◇ Optique

• Optique géométrique

⊛ Prisme :

$$n = \frac{\sin\left(\frac{A+D_m}{2}\right)}{\sin\left(\frac{A}{2}\right)} \qquad n^2 = a + \frac{b}{\lambda^2}$$

⊛ Miroirs sphériques :

$$\gamma = \frac{\overline{FA'}}{\overline{FS}} = \frac{\overline{FS}}{\overline{FA}} = -\frac{\overline{SA'}}{\overline{SA}} = \frac{\overline{CA'}}{\overline{CA}} \qquad \overline{FA}\,\overline{FA'} = FS^2 \text{ (Newton)} \qquad \frac{1}{\overline{SA'}} + \frac{1}{\overline{SA}} = \frac{1}{\overline{SF}} \text{ (Descartes)}$$

⊛ Lentilles :

$$\gamma = \frac{\overline{F'A'}}{\overline{F'O}} = \frac{\overline{FO}}{\overline{FA}} = \frac{\overline{OA'}}{\overline{OA}} \qquad \overline{FA}\,\overline{FA'} = -f'^2 \text{ (Newton)} \qquad \frac{1}{\overline{OA'}} - \frac{1}{\overline{OA}} = \frac{1}{f'} \text{ (Descartes)}$$

• Modèle scalaire de la lumière

$$E = h\nu = h\frac{c}{\lambda} = \hbar\omega \qquad \phi(M) = \frac{2\pi}{\lambda_{vide}}(SM) + \phi_S \qquad \delta = p\lambda$$

• Trous d'Young

$$\delta = \frac{2ax}{D} \qquad i = \frac{\lambda D}{2a}$$

• Michelson

⊛ Coin d'air : $\delta = 2e = 2\alpha x \qquad i = \frac{\lambda}{2\alpha}$

⊛ Lame d'air : $\delta = 2e\cos i$

⊛ Contraste/Visibilité : $\mathcal{C} = \frac{E_{max} - E_{min}}{E_{max} + E_{min}}$

• Diffraction

$$\sin i' - \sin i = pn\lambda = p\frac{\lambda}{d}$$

◇ Mécanique

• Mouvements dans les champs $\vec{E}$ et $\vec{B}$

$$\vec{f}_{\text{Laplace}} = q\left(\vec{E} + \vec{v} \wedge \vec{B}\right) \qquad Ep_{\grave{e}l} = qV + C^{ste}$$

• Mouvement à forces centrales

$$\vec{F} = \frac{k}{r^2} \qquad E_p = \frac{k}{r} \qquad r^2\dot{\theta} = C^{ste} \text{ Vitesse aréolaire} \qquad \frac{T^2}{a^3} = C^{ste} \qquad v_{lib} = \sqrt{2}v_{sat} = \sqrt{2\frac{GM}{R_T}}$$

• Changements de référentiels

$$\vec{v}_e = \left.\frac{d\overrightarrow{OO'}}{dt}\right|_{\mathcal{R}} + \vec{\Omega}_{\mathcal{R}'/\mathcal{R}} \wedge \overrightarrow{O'M} \qquad \vec{f}_{ie} = m\Omega^2\overrightarrow{HM} \qquad \vec{f}_{ic} = -2m\vec{\Omega}_{\mathcal{R}'/\mathcal{R}} \wedge \vec{v}_r$$

• Réduction du problème à 2 corps

$$\vec{r} = r\,\vec{e}_r = \overrightarrow{M_1M_2} \qquad \mu = \frac{m_1\,m_2}{m_1 + m_2}\ (masse\ r\acute{e}duite) \qquad \mu\ddot{\vec{v}} = f_G(r)\vec{e}_r \Rightarrow \vec{r}(t)\begin{cases} \vec{r}(t) = \vec{r}_1(t) + \vec{r}_2(t) \\ m_1\vec{r}_1(t) + m_2\vec{r}_2(t) \end{cases}$$

• Cinétique des systèmes matériels

$$\vec{v} = \begin{pmatrix} \dot{r} \\ r\,\dot{\theta} \\ \dot{z} \end{pmatrix} \qquad \vec{a} = \begin{pmatrix} \ddot{r} - r\,\dot{\theta}^2 \\ r\,\ddot{\theta} + 2\dot{r}\,\dot{\theta} \\ \ddot{z} \end{pmatrix} \qquad \vec{v} = \frac{ds}{dt}\,\vec{T} \qquad \vec{a} = \vec{a}_T + \vec{a}_N = \frac{dv}{dt}\,\vec{T} + \frac{v^2}{\mathbb{R}}\vec{N}$$

$$\vec{\sigma}_A = \vec{\sigma}_B + \overrightarrow{AB} \wedge m\,\vec{v}_g \text{ (Varignon)} \qquad \vec{\sigma}_A = \vec{\sigma}^\star + \overrightarrow{AG} \wedge m\,\vec{v}_g \qquad E_c = E_c^\star + \frac{1}{2}m\,v_G^2 \text{ (König)}$$

• Cinématique du solide

$$\vec{v}_P = \vec{v}_Q + \overrightarrow{PQ} \wedge \vec{\Omega}_{\mathcal{S}} \qquad \sigma_\Delta = \mathcal{J}_\Delta\,\Omega \qquad E_c = \mathcal{J}_\Delta\frac{\Omega^2}{2} \qquad \overrightarrow{M_A} = \overrightarrow{M_B} + \overrightarrow{BA} \wedge \vec{F}$$

• Lois de Coulomb

Glissement (opposé au mouvement) : $\left\|\vec{T}\right\| = f\,\left\|\vec{N}\right\|$ Non glissement : $\left\|\vec{T}\right\| \leq f\,\left\|\vec{N}\right\|$

• Puissance et travail

$$\mathcal{P}_{glisseur} = \vec{F}\cdot\vec{v}_{pt\ app} \qquad \mathcal{P}_{couple} = \vec{\Omega}\cdot\vec{\Gamma} \qquad \delta W_{conserv} = -dE_px$$

$$\frac{dE_c}{dt} = \frac{\delta W_{int}}{dt} + \frac{\delta W_{ext}}{dt} = \mathcal{P}_{int} + \mathcal{P}_{ext}$$

◇ Opérateurs différentiels

• Opérateur gradient

$$\mathrm{dU} = \overrightarrow{\mathrm{grad}}\,\mathrm{U} \cdot \overrightarrow{\mathrm{d}l}$$

$$\overrightarrow{\mathrm{grad}}\,\mathrm{U} = \begin{pmatrix} \frac{\partial \mathrm{U}}{\partial x} \\ \frac{\partial \mathrm{U}}{\partial y} \\ \frac{\partial \mathrm{U}}{\partial z} \end{pmatrix} \qquad \overrightarrow{\mathrm{grad}}\,\mathrm{U} = \begin{pmatrix} \frac{\partial \mathrm{U}}{\partial r} \\ \frac{1}{r}\frac{\partial \mathrm{U}}{\partial \theta} \\ \frac{\partial \mathrm{U}}{\partial z} \end{pmatrix} \qquad \overrightarrow{\mathrm{grad}}\,\mathrm{U} = \begin{pmatrix} \frac{\partial \mathrm{U}}{\partial r} \\ \frac{1}{r}\frac{\partial \mathrm{U}}{\partial \theta} \\ \frac{1}{r\sin\theta}\frac{\partial \mathrm{U}}{\partial \varphi} \end{pmatrix}$$

$$\overrightarrow{\mathrm{grad}}\,\mathrm{U} = \vec{\nabla}\mathrm{U} \text{ où (en cartésiennes) } \vec{\nabla} = \begin{pmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \\ \frac{\partial}{\partial z} \end{pmatrix}$$

Formule du gradient : $\displaystyle\oiint_{(\Sigma)} \mathrm{U}(\mathrm{M},t)\,\overrightarrow{\mathrm{dS}} = \iiint_{(\mathrm{V})} \overrightarrow{\mathrm{grad}}\,\mathrm{U}(\mathrm{M},t)\,\mathrm{d}\tau$

• Opérateur divergence

$$\oiint_{(\Sigma)} \vec{a}(\mathrm{M},t)\cdot\overrightarrow{\mathrm{dS}} = \iiint_{(\mathrm{V})} \mathrm{div}\,\vec{a}(\mathrm{M},t)\,\mathrm{d}\tau\ ,\forall \mathrm{V}$$

$$\mathrm{div}\,\vec{a} = \frac{\partial a_x}{\partial x} + \frac{\partial a_y}{\partial y} + \frac{\partial a_z}{\partial z}$$

$$\mathrm{div}\,\vec{a} = \vec{\nabla}\cdot\vec{a}$$

• Opérateur rotationnel

$$\oint_{(\mathscr{C})} \vec{a}(\mathrm{M},t)\cdot\overrightarrow{\mathrm{d}l} = \iint_{(\mathscr{S})} \overrightarrow{\mathrm{rot}}\,\vec{a}(\mathrm{M},t)\cdot\overrightarrow{\mathrm{dS}}$$

$$\overrightarrow{\mathrm{rot}}\,\vec{a} = \vec{\nabla}\wedge\vec{a}$$

• Opérateur laplacien

$$\Delta\mathrm{U} = \mathrm{div}\left(\overrightarrow{\mathrm{grad}}\,\mathrm{U}\right) \qquad \vec{\Delta}\vec{a} = \overrightarrow{\mathrm{grad}}\,(\mathrm{div}\,\vec{a}) - \overrightarrow{\mathrm{rot}}\left(\overrightarrow{\mathrm{rot}}\,\vec{a}\right) = \nabla^2\vec{a}$$

En cartésiennes : $\Delta\mathrm{U} = \nabla^2\mathrm{U} = \dfrac{\partial^2\mathrm{U}}{\partial x^2} + \dfrac{\partial^2\mathrm{U}}{\partial y^2} + \dfrac{\partial^2\mathrm{U}}{\partial z^2}$ $\qquad \vec{\Delta}\vec{a}\begin{pmatrix} \Delta a_x \\ \Delta a_y \\ \Delta a_z \end{pmatrix}$ $\qquad \Delta\left(\dfrac{1}{r}\right) = 0$

• Quelques formules de calcul

⊛ À savoir par coeur :

$$\overrightarrow{\mathrm{rot}}\left(\overrightarrow{\mathrm{grad}}\,\mathrm{U}\right) = 0 \qquad \mathrm{div}\left(\overrightarrow{\mathrm{rot}}\,\vec{a}\right) = 0 \qquad \overrightarrow{\mathrm{rot}}\left(\overrightarrow{\mathrm{rot}}\,\vec{a}\right) = \overrightarrow{\mathrm{grad}}\,(\mathrm{div}\,\vec{a}) - \vec{\Delta}\vec{a}$$

$$\vec{u}\wedge(\vec{v}\wedge\vec{w}) = (\vec{u}\cdot\vec{w})\vec{v} - (\vec{u}\cdot\vec{v})\vec{w}$$

⊛ À savoir retrouver :

$$\overrightarrow{\mathrm{grad}}\,(\mathrm{U\,V}) = \mathrm{U}\,\overrightarrow{\mathrm{grad}}\,\mathrm{V} + \mathrm{V}\,\overrightarrow{\mathrm{grad}}\,\mathrm{U} \qquad \mathrm{div}\,(\vec{a}\wedge\vec{b}) = \vec{b}\cdot\overrightarrow{\mathrm{rot}}\,\vec{a} - \vec{a}\cdot\overrightarrow{\mathrm{rot}}\,\vec{b}$$

• Dérivée particulaire

$$\frac{\mathrm{D}\vec{a}}{\mathrm{D}t} = \frac{\partial\vec{a}}{\partial t} + \left(\vec{a}\cdot\overrightarrow{\mathrm{grad}}\right)(\vec{a}) = \frac{\partial\vec{a}}{\partial t} + \overrightarrow{\mathrm{grad}}\left(\frac{a^2}{2}\right) - \vec{a}\wedge\overrightarrow{\mathrm{rot}}\,\vec{a}$$

◇ Éléctromagnétisme

• Électrocinétique

$$i = C\frac{dU_c}{dt} \qquad q = CU \qquad U = L\frac{di}{dt} \qquad e = r\eta \text{ (Thèvenin} \sim \text{Norton)}$$

Ampli Op : **Idéal** $\Rightarrow i^{\oplus} = i^{\ominus} = 0$ et en régime **linéaire** $\Rightarrow V^{\oplus} = V^{\ominus}$

$$\tau = RC = \frac{L}{R} \qquad \mathcal{E} = \frac{1}{2}Li^2 = \frac{1}{2}CE^2 \qquad \omega_0^2 = \frac{1}{LC}$$

• Filtres

$$x = \frac{\omega}{\omega_c} \qquad \underline{H}(\jmath\omega) = \frac{\underline{H_0}}{1+\jmath x} \qquad \underline{H}(\jmath\omega) = \frac{\underline{H_0}\,\jmath x}{1+\jmath x}$$

$$x = \frac{\omega}{\omega_0} \qquad \underline{H}(\jmath\omega) = \frac{\underline{H_0}}{1-x^2+\jmath\frac{x}{Q}} \qquad \underline{H}(\jmath\omega) = \frac{-x^2\,\underline{H_0}}{1-x^2+\jmath\frac{x}{Q}} \qquad \underline{H}(\jmath\omega) = \frac{\underline{H_0}}{1+\jmath\, Q\left(x-\frac{1}{x}\right)} \qquad \Delta x = \frac{1}{Q}$$

⊛ Résonance si $Q > \frac{1}{\sqrt{2}}$. Si $Q \gg 1 \Rightarrow x_r \simeq 1$ et $\beta = Q$ la surtension de résonance

• Puissance en régime sinusoïdal

$$\mathscr{P}_{instant} = U\,i \qquad \mathscr{P}_{moy} = U_{eff}\,I_{eff}\cos\varphi = \Re e(\underline{\mathcal{Z}})\,I_{eff}^2 = \Re e(\underline{Y})\,U_{eff}^2 =$$

⊛ Adaptation d'impédance : $\mathcal{Z}_c = \mathcal{Z}_g^{\star}$

• Electro & Magnéto statique

$$\vec{E}(M) = \frac{1}{4\pi\varepsilon_0}\iiint \frac{\rho(P)}{PM^2}\vec{u}_{PM}\,d\tau \text{ (Gauss)} \qquad V(M) = \frac{1}{4\pi\varepsilon_0}\iiint \frac{\rho}{r}\,d\tau$$

$$\vec{B}(M) = \frac{\mu_0}{4\pi}\int \frac{i\,\overrightarrow{dl}\wedge\vec{u}_{PM}}{r^2} = \frac{\mu_0}{4\pi}\iiint \frac{\vec{j}\wedge\vec{u}_{PM}}{r^2} \text{ (Biot \& Savart)}$$

$$\Phi_{\mathcal{S}}(\vec{E}) = \frac{Q_{int}}{\varepsilon_0} \qquad \Phi_{\mathcal{S}}(\vec{g}) = -4\pi G M_{int} \qquad \oint_{\mathscr{C}} \vec{B}\cdot\overrightarrow{dl} = \mu_0 I_{enlacé}$$

$$d\vec{f}_{\text{Laplace}} = i\,\overrightarrow{dl}\wedge\vec{B} = \vec{j}\,d\tau\wedge\vec{B} \qquad C = \frac{\varepsilon_0 S}{e}$$

⊛ Dipôles :

$$\vec{p} = q\,\overrightarrow{NP} \qquad V(r,\theta) = \frac{p\cos\theta}{4\pi\varepsilon_0 r^2} \qquad \vec{E} = -\overrightarrow{\text{grad}}\,V = \frac{1}{4\pi\varepsilon_0 r^3}\begin{pmatrix} 2p\cos\theta \\ p\sin\theta \end{pmatrix} \qquad \vec{\Gamma} = \vec{P}\wedge\vec{E}_{ext}$$

$$\overrightarrow{M} = \vec{S}\,I \qquad \vec{B} = \frac{\mu_0}{4\pi r^3}\begin{pmatrix} 2M\cos\theta \\ M\sin\theta \end{pmatrix} \qquad \vec{\Gamma} = \overrightarrow{M}\wedge\vec{B} \qquad Ep = -\vec{p}\cdot\vec{E}_{ext} = \overrightarrow{M}\cdot\vec{B}_{ext}$$

• Loi d'Ohm

$$I = \frac{dQ}{dt} = \iint_{S}\vec{j}\cdot\overrightarrow{dS} \qquad \vec{j} = nq\vec{v} \qquad \vec{j} = \gamma\vec{E} \qquad \rho = \frac{1}{\gamma}\ (\Omega.m) \qquad \mathscr{P}_{\text{Joule}} = \vec{j}\cdot\vec{E} = \gamma E^2$$

En série : $R = \int \frac{\rho\,dl}{S}$ En parallèle : $G = \int \frac{\gamma\,dS}{l}$ $\Rightarrow$ Fil cylindrique : $R = \frac{\rho\,l}{S}$

- **Équations de Maxwell**

$$\operatorname{div}\vec{\mathrm{B}}(\mathrm{M};t) = 0 \qquad \overrightarrow{\mathrm{rot}}\ \mathrm{E}(\mathrm{M};t) = -\frac{\partial\vec{\mathrm{B}}}{\partial t}(\mathrm{M};t)$$

$$\operatorname{div}\vec{\mathrm{E}}(\mathrm{M};t) = \frac{\rho(\mathrm{M};t)}{\varepsilon_0} \qquad \overrightarrow{\mathrm{rot}}\ \mathrm{B}(\mathrm{M};t) = \mu_0\,\vec{j}(\mathrm{M};t) + \varepsilon_0\frac{\partial\vec{\mathrm{E}}}{\partial t}(\mathrm{M};t)$$

$$\vec{\mathrm{B}} = \overrightarrow{\mathrm{rot}}\ \vec{\mathrm{A}} \qquad \vec{\mathrm{E}} = -\frac{\partial\vec{\mathrm{A}}}{\partial t} - \overrightarrow{\mathrm{grad}}\,\mathrm{V} \qquad \vec{\mathrm{E}}_2 - \vec{\mathrm{E}}_1 = \frac{\sigma}{\varepsilon_0}\vec{n}_{1\to 2} \qquad \vec{\mathrm{B}}_2 - \vec{\mathrm{B}}_1 = \mu_0\vec{j}_{\mathcal{S}} \wedge \vec{n}_{1\to 2}$$

$$\mathrm{d}\mathscr{P}_{\text{LORENTZ}} = \vec{j}\cdot\vec{\mathrm{E}}\ \mathrm{d}\tau \qquad \vec{\Pi} = \frac{\vec{\mathrm{E}}\wedge\vec{\mathrm{B}}}{\mu_0} \qquad e = \frac{\varepsilon_0}{2}\mathrm{E}^2 + \frac{1}{2\mu_0}\mathrm{B}^2\ (J.m^{-3})$$

- **Propagation des OEM**

$$c^2 = \frac{1}{\varepsilon_0\mu_0} \qquad \vec{\mathrm{B}} = \frac{\vec{u}\wedge\vec{\mathrm{E}}}{c} = \frac{\vec{k}\wedge\vec{\mathrm{E}}}{\omega}$$

- **Milieux diélectriques**

$$\vec{\mathrm{P}} = \chi_e\varepsilon_0\vec{\mathrm{E}} \qquad \varepsilon_r = 1 + \chi_e \qquad n = \sqrt{\varepsilon_r(\omega)}$$

- **Induction**

$$\vec{\mathrm{E}}_m = -\frac{\partial\vec{\mathrm{A}}}{\partial t} + \vec{v}_e\wedge\vec{\mathrm{B}} \qquad e_{\mathrm{AB}} = \int_{\mathrm{A}}^{\mathrm{B}}\vec{\mathrm{E}}_m\cdot\overrightarrow{\mathrm{d}l} \qquad e = -\frac{\mathrm{d}\Phi}{\mathrm{d}t} \qquad \Phi = \mathrm{L}\,i$$

◇ Phénomènes de propagation

$$\frac{\Delta\mathrm{L}}{\mathrm{L}} = \frac{\mathrm{F}}{\mathrm{ES}} \qquad c = \sqrt{\frac{\mathrm{E}}{\mu_{vol}}} = \sqrt{\frac{\mathrm{T}}{\mu_{lin}}}$$

$$k = \frac{\omega}{c} \qquad \lambda = \frac{2\pi}{k} = \frac{2\pi c}{\omega} = c\mathrm{T} \qquad v_\phi = \frac{\omega}{k'} \qquad v_g = \frac{\mathrm{d}\omega}{\mathrm{d}k}$$

◇ Mécanique des fluides

• Statique des fluides

⊛ Relation fondamentale de la statique des fluides et applications :

$$\overrightarrow{\mathrm{d}f_p} = \mathrm{P}\,\overrightarrow{\mathrm{dS}} \qquad \overrightarrow{\mathrm{grad}}\,\mathrm{P} = \overrightarrow{f_{vol}} \qquad \frac{\mathrm{dP}}{\mathrm{d}z} = -\rho\,\mathrm{g} \qquad \mathrm{P}(z) = \mathrm{P}_0\,\exp\left(\frac{-\mathrm{M}_{air}\mathrm{g}\,z}{\mathrm{RT}_0}\right)$$

⊛ Poussée d'Archimède : $\vec{\Pi} = \vec{\mathrm{P}_\mathrm{A}} = -\rho\,\mathrm{V}\,\mathrm{g}$

• Cinématique des fluides

⊛ Conservation de la masse :

$$\frac{\partial\rho}{\partial t} + \mathrm{div}\,\rho\vec{v} = 0 \qquad \rho = \mathrm{C}^{ste} \;\to \mathrm{div}\,\vec{v} = 0 \;\to \vec{v}\cdot\vec{\mathrm{S}} = \mathrm{C}^{ste}$$

⊛ Vecteur tourbillon : $\vec{\Omega} = \frac{1}{2}\overrightarrow{\mathrm{rot}}\,\vec{v}$

• La viscosité

$$\overrightarrow{\mathrm{d}f_{viscosit\acute{e}}} = \eta\frac{\mathrm{dV}_x}{\mathrm{d}y}\,\mathrm{dS}\,\vec{x} \qquad \overrightarrow{f_{vol/viscosit\acute{e}}} = \eta\,\Delta\vec{v} \qquad \nu = \frac{\eta}{\rho} \quad (m^2.s^{-1})$$

$$\rho\frac{\mathrm{D}\vec{v}}{\mathrm{D}t} = -\overrightarrow{\mathrm{grad}}\,\mathrm{P} + \rho\,\vec{g} + \eta\,\Delta\vec{v} \qquad \text{Navier-Stockes}$$

On en déduit : Bernouilli (permanent, parfait, incompressible, LdC/irrotationnel)

$$\rho\frac{v^2}{2} + \mathrm{P} + \rho g z = \mathrm{C}^{ste}$$

$$\overrightarrow{f_{flu\to sph\grave{e}re}} = -6\pi\eta\,r\,\vec{v} \qquad \mathrm{Re} = \frac{rv}{\nu} \qquad \overrightarrow{f_{flu\to objet}} = \frac{1}{2}\rho\,v^2\,\mathrm{S}\,\mathrm{C}_x \text{ (coeff trainée)}$$

• Ondes acoustiques

$$c^2 = \frac{1}{\rho_0\chi_\mathrm{S}} \qquad c = \sqrt{\frac{\gamma\mathrm{RT}}{\mathrm{M}}} \qquad \mathrm{P} = \mathcal{Z}\,v \quad \mathcal{Z} = \pm\rho_0 c$$

$$\mathrm{E} = \frac{1}{2}\rho_0 v^2 + \frac{1}{2}\chi_\mathrm{S} p^2$$

◇ Thermodynamique

• Coefficients thermo-élastiques

$$\alpha = \frac{1}{V}\left.\frac{\partial V}{\partial T}\right|_P \text{ Dilatation thermique} \qquad \chi_T = \frac{-1}{V}\left.\frac{\partial V}{\partial P}\right|_T \text{ Compressibilité isotherme}$$

• Equations d'état

$$PV = nRT \qquad \left(P + \frac{n^2}{V^2}a\right)(V - nb) = nRT$$

• Capacités thermiques

$$C_V = \left.\frac{\partial U}{\partial T}\right|_V \leftrightarrow dU = C_V\,dT \qquad C_P = \left.\frac{\partial H}{\partial T}\right|_P \leftrightarrow dH = C_P\,dT$$

$$C_P - C_V = nR \qquad \gamma = \frac{C_P}{C_V} \qquad C_V = \frac{nR}{\gamma - 1} \qquad C_P = \frac{nR\gamma}{\gamma - 1}$$

• Loi de Laplace

$$TV^{\gamma-1} = C^{ste} \qquad PV^{\gamma} = C^{ste'} \qquad T^{\gamma}P^{1-\gamma} = C^{ste''}$$

• Fonctions d'état

$$H = U + PV \qquad G = H - TS \qquad F = U - TS \qquad \delta W = -P_{ext}\,dV$$

$$dU = T\,dS - P\,dV \qquad dH = T\,dS + V\,dP \qquad dF = -S\,dT - P\,dV \qquad dG = -S\,dT + V\,dP$$

• Formule de Clapeyron

$$h_2 - h_1 = T(v_2 - v_1)\left(\frac{dP}{dT}\right)_{éq}$$

$$\underset{0°C}{\text{Glace}} \xrightarrow{334\,kJ.kg^{-1}} \underset{0°C}{\text{Eau}} \xrightarrow[\textit{donc}\ 418\,kJ.kg^{-1}]{4.18\,kJ.kg^{-1}.K^{-1}} \underset{100°C}{\text{Eau}} \xrightarrow{2260\,kJ.kg^{-1}} \underset{100°C}{\text{Vapeur}}$$

• Phénomènes de diffusion

Loi de Stephan : $\mathcal{P}_{tot} = \sigma\, T^4$ Loi de Wien : $T\,\lambda_{max} \approx 2800$ K.μm

$$\frac{\partial e}{\partial t} + \operatorname{div}\vec{j} = 0 \ (\textit{conservation}) \qquad \underset{part.m^{-3}}{\vec{j}_n} = -D\,\overrightarrow{\text{grad}}\,C \ (\text{Fick}) \qquad \underset{W.m^{-2}}{\vec{j}_Q} = -\lambda\,\overrightarrow{\text{grad}}\,T \ (\text{Fourier})$$

$$\frac{\partial T}{\partial t} = \frac{\lambda}{\rho c}\,\Delta T \ (\textit{eq chaleur}) \qquad \Phi_{1\to 2} = hS(T_1 - T_2) \ (\text{Newton})$$