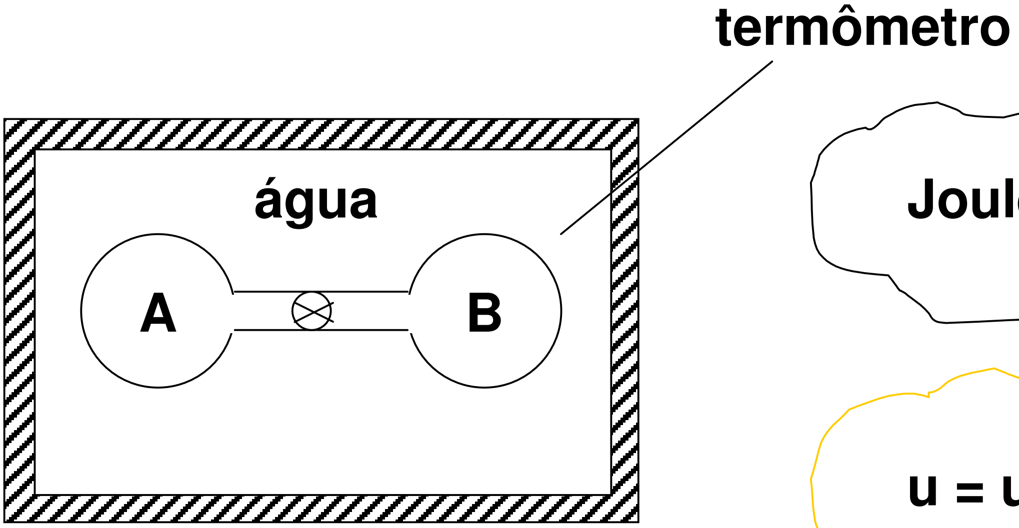
u = u(T)
h = h(T)

$$C_{vo} = \frac{\partial u}{\partial T} \quad \textbf{e} \quad C_{po} = \frac{\partial h}{\partial T}$$

Pressão zero

$$dU = mC_{vo}\, dT \qquad dH = mC_{po} dT$$





Joule 1843

$u = u(T)$

Relação entre C_{po} e C_{vo}

$$h = u + pv = u + RT$$

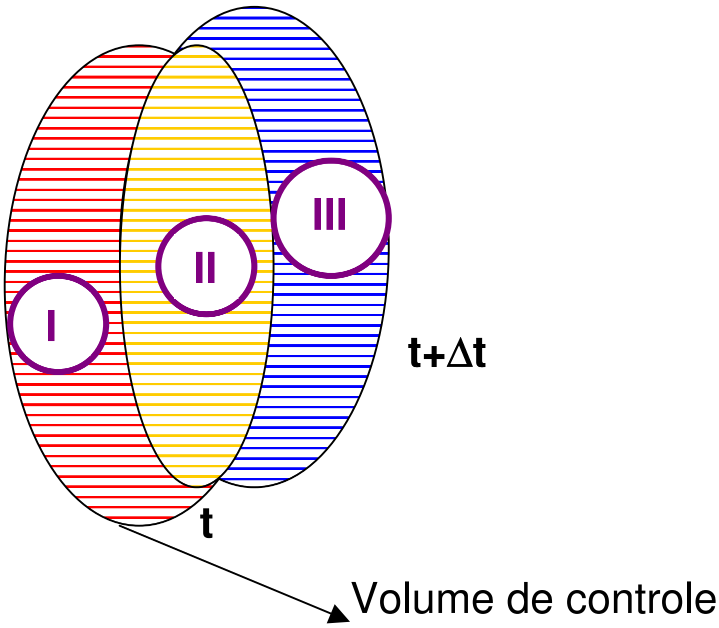
$$dh = du + RdT$$

$$C_{po}dT = C_{vo}dT + RdT$$

$$C_{po} - C_{vo} = R$$

Teorema do Transporte de Reynolds
(relação entre sistema e V.C.)

seja $\eta = \dfrac{N}{m} \qquad \rightarrow \qquad N = \int_{\forall} \eta \rho \, d\forall$



$$\left(\frac{dN}{dT}\right)_{Sist.} = \lim_{\Delta t \to 0} \left[\frac{\left(\int_{\forall\ III} \eta\rho d\forall + \int_{\forall\ II} \eta\rho d\forall \right)_{t+\Delta t} - \left(\int_{\forall\ I} \eta\rho d\forall + \int_{\forall\ II} \eta\rho d\forall \right)_{t}}{\Delta t} \right]$$

$$\left(\frac{dN}{dT}\right)_{Sist.} = \lim_{\Delta t \to 0} \left[\frac{\left(\int_{\forall\ II} \eta\rho d\forall \right)_{t+\Delta t} - \left(\int_{\forall\ I} \eta\rho d\forall \right)_{t}}{\Delta t} \right] +$$

$$+\lim_{\Delta t\to 0}\left[\frac{\left(\int_{\forall\, III}\eta\rho d\forall\right)_{t+\Delta t}}{\Delta t}\right]-\lim_{\Delta t\to 0}\left[\frac{\left(\int_{\forall\, I}\eta\rho d\forall\right)_{t}}{\Delta t}\right]$$

A $\rightarrow \frac{d}{dt}\int_{\forall.C}\eta\rho d\forall$

B $\rightarrow \int_{S.C.S.}\eta\rho\vec{v}.\vec{n}dS$ (saída)

C $\rightarrow \int_{S.C.E}\eta\rho\vec{v}.\vec{n}dS$ (entrada)

$$\therefore\left(\frac{dN}{dt}\right)_{sist.}=\frac{d}{dt}\int_{\forall.C.}\eta\rho d\forall+\int_{S.C.}\eta\rho\vec{v}.\vec{n}dS$$

.

***para N = m ⇒ η = 1 e**

$$\left(\frac{dm}{dt}\right)_{sist.}=0=\frac{d}{dt}\int_{\forall}\rho d\forall+\int_{S.C}\rho\vec{v}.\vec{n}dS$$

***para N =E** $\Rightarrow \eta = e = u + gz + \frac{v^2}{2}$

$$\dot{Q}_{v.c.} = \frac{d}{dt}\int_{v.c.} e\rho d\forall + \int_{s.c.}\left(u + gz + \frac{v^2}{2}\right)\rho\vec{v}.\vec{n}dS + \dot{W}$$

$$\dot{W} \rightarrow \dot{W}_{v.c.}$$

$$\dot{W} \rightarrow \dot{W}_{p}$$

$$\dot{W}_P = -\int_{s.c.} \sigma_n \vec{v}_r.\vec{n}dS$$ com $\sigma_n = -p$

$$\dot{W}_p = \int_{s.c.} p\left(\vec{v}_r.\vec{n}dS\right)$$

$$\dot{Q}_{\text{v.c.}} = \frac{d}{dt}\int_{\text{v.c.}} e\rho d\forall + \int_{s.c.}\left(u + gz + \frac{v^2}{2}\right)\rho\vec{v}_r.\vec{n}dS + \dot{W}_{r.c.} + \int_{s.c.} p\left(\vec{v}_i.\vec{n}dS\right)$$

$$\dot{Q}_{\text{v.c.}} = \frac{d}{dt}\int_{\text{v.c.}} e\rho d\forall + \int_{s.c.}\left[\left(u + gz + \frac{v^2}{2}\right) + pv\right]\rho\vec{v}_r.\vec{n}dS + \dot{W}_{\text{v.c.}}$$

lembrando que $h = u + pv$:

$$\dot{Q}_{v.c.} = \frac{d}{dt}\int_{v.c.} e\rho d\forall + \int_{s.c.}\left(h + gz + \frac{v^2}{2}\right)\rho\vec{v}_r.\vec{n}dS + \dot{W}_{v.c.}$$

Para condições em que as propriedades são uniformes nas seções onde há fluxos:

$$\dot{Q}_{V.c.} = \frac{d}{dt}\int_{V.c.} e\rho d\forall + \sum \dot{m}_s \left(h_s + gz_s + \frac{v_s^2}{2} \right) - \sum \dot{m}_e \left(h_e + gz_e + \frac{v_e^2}{2} \right) + \dot{W}_{V.c.}$$

Processo em Regime Uniforme com Escoamento Uniforme

<u>Hipóteses</u> - **V.C. fixo em relação ao sistema de referência**
- **estado da massa dentro do V.C. é uniforme para cada "t"**
- **estado da massa que cruza as S.C. é cte com "t", embora os "$\dot{m}_i$" possam variar com "t".**

<u>Balanço de Massa</u>:

$$\frac{d}{dt}\left(m_{v.c.}\right)+\sum \dot{m}_s-\sum \dot{m}_e=0$$

$$\left(m_2-m_1\right)_{\text{v.c.}}+\sum m_s-\sum m_e=0$$

1ª Lei:

$$\dot{Q}_{V.C.}+\sum \dot{m}_e\left(h_e+\frac{v_e^2}{2}+Z_e g\right)=\frac{d}{dt}\left(E_{V.C.}\right)+\sum \dot{m}_s\left(h_s+\frac{v_s^2}{2}+z_s g\right)+\dot{W}_{\text{V.C.}}$$

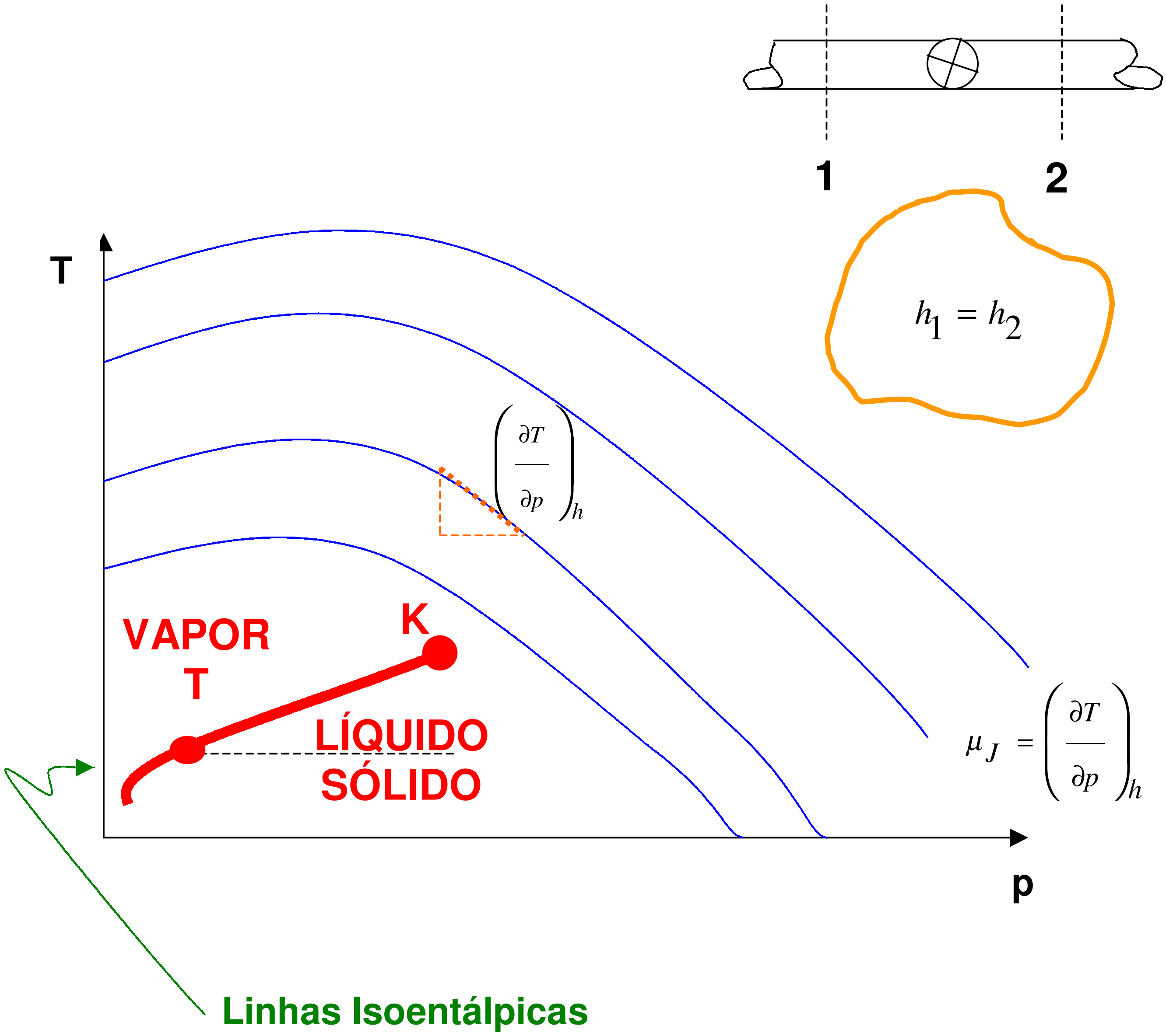
$$\frac{d}{dt}E_{v.c.}=\frac{d}{dt}\left[m\left(u+\frac{v^2}{2}+gz\right)\right]_{\text{v.c.}}$$

integrando entre os instantes 1 e 2:

$$\dot{Q}_{v.c.}=m_2\left(u_2+\frac{v_2^2}{2}+gz_2\right)-m_1\left(u_1+\frac{v_1^2}{2}+gz_1\right)+\sum m_s\left(h_s+\frac{v_s^2}{2}+gz_s\right)$$

$$-\sum m_e\left(h_e+\frac{v_e^2}{2}+gz_e\right)+W_{v.c.}$$

Coeficiente de Joule-Thomson



$\mu_J \rightarrow$ importante na análise de sistemas destinados à liquefação de gases