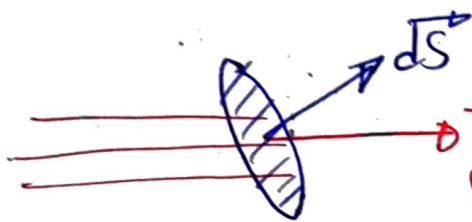


$$\frac{\delta Q_{th}}{\delta t} = P_{th} = \text{puissance thermique} \\ = \text{flux thermique (watt)}$$



$\vec{J}_{th}$ = vecteur densité
de courant thermique

$$P_{th} = \Phi_{th} = \iint \vec{J}_{th} \cdot \vec{dS}$$

$$I = \iint \vec{J}_e \cdot \vec{dS}$$

La loi d'Ohm locale

$$\vec{J}_e = \gamma \vec{E} = -\gamma \text{grad} V$$

Loi phénoménologique

$$\vec{J}_{th} = -\lambda \text{grad} T$$

γ ————— λ : conductivité
thermique

V ————— T

$\vec{J}_e$ ————— $\vec{J}_{th}$

I ————— Φ

$$J_{\text{diffus}} = -D \text{ grad}(n)$$

La loi de Adolphe Fick

1^{er} principe:

$$\frac{dH}{dt} = \frac{\delta W}{dt} + \frac{\delta Q_{\text{th}}}{dt} + \underbrace{P_{\text{pond}}}_{\text{fermé}}$$

Système indéformable : $\delta W = 0$

$$\left(\frac{\delta Q_{\text{th}}}{dt} \right)_{\text{recue}} = - \oint \vec{J}_{\text{th}} \cdot \vec{dS}$$



$$= - \iiint \text{div } \vec{J}_{\text{th}} d\tau$$

$$dH = \iiint dm c [T(\eta, t+dt) - T(\eta, t)]$$

$$\frac{dH}{dt} = \iiint dm c \frac{\partial T(\eta, t)}{\partial t} = \iiint \rho c \frac{\partial T}{\partial t} d\tau$$

$$P_{\text{pond}} = \iiint p_v d\tau$$

$$p_v = \vec{j}_e \cdot \vec{E}$$

$p_v = \text{donnée}$

$$\iiint \rho c \frac{\partial T}{\partial t} d\tau = - \iiint \text{div} \vec{j}_{\text{th}} d\tau + \iiint p_v d\tau$$

$$\rho c \frac{\partial T}{\partial t} = - \text{div} \vec{j}_{\text{th}} + p_v$$

$$= - \text{div} (-\lambda \text{grad} T) + p_v$$

$$\boxed{\frac{\rho c}{\lambda} \frac{\partial T}{\partial t} = \Delta T + \frac{p_v}{\lambda}}$$

Régime stationnaire $\frac{\partial T}{\partial t} = 0$

$$\Delta T(\mathbf{r}) + \frac{P}{\lambda} = 0$$

$$\Delta V(\mathbf{r}) + \frac{\rho}{\epsilon_0} = 0$$

Si en outre $P = 0$:

$$\Delta T(\mathbf{r}) = 0 \quad \text{Laplace.}$$

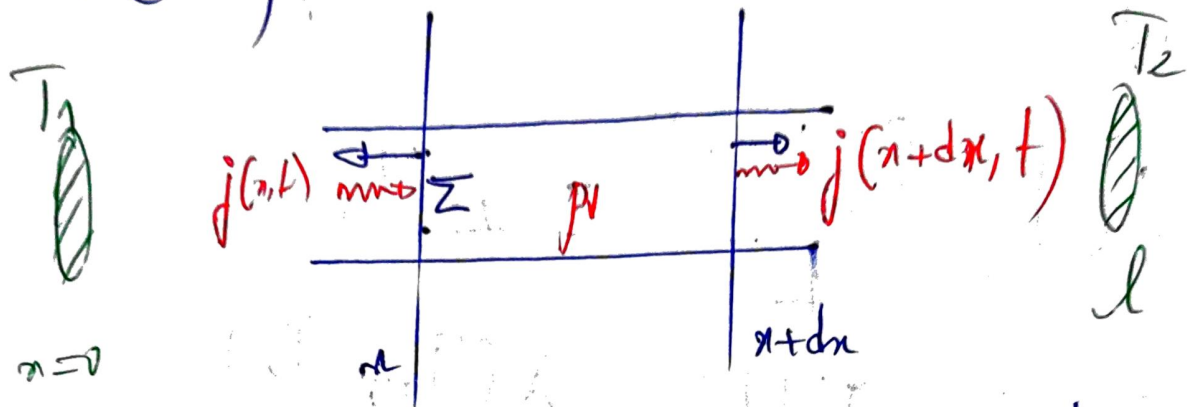
$$\Delta V(\mathbf{r}) = 0$$

Si $P = 0$

$$\frac{\partial}{\partial \lambda} \frac{\partial T}{\partial t} = \Delta T(\mathbf{r}, t)$$

$$\Delta \vec{E} - \mu_0 \gamma \frac{\partial \vec{E}}{\partial t} = 0$$

Gas cartésienne
 $T(x, t)$



$$\bullet \quad dH = dm c \frac{\partial T}{\partial t} dt = \rho c (\Sigma dx) \frac{\partial T}{\partial t} dt$$

$$\bullet \quad \frac{\delta Q_{th}}{dt} = - \oint \vec{j}_{th} \cdot d\vec{\Sigma}$$

$$= + [j_{th}(x, t) - j_{th}(x+dx, t)] \Sigma$$

$$\frac{\delta Q_{th}}{dt} = - \frac{\partial j_{th}}{\partial x} (dx \Sigma) ; \quad dP_{pno} = p_V \Sigma dx$$

$$\Rightarrow \rho c \frac{\partial T}{\partial t} = - \frac{\partial j_{th}}{\partial x} + p_V$$

$$\frac{\rho c}{\lambda} \frac{\partial T}{\partial t} = \frac{\partial^2 T}{\partial x^2} + \frac{p_V}{\lambda}$$

Steady state et $p_1 = 0$

$$\frac{d^2 T(x)}{dx^2} = 0$$

$$T(x) = \alpha x + \beta$$

$$T(x) = \frac{(T_2 - T_1)}{L} x + T_1$$

$$j(x) = -\lambda \frac{dT}{dx} = \frac{\lambda (T_1 - T_2)}{L}$$

$$\Phi = j(x) S = \frac{\lambda S}{L} (T_1 - T_2)$$

↓

$$I = \frac{(V_1 - V_2)}{R_e} \Rightarrow R_e = \frac{1}{\gamma} \frac{L}{S}$$

$$\Phi = \frac{T_1 - T_2}{R_{th}} \Rightarrow R_{th} = \frac{1}{\lambda} \frac{L}{S}$$

$G_{th} = \text{conductance thermique} = \frac{1}{R_{th}}$

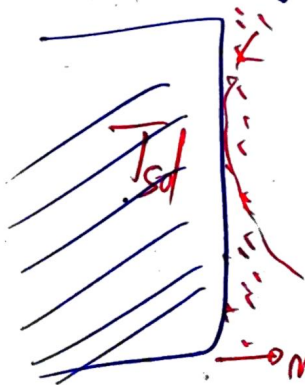
$R_{th} \rightarrow \text{K/watt}$

unité de (j_{th}) ; $\Phi = \int j_{th} dS$

$j_{th} \rightarrow \text{watt/m}^2$

• unité : λ $j_{th} = -\lambda \text{grad } T$
 $\lambda = \frac{\text{watt} \cdot \text{m}^{-2}}{\text{m}^{-1} \cdot \text{K}} = \text{watt} \cdot \text{K}^{-1} \cdot \text{m}^{-1}$

• convection : $j_{th} = h (T_{sd} - T_{\infty}) \vec{n}$



$T_{\infty} = T_{\text{fluide}}$

$h =$ coefficient conducto-convection

$h = \frac{\lambda_{\text{fluide}}}{m} = \text{watt K}^{-1} \cdot \text{m}^{-2}$

$\Phi_{th} = j_{th} S = h S (T_{sd} - T_{\text{fluide}})$

$R_{th}^{conv} = \frac{1}{h S}$

Bilan entropique

$$dS = \delta S_{ech} + \delta S_{créé}$$

$$\delta S_{ech} = \frac{\delta Q_{in}}{T(n,t)} - \frac{\delta Q_{out}}{T(n+dn,t)}$$

$$\delta S_{ech} = \frac{j_{th}(n,t) \Sigma dt}{T(n,t)} - \frac{j_{th}(n+dn,t) \Sigma dt}{T(n+dn,t)}$$

$$\frac{\delta S_e}{dt} = \left[- \frac{\partial}{\partial n} \left(\frac{j(n,t)}{T(n,t)} \right) \right] \Sigma dn$$

$$\begin{aligned} \frac{\delta S_e}{dt} &= \left[\lambda \frac{\partial}{\partial n} \left(\frac{1}{T} \frac{\partial T}{\partial n} \right) \right] \Sigma dn \\ &= \lambda \left[- \frac{1}{T^2} \left(\frac{\partial T}{\partial n} \right)^2 + \frac{1}{T} \frac{\partial^2 T}{\partial n^2} \right] \Sigma dn \end{aligned}$$

$$\text{or } dH = T dS - P dV \quad \text{Isochore}$$

$$dS = \frac{dH}{T} = \frac{g_c}{T} \frac{\partial T}{\partial n} (\Sigma dn)$$

$$\delta S_{\text{créée}} = dS - \delta S_{\text{ech}}$$

$$\frac{\delta S_{\text{créée}}}{dt} = \left[\frac{g_c}{T} \frac{\partial T}{\partial n} - \frac{1}{T} \frac{\partial^2 T}{\partial n^2} + \frac{\lambda}{T^2} \left(\frac{\partial T}{\partial n} \right)^2 \right] \Sigma dn$$

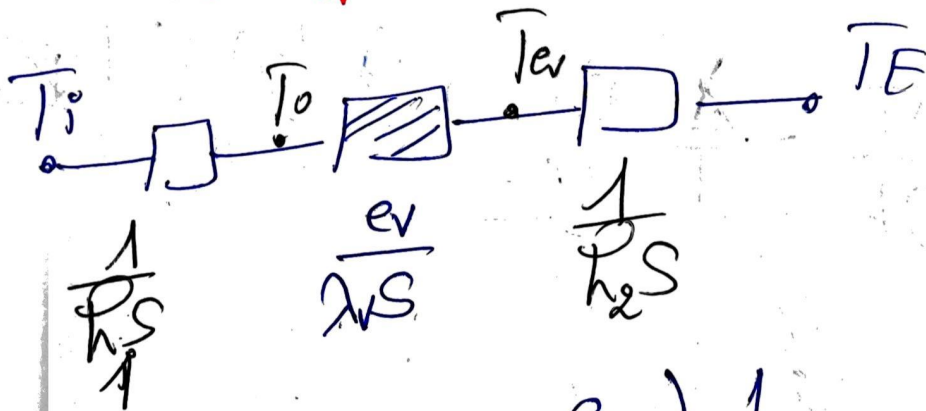
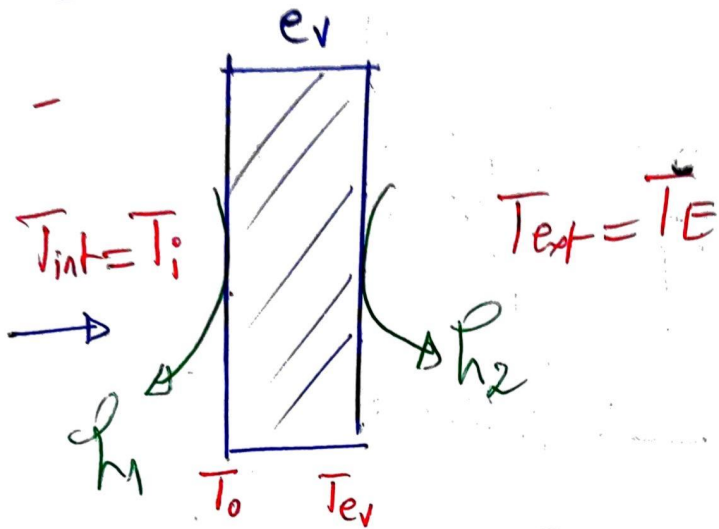
$$\frac{\delta S_{\text{créée}}}{dt} = \left[P_v + \frac{\lambda}{T^2} \left(\frac{\partial T}{\partial n} \right)^2 \right] \Sigma dn$$

$> 0 \qquad \qquad \qquad > 0$

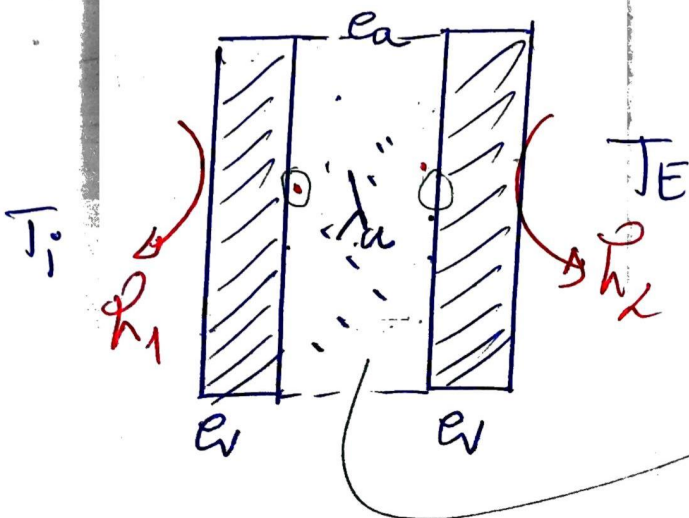
$$P_{\text{créée}} = \frac{\delta S_{\text{créée}}}{\Sigma dt dn} = p_v + \frac{\lambda}{T^2} \left(\frac{\partial T}{\partial n} \right)^2$$

↓
entropie volumique par unité de temps
: flux de création

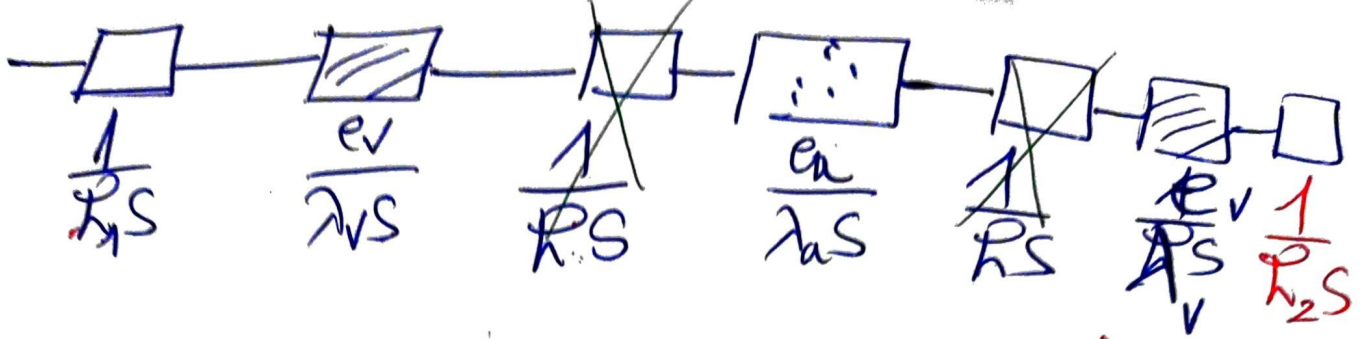
Ex 1



$$R_E = \left(\frac{1}{h_1} + \frac{1}{h_2} + \frac{e_v}{\lambda_v} \right) \frac{1}{S}$$



$$\frac{1}{h_1 S}$$

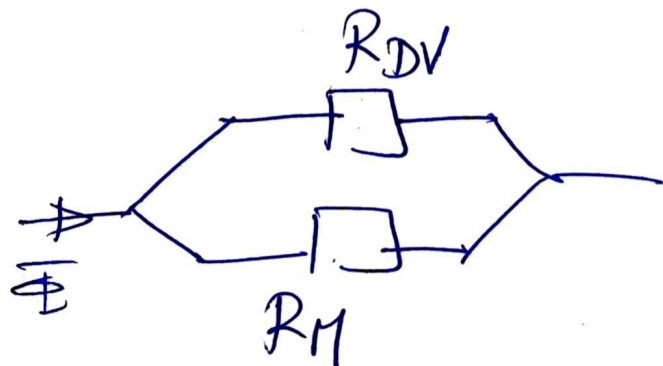
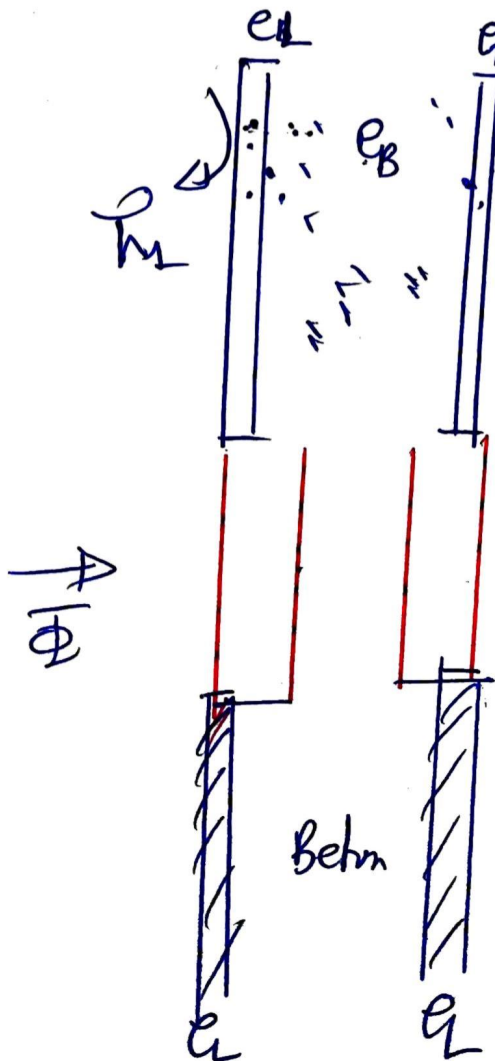


$$R_{DV} = \left(\frac{1}{h_1 S} + \frac{1}{h_2 S} + \frac{2e_v}{\lambda_v S} + \frac{e_a}{\lambda_a S} \right)$$

$$R_{DV} > R_{SH}$$

$$R_{SH} \nearrow, \quad \Phi_{SH} \searrow$$

$$R_{H1} = ?? \quad \left(\frac{1}{h_1} + \frac{1}{h_2} + \frac{2e_L}{\lambda_L} + \frac{e_B}{\lambda_B} \right) \frac{1}{S}$$



$$R_E = \frac{R_{H1} \cdot R_{DV}}{R_{H1} + R_{DV}}$$