

$$\vec{F}_{\text{mol}} = \frac{1}{2} [\vec{J}_S \wedge \vec{B}] dS$$

$$\boxed{\vec{J} = \gamma \vec{E}}$$

$$v_g = \frac{c}{n} < 1$$

$$\vec{F}_{\text{Lap}} = \left(\frac{\vec{J} \wedge \vec{B}_{\text{tot}}}{2} \right) d\tau$$

$$n_{\text{air}} = 2$$

$$n_{\text{verre}} > 1$$

$$\underline{k} = k' - i k''$$

atténuation

$$n_{\text{eau}} > 1$$

prop

$$\frac{P_{\text{plasma}}}{N \underline{V}}$$

+ e M : Ions

- e m : électrons

$$\underline{E} = \underline{E}_0 e^{i(kz - \omega t)} \quad (0z)^+$$

$$\underline{E}_0 = E_0 \begin{vmatrix} 1 \\ i\alpha \\ 0 \end{vmatrix}$$

$$\frac{\|\vec{F}_{\text{mag}}\|}{\|\vec{F}_{\text{el}}\|} = \left| \frac{q \vec{v} \wedge \vec{B}}{q \vec{E}} \right| = \frac{v(B)}{E}$$

$$\sim \frac{v}{v_g} \sim \frac{v}{c} \ll 1 \quad \leftarrow \text{particule}$$

non relativiste

$$m \frac{d\vec{v}}{dt} = -e\vec{E} \Rightarrow -i\omega m \vec{v} = -e\vec{E}$$

$$\vec{v} = \frac{e}{i m \omega} \vec{E} = -\frac{ie}{m\omega} \vec{E}$$

$$\boxed{\vec{V} = \frac{+ie}{m\omega} \vec{E}}$$

$$g = +e$$

$$g_{ele} = -e$$

$$\vec{J} = e \vec{v} + e_{\text{I}} \vec{V} = \sum_{i=1} \int \rho_i \vec{v}_i$$

$$= N(-e) \vec{v} + N(e) \vec{V}$$

$$\vec{J}_{\text{tot}} = +\frac{iNe^2}{\omega} \left(\frac{1}{m} + \frac{1}{M} \right) \vec{E}$$

$$\frac{1}{m} + \frac{1}{M} = \frac{1}{\mu} \Rightarrow \mu = \frac{mM}{m+M}$$

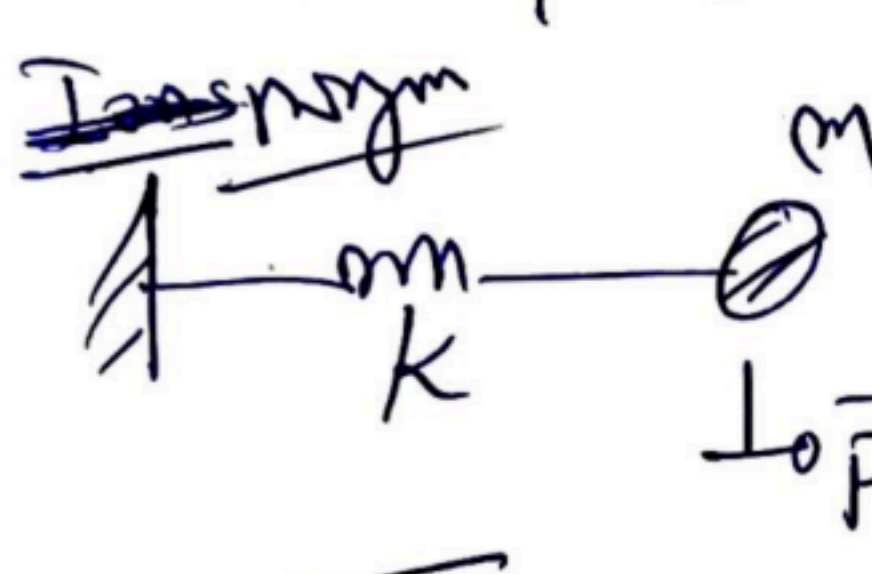
$\mu =$ la masse réduite

$$m \ll M \Rightarrow \mu \simeq m$$

$$\underline{\vec{J}_{tot}} = \frac{i N e^2}{\omega m} \underline{\vec{E}}$$

$$\omega_p^2 = \frac{N e^2}{m \epsilon_0} \Rightarrow \underline{\vec{J}_{tot}} = \left(\frac{i \epsilon_0 \omega_p^2}{\omega} \right) \underline{\vec{E}}$$

~~Transmym~~



$m(-e)$

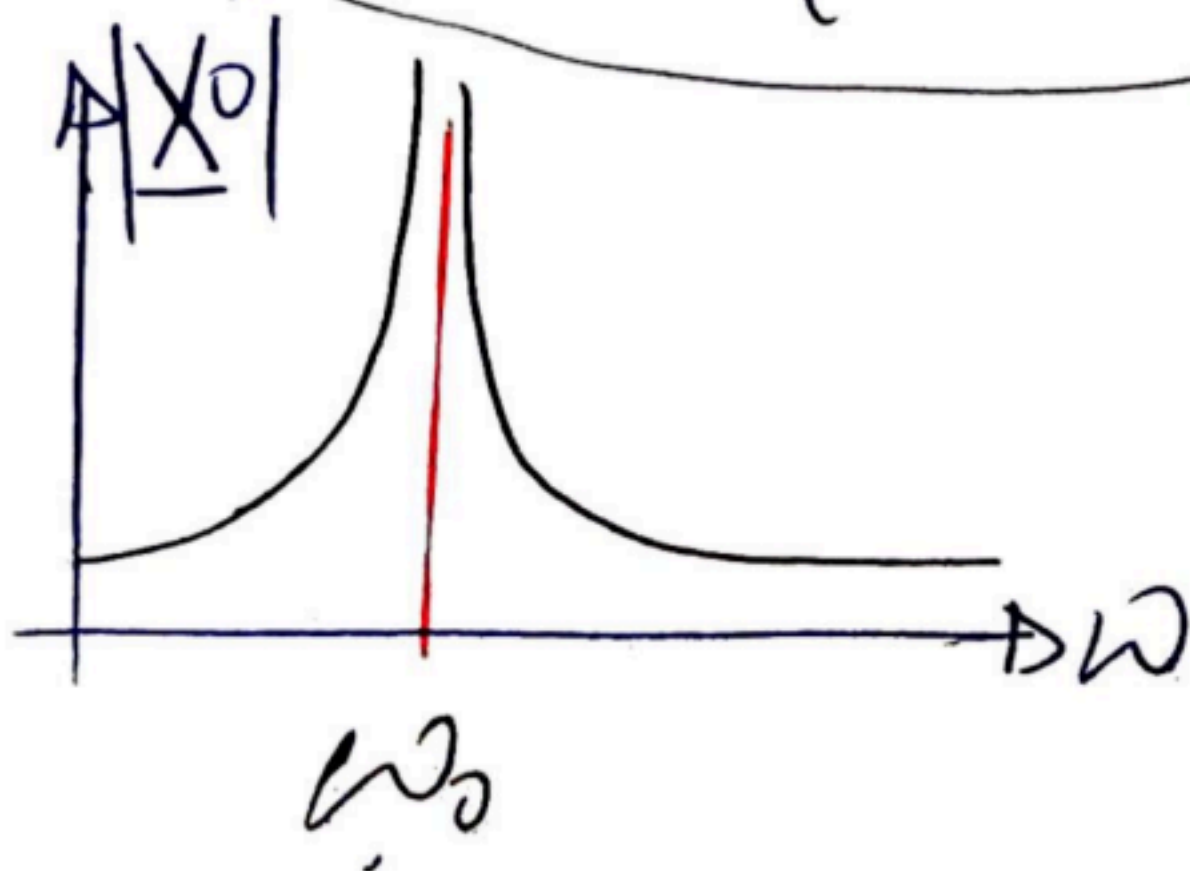
$\underline{\vec{F}}(t)$

$\underline{m} \ddot{x} + \frac{k}{m} x = \frac{F_0}{m} \cos(\omega t)$

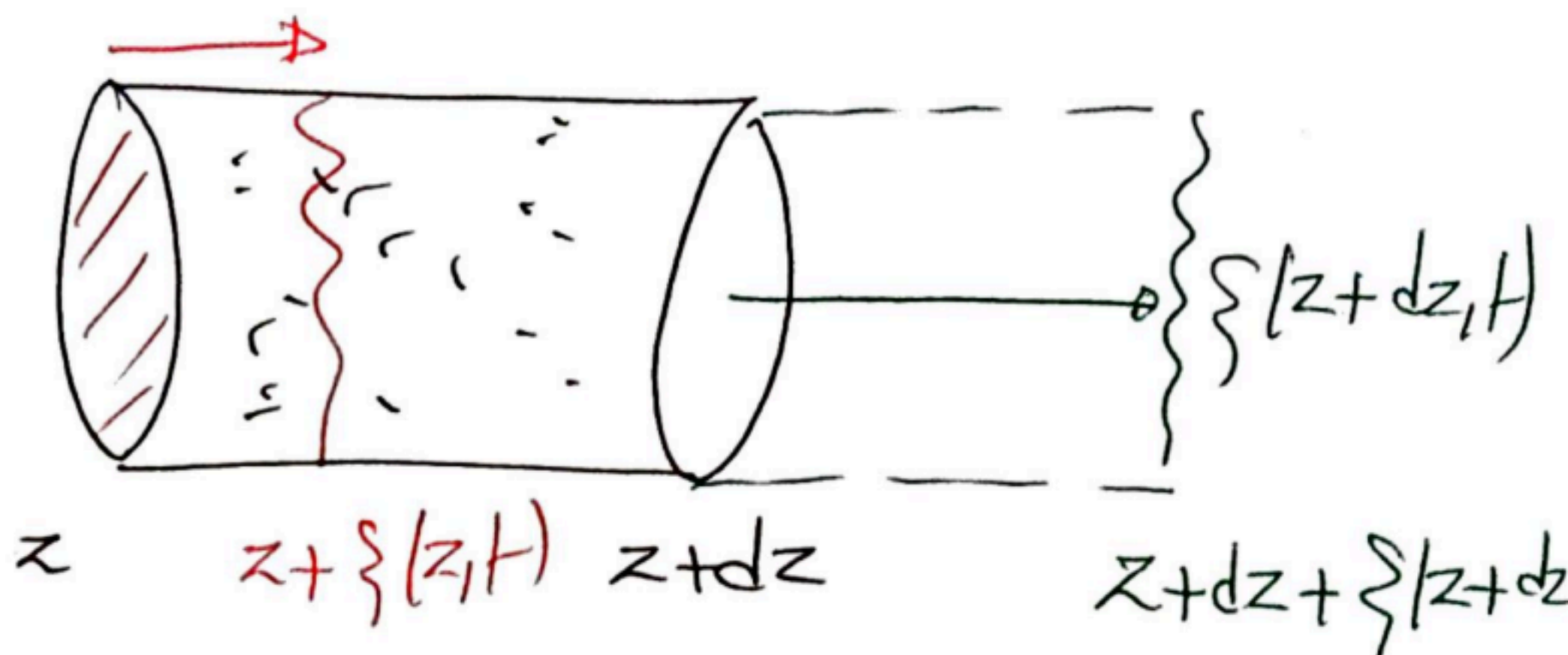
$$\omega_0 = \sqrt{\frac{k}{m}} ; \ddot{x} + \omega_0^2 x = \frac{F_0}{m} \cos(\omega t)$$

$$\underline{x} (+\omega_0^2 - \omega^2) = \frac{F_0}{m} e^{j\omega t}$$

$$\underline{x} = \frac{\frac{F_0}{m} e^{j\omega t}}{(\omega_0^2 - \omega^2)} = \underline{X_0} e^{j\omega t}$$



3) a)



$$N(Sdz) = N^- S [dz + \xi(z+dz, t) - \xi(z, t)]$$

$\downarrow$ am repos $\downarrow$ en mov

$$N = N^- \left(1 + \frac{\partial \xi}{\partial z} \right)$$

$$N^- = N \left(1 - \frac{\partial \xi}{\partial z} \right) \therefore \underline{\underline{d.l}}$$

$$\boxed{N^+ = N} \quad \underline{\text{Ions fixes}} \quad \underline{\rho \gg m}$$

$$\rho = N^+ e - \bar{N} e$$

$$= N e - N \left(1 - \frac{\partial \xi}{\partial z} \right) e = + N e \frac{\partial \xi}{\partial z}$$

$$\rho = N e \frac{\partial \xi(z, t)}{\partial z}$$

$$\frac{\partial E}{\partial z} = \frac{\rho}{\epsilon_0} = \frac{Ne}{\epsilon_0} \frac{\partial \xi(z,t)}{\partial z}$$

$$E(z,t) = \frac{Ne}{\epsilon_0} \xi(z,t)$$

RFD $m \ddot{\xi} = -\frac{e^2 N}{\epsilon_0} \xi(z,t) \quad \underline{\omega_p^2}$

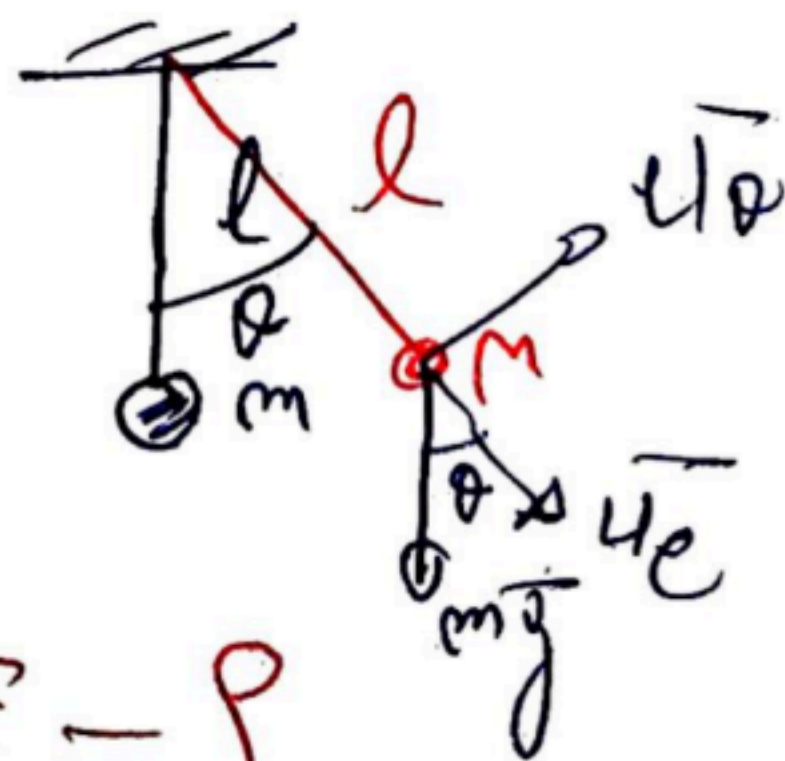
$$\ddot{\xi}(z,t) + \left(\frac{Ne^2}{m\epsilon_0} \right) \xi(z,t) = 0$$

$$\omega_p^2 = \frac{Ne^2}{m\epsilon_0}$$

$$\ddot{x} + \omega^2 x = 0$$

$$\ddot{\theta} + \omega^2 \theta = 0$$

$$\ddot{\theta} + \frac{g}{l} \theta = 0$$



$$\text{div } \underline{E} = \frac{\rho}{\epsilon_0}$$

4) $\text{div } \underline{J} + \frac{\partial \rho}{\partial t} = 0$

$$\textcircled{0} \text{div } \underline{E} + \frac{\partial \rho}{\partial t} = 0 \Rightarrow \frac{1}{\epsilon_0} \rho + (-i\omega) \rho = 0$$

$$\frac{1}{\epsilon_0} = \frac{\gamma}{\epsilon_0}$$

$$\rho \left[\frac{i\omega p^2}{\omega} - i\omega \right] = 0 \Rightarrow \underline{\rho} = 0 \quad \omega \neq \omega_p$$

$$(\text{div}) \vec{E} = 0 = +i \vec{k} \cdot \vec{E} \Rightarrow \underline{\vec{k} \perp \vec{E}}$$

$$(\vec{\nabla} \cdot \vec{E}):$$

$$\begin{aligned} 5) \vec{\nabla} \cdot (\vec{\nabla} \times \vec{E}) &= \vec{\nabla} \cdot \left(-\frac{\partial \vec{B}}{\partial t} \right) = -\frac{\partial (\vec{\nabla} \cdot \vec{B})}{\partial t} \\ &= -\frac{\partial}{\partial t} \left(\mu_0 \left(\underline{\nabla} \cdot \vec{E} + \epsilon_0 \frac{\partial \vec{E}}{\partial t} \right) \right) = -\Delta \vec{E} \\ \Rightarrow \underline{\Delta \vec{E}} - \mu_0 \underline{\nabla} \cdot \left(\frac{\partial \vec{E}}{\partial t} \right) - \frac{1}{c^2} \frac{\partial^2 \vec{E}}{\partial t^2} &= 0 \end{aligned}$$

$$\left[-k^2 \vec{E} - \mu_0 \underline{\nabla} \cdot (-i\omega) - \frac{1}{c^2} (-\omega^2) \right] \vec{E} = 0$$

$$\underline{k^2} = \frac{\omega^2}{c^2} + i \mu_0 \underline{\nabla} \omega$$

$$\underline{k^2} = \frac{\omega^2}{c^2} \left[1 + \frac{i \underline{\nabla}}{\epsilon_0 \omega} \right]; \underline{\nabla} = \frac{i \epsilon_0 \omega_p^2}{\omega}$$

$$\boxed{\underline{k^2} = \frac{\omega^2}{c^2} \left[1 - \frac{\omega_p^2}{\omega^2} \right]} \quad \text{dispersion}$$

$$\underline{k^2 < 0} \quad \underline{\omega < \omega_p} \quad \underline{k = \pm i k''}$$

$$\underline{k} = +i k'' \quad (k' = 0);$$

$$\begin{aligned} \underline{\vec{E}} &= \underline{\vec{E}_0} \exp i \left(\textcolor{red}{i k'' z} - \omega t \right) \\ &= \underline{\vec{E}_0} \exp(-k'' z) e^{-i\omega t} \end{aligned}$$

5) a) évanescence : reflexion totale : ne se propage pas

$$\textcolor{red}{Pq} \quad \underline{\vec{B}} = \frac{\underline{k} \wedge \underline{\vec{E}}}{\omega} = \frac{i k''}{\omega} \underline{\vec{E}} (\underline{\vec{u}}_z \wedge \underline{\vec{u}}_x) = \frac{i k''}{\omega} \underline{\vec{E}} \underline{\vec{u}}_y$$

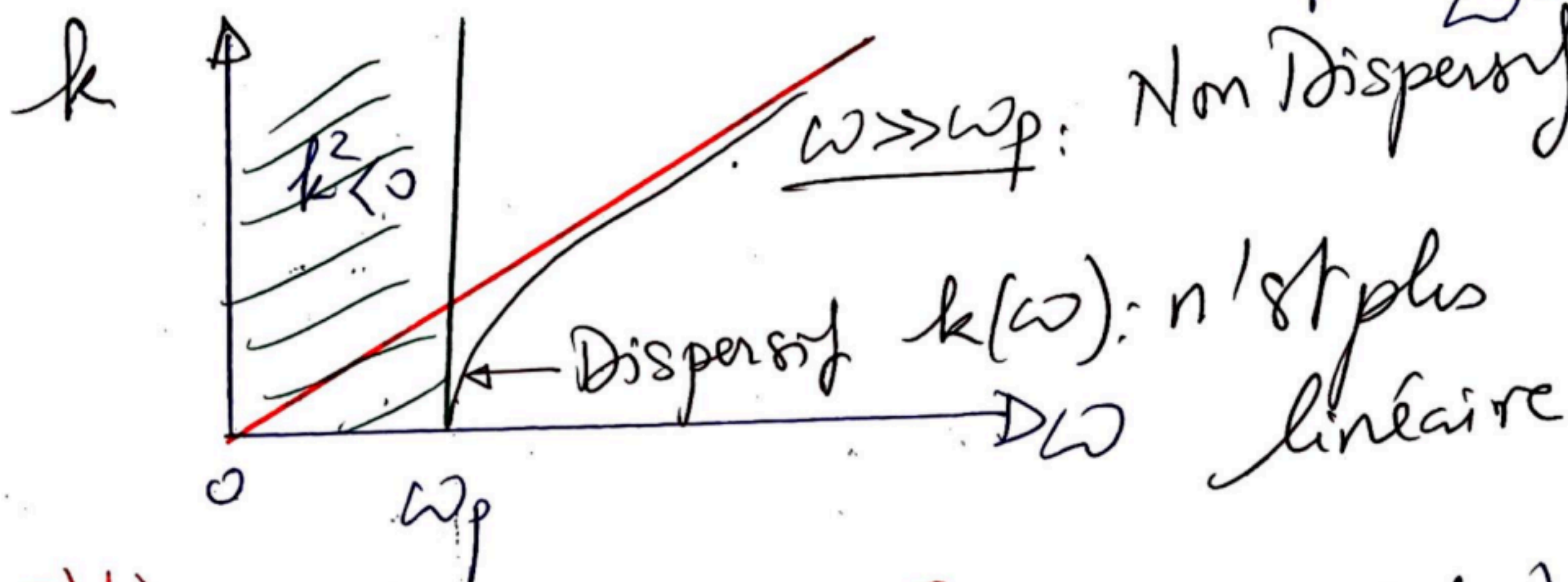
$$\langle \vec{R} \rangle = \frac{1}{2\mu_0} \text{Re} \left[\underline{\vec{E}} \wedge \underline{\vec{B}}^* \right] \quad \textcolor{red}{\rightarrow 0}$$

$$\left[\frac{E_0 e^{-k'' z} e^{-i\omega t}}{2\mu_0} \cdot \textcolor{red}{\text{Imaginaire pur}} \frac{i k''}{\omega} E_0 e^{-k'' z} e^{i\omega t} \right]$$

$$\underline{k^2 > 0}$$

$$\underline{\omega > \omega_p}$$

$$k = k' = \frac{\omega}{c} \sqrt{1 - \frac{\omega_p^2}{\omega^2}}$$



5) b)

Rq: $v_g = \frac{\omega}{k'(\omega)} = \frac{c}{\sqrt{1 - \frac{\omega_p^2}{\omega^2}}} = v_{\varphi}(\omega)$

dépend de ω : $\rightarrow$ Dispersif

$\omega \gg \omega_p$ $v_g \simeq c$: Non dispersif

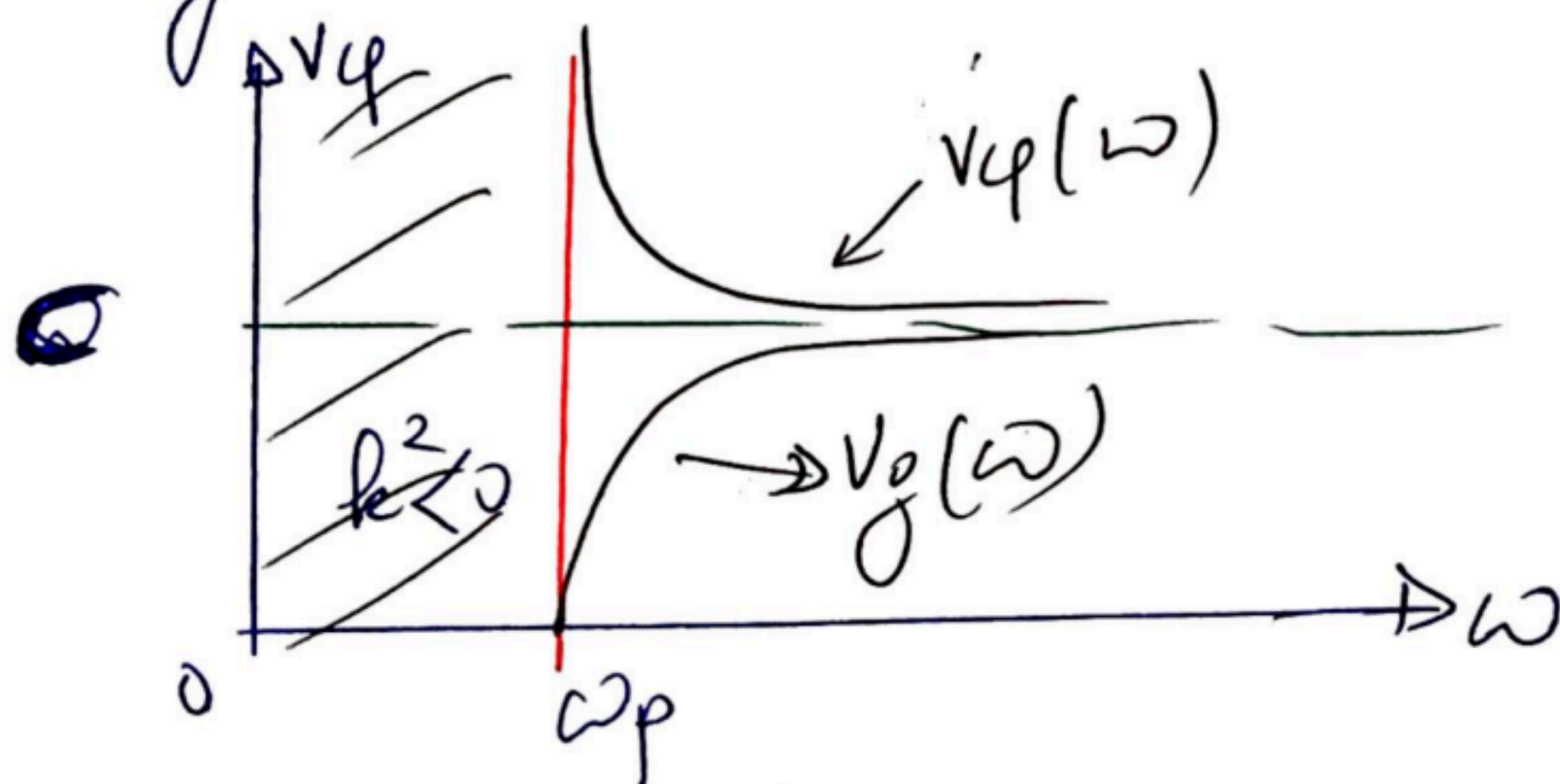
$$* k^2 = \frac{\omega^2}{c^2} - \left(\frac{\omega_p^2}{c^2} \right) = \frac{\omega^2}{c^2} + \text{cte}$$

$$2 k dk = \frac{2 \omega d\omega}{c^2}$$

$$\frac{d\omega}{dk} = \frac{c^2}{\omega/k} \Rightarrow v_g = \frac{c^2}{v_{\varphi}} = c \sqrt{1 - \frac{\omega_p^2}{\omega^2}}$$

$$v_g = c \sqrt{1 - \frac{\omega_p^2}{\omega^2}} < c$$

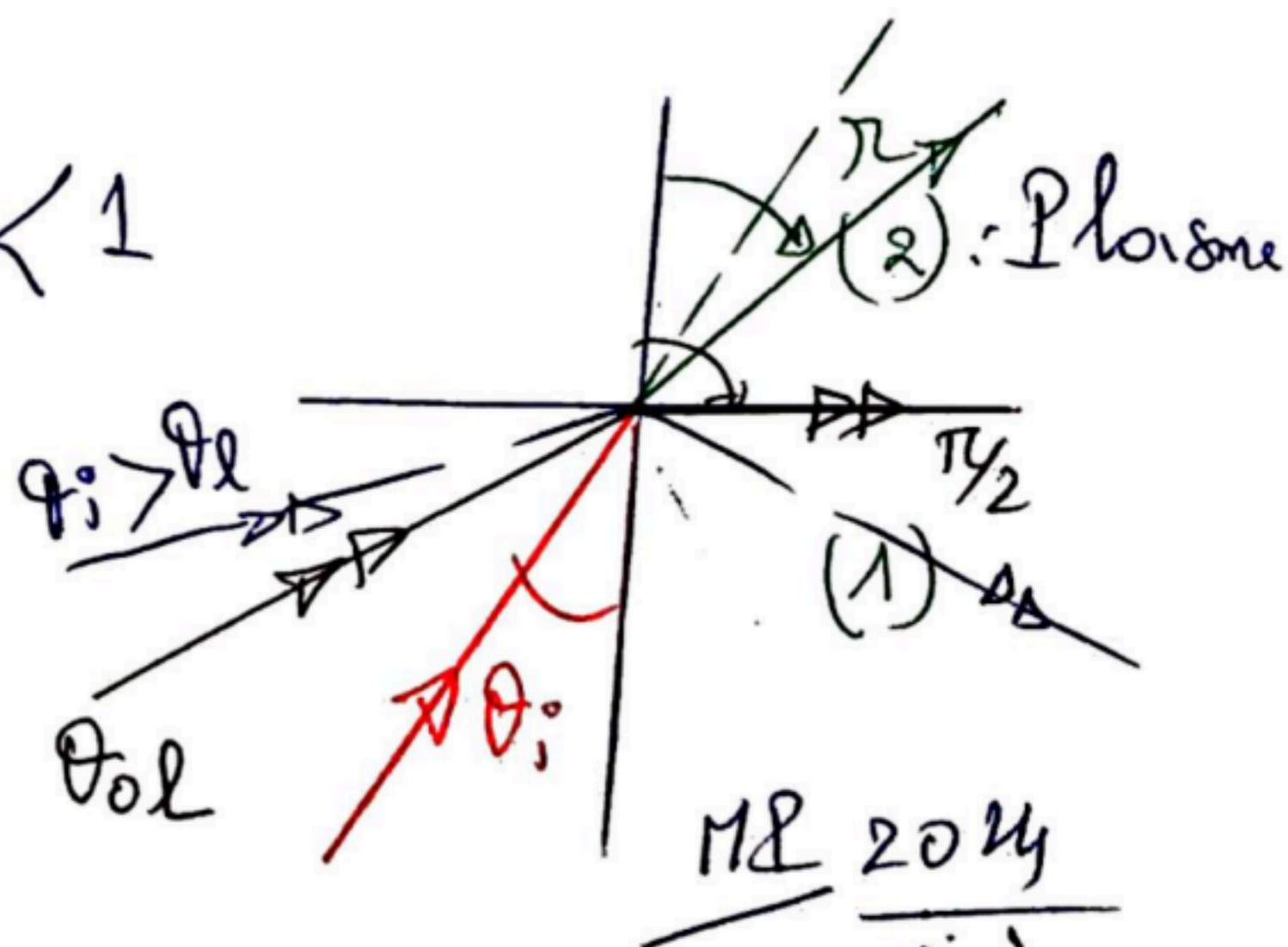
$$v_g \cdot v_\phi = c^2 \quad \text{Transparent}$$



$$n = \sqrt{1 - \frac{\omega_p^2}{\omega^2}} < 1$$

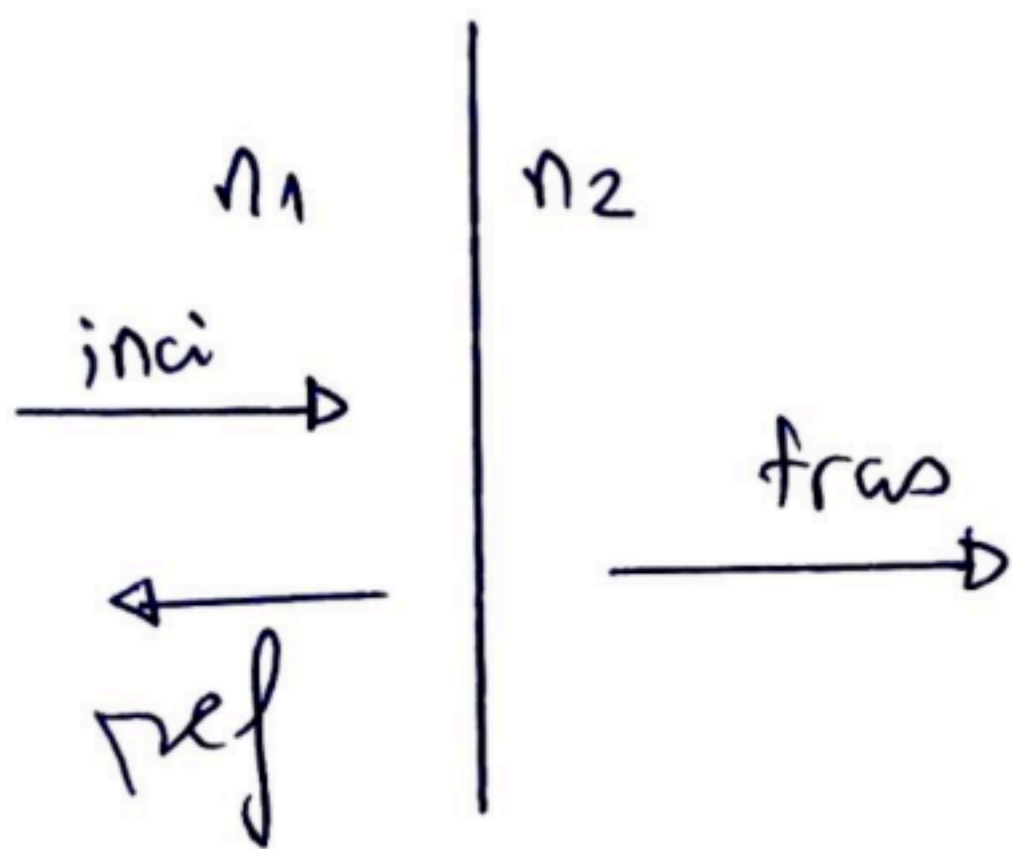
$$\sin \theta_i = n \sin \pi$$

$$\theta_i < \pi$$



$$\text{Si angle } \pi = \frac{\pi}{2} \Rightarrow \theta_{il} = \arcsin(n)$$

11/8, $\theta_i > \theta_{ilimite}$: reflexion totale $k^2 > 0$



$$r_{12} = \frac{n_1 - n_2}{n_1 + n_2}$$

$$t_{12} = \frac{2n_1}{n_1 + n_2}$$

$$\text{Si: } n_1 = 1, \quad n_2 = n = \sqrt{1 - \frac{\omega_p^2}{\omega^2}}$$

$$r_{12} = \frac{1 - n}{1 + n}, \quad t_{12} = \frac{2}{1 + n}, \quad \underline{k^2 > 0}$$

Pg

Dielectric

$$\epsilon = \epsilon_0 \epsilon_r$$

$$\vec{j}_{\text{ind}} = \vec{\sigma}$$

$$\vec{\nabla} \times \vec{B} = \mu_0 \epsilon_0 \epsilon_r \frac{\partial \vec{E}}{\partial t}$$

$$\underline{\text{Phasor}}: \vec{\nabla} \times \vec{B} = \mu_0 \left[\underline{\sigma} \vec{E} + \epsilon_0 \frac{\partial \vec{E}}{\partial t} \right]$$

$$= \mu_0 \left[\frac{\underline{\sigma}}{\epsilon_0(-i\omega)} + 1 \right] \epsilon_0 (-i\omega \vec{E})$$

$$= \mu_0 \epsilon_0 \left(1 + i \frac{\underline{\sigma}}{\epsilon_0 \omega} \right) \frac{\partial \vec{E}}{\partial t}$$

$$\underline{\epsilon} = 1 + i \frac{\sigma}{\omega} = 1 - \frac{\omega_p^2}{\omega^2}$$

$$\sigma = \frac{i \epsilon_0 \omega_p^2}{\omega} ; \boxed{\epsilon = n^2(\omega)}$$

Eq: eqn^l de prop^l de l'onde

$$\Delta \vec{E} - \frac{1}{c^2} \epsilon \frac{\partial^2 \vec{E}}{\partial t^2} = 0$$

$$\left[-k^2 - \frac{\epsilon}{c^2} (-\omega^2) \right] \vec{E} = 0$$

$$\boxed{k^2 = \frac{\omega^2}{c^2} \epsilon}$$

$$\boxed{k = \frac{\omega}{c} n}$$

$$\boxed{n^2 = \epsilon}$$

$$b) \vec{F}_{vis} = -m \alpha \vec{v}$$

$$m \frac{d\vec{v}}{dt} = -e \vec{E} - m \alpha \vec{v}$$

$$\frac{d\vec{v}}{dt} + \alpha \vec{v} = -\frac{e}{m} \vec{E}$$

$$(-i\omega + \alpha) \underline{\vec{v}} = -\frac{e}{m} \underline{\vec{E}}$$

$$\underline{\vec{v}} = -\frac{e}{m} \frac{\underline{\vec{E}}}{(\alpha - i\omega)}$$

$$\underline{\vec{v}} = \frac{-ie}{m\omega} \frac{\underline{\vec{E}}}{1 - \frac{\alpha}{i\omega}}$$

$$\boxed{\underline{\vec{v}} = \frac{-ie}{m\omega} \frac{\underline{\vec{E}}}{1 + \frac{i\alpha}{\omega}}} ; \underline{J} = -Ne\underline{\vec{v}}$$

$$\underline{\sigma} = \frac{i\varepsilon\omega p^2}{\omega} \frac{1}{1 + \frac{i\alpha}{\omega}}$$

$$b) k^2 = \frac{\omega^2}{c^2} \left(1 + i \frac{\underline{\sigma}}{\varepsilon_0 \omega} \right)$$

$$k^2 = \frac{\omega^2}{c^2} \left(1 - \frac{\omega p^2}{\omega^2} \frac{1}{1 + \frac{i\alpha}{\omega}} \right)$$

$$\omega^2 \ll \omega_p^2$$

$$\alpha = \frac{1}{\tau}$$

$$k^2 = \frac{\omega^2}{c^2} \left[1 - \frac{\omega_p^2}{\omega^2} \cdot \frac{\omega}{i\alpha} \right]$$

$$k^2 = \frac{\omega^2}{c^2} \left[1 + i \left(\frac{\omega_p}{\omega} \right) \left(\frac{\omega_p}{\alpha} \right) \right]$$

$$\underline{k}^2 \simeq \frac{\omega^2}{c^2} \left(\frac{i \omega_p^2}{\alpha \omega} \right) = \frac{i \omega \omega_p^2}{\alpha c^2} = \underline{k}^2$$

$$\underline{k}^2 = \frac{(1+i)^2}{2\alpha c^2} = \left(\frac{1+i}{\delta} \right)^2 \quad \underline{k} = -i k''$$

évanescence

$$\underline{k} = \frac{1}{\delta} + i \frac{1}{\delta}$$

$$\textcircled{*} \quad \alpha^2 \ll \omega_p^2 \ll \omega^2 \quad ; \quad \frac{\alpha}{\omega} \ll 1$$

$$k^2 \simeq \frac{\omega^2}{c^2} \left(1 + \frac{\omega_p^2}{\omega^2} \left(1 - \frac{i\alpha}{\omega} \right) \right)$$

$$\underline{k}^2 \simeq \frac{\omega^2}{c^2} \left[\underbrace{1 - \frac{\omega_p^2}{\omega^2}}_{\omega^2} + \frac{i \alpha \omega_p^2}{\omega^3} \right]$$

$$\underline{k}^2 \simeq \frac{\omega^2}{c^2} \left(1 + \frac{i \alpha \omega_p^2}{\omega^3} \right)$$

$$\underline{k} = \frac{\omega}{c} \left[1 + \frac{i \alpha \omega_p^2}{2 \omega^3} \right]$$

$$\underline{k} = \frac{\omega}{c} + \frac{i \alpha \omega_p^2}{2 \omega^3 c}$$

$$\underline{k} = k' + i k''$$

↪ faiblement atténuée

↙
préje

$$B) \quad k^2 = \frac{\omega^2 - \omega_p^2}{c^2}$$

$$\underline{\vec{E}} = E_0 \exp i(kz - \omega t) \underline{\vec{e}}_z$$

$$1) \quad \underline{\vec{B}} = \frac{k}{\omega} \underline{\vec{E}} \underline{\vec{e}}_y = \frac{1}{c} n E_0 e^{i(kz - \omega t)} \underline{\vec{e}}_y$$

$$\omega < \omega_p \quad n = i n''$$

$$\underline{\omega} > \underline{\omega_p} \quad n = n' = \sqrt{1 - \frac{\omega_p^2}{\omega^2}}$$

$$\underline{\vec{B}} = \frac{\sqrt{1 - \frac{\omega_p^2}{\omega^2}}}{c} E_0 e^{i\left(\frac{\omega}{c} n' - \omega t\right)} \underline{\vec{e}}_y$$

$$2) \quad \langle u_e \rangle = \left\langle \frac{\epsilon_0 E^2}{2} \right\rangle = \frac{\epsilon_0 E_0^2}{2} \frac{1}{2} = \frac{\epsilon_0 E_0^2}{4}$$

$$\langle u_m \rangle = \left\langle \frac{B^2}{2\mu_0} \right\rangle = \frac{1}{2\mu_0} \left(\frac{E_0 n'}{c} \right)^2 \frac{1}{2}$$

$$\langle u_m \rangle = \frac{E_0^2}{4\mu_0 c^2} n'^2 = \frac{\epsilon_0 E_0^2}{4} \left(1 - \frac{\omega_p^2}{\omega^2} \right)$$

$$b) \quad \langle u_c \rangle = \underbrace{\langle \frac{1}{2} m v^2 \rangle}_\text{Joules} N; \quad \text{J/m}^3$$

$$\underline{\vec{v}} = -\frac{ie}{m\omega} \underline{\vec{E}}$$

$$\underline{\vec{v}}^* = +\frac{ie}{m\omega} \underline{\vec{E}}^*$$

$$\langle u_c \rangle = \frac{1}{2} mN \frac{1}{2} \text{Re}(\underline{\vec{v}} \cdot \underline{\vec{v}}^*)$$

$$= \frac{mN}{4} \frac{e^2}{m^2 \omega^2} E_0^2 = \frac{Ne^2}{m\epsilon} \left(\frac{\epsilon E_0^2}{4\omega^2} \right)$$

$$\langle u_c \rangle = \frac{\omega_p^2}{\omega^2} \langle u_e \rangle$$

$$\langle u_{\text{tot}} \rangle = \langle u_e \rangle + \langle u_m \rangle + \langle u_c \rangle$$

$$= \langle u_e \rangle \left[1 + \left(1 - \frac{\omega_p^2}{\omega^2} \right) + \frac{\omega_p^2}{\omega^2} \right]$$

$$\langle u_{\text{tot}} \rangle = 2 \langle u_e \rangle$$

$$3) \langle \vec{R} \rangle = \frac{1}{2\mu_0} \text{Re} \left[\underline{\vec{E}}^* \cdot \left(\frac{\vec{k} \wedge \underline{\vec{E}}}{\omega} \right) \right]$$

$$(\vec{a} \wedge \vec{b})^* = \vec{a}^* \wedge \vec{b}^*$$

$$(\vec{a} + \vec{b})^* = \vec{a}^* + \vec{b}^*$$

$$\langle \vec{R} \rangle = \frac{1}{2\mu\omega} \text{Re}l \left[\vec{k} \cdot (\vec{E} \cdot \vec{E}^*) - \vec{E}^* (\vec{k} \cdot \vec{E}) \right]$$

$$= \frac{1}{2\mu\omega} E_0^2 \text{Re}l(\underline{k}) \vec{u}_z$$

$$\underline{\omega < \omega_p}$$

$$\underline{k} = i k''$$

$$\langle \vec{R} \rangle = \vec{0}$$

$$k = k' = \frac{\omega}{c} n$$

$$\underline{\omega > \omega_p}$$

$$\langle \vec{R} \rangle = \frac{E_0^2}{2\mu_0 c} \sqrt{1 - \frac{\omega_p^2}{\omega^2}} \vec{u}_z$$

$$\langle \vec{R} \rangle = \frac{\epsilon_0 E_0^2}{2} c \sqrt{1 - \frac{\omega_p^2}{\omega^2}} \vec{u}_z$$

$$\langle \vec{R} \rangle = \langle u_{\text{tot}} \rangle \sqrt{\epsilon_0}$$

$$\vec{v}_e = \frac{\langle \vec{R} \rangle}{\langle u_{\text{tot}} \rangle} = \sqrt{\epsilon_0}$$

$$\langle f^2 \rangle = \frac{1}{2} \text{Rél} [f f^*]$$

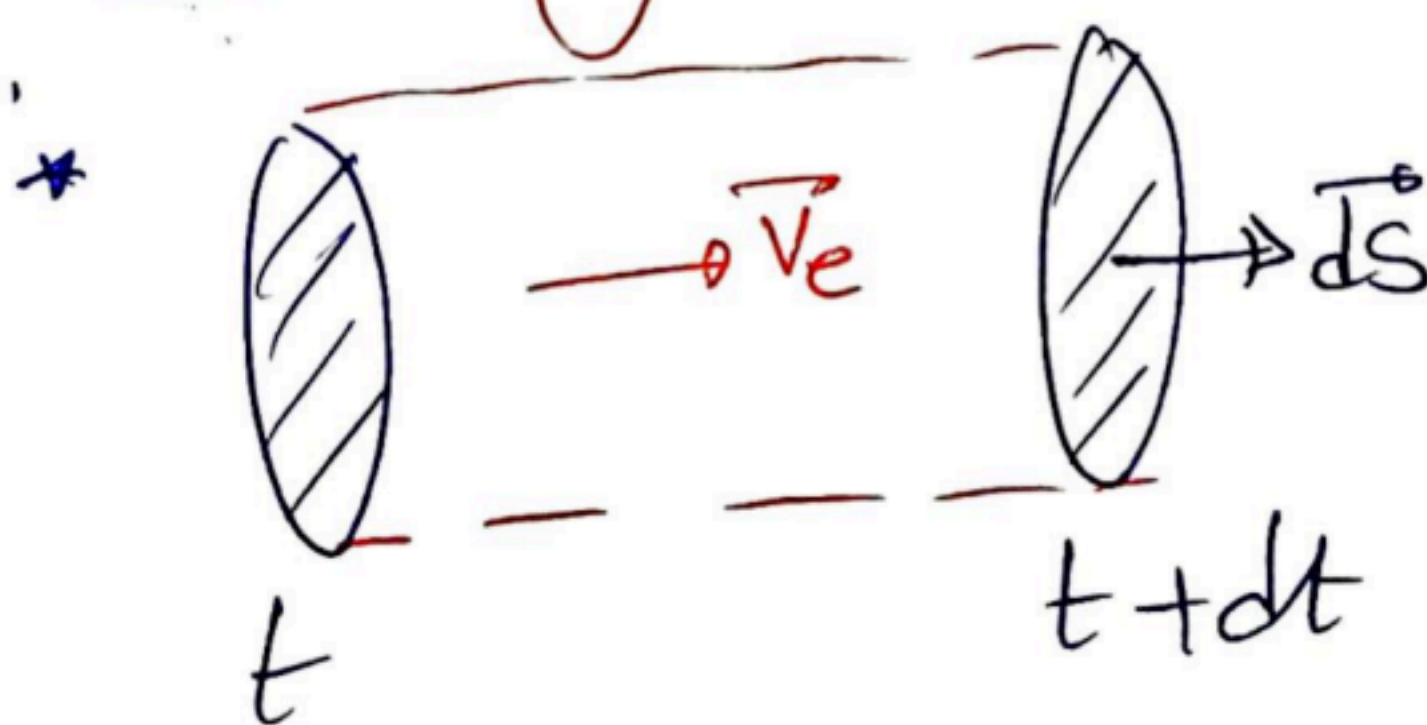
$$\langle f g \rangle = \frac{1}{2} \text{Rél} [f g^*]$$

4/a) $\langle P_{\text{moy}} \rangle = \langle \vec{j} \cdot \vec{E} \rangle \times \cancel{\int \vec{E} \cdot \vec{E}^* dS}$

$$= \frac{1}{2} \text{Rél} [\vec{j} \cdot \vec{E}^*]$$

$$= \frac{1}{2} \text{Rél} \left[\frac{i \epsilon_0 \omega p^2}{\omega} \underbrace{\vec{E} \cdot \vec{E}^*}_{E_0^2} \right] = 0$$

Sans gradient



$$d\tau = (\vec{v}_e dt) d\vec{S}$$

$$\begin{aligned} \langle dH_{\text{tot}} \rangle &= \langle u_{\text{tot}} \rangle \cdot d\vec{S} \vec{v}_e dt \\ &= \langle \vec{P} \rangle d\vec{S} dt \end{aligned}$$

Ident : $\langle \vec{P} \rangle = \langle u_{\text{tot}} \rangle \cdot \vec{v}_e$

$$\begin{aligned}
 5) \quad \tau &= \frac{D-H}{c} + \frac{H}{v_g} \\
 &= \frac{D}{c} - \frac{H}{c} + \frac{H}{c \sqrt{1 - \omega_p^2/\omega^2}}, \quad \omega \gg \omega_p \\
 &\approx \frac{D}{c} - \frac{H}{c} + \frac{H}{c} \left(1 + \frac{1}{2} \frac{\omega_p^2}{\omega^2} \right)
 \end{aligned}$$

$$\tau = \frac{D}{c} \oplus \frac{1}{2} \frac{\cancel{f_p^2}}{f^2} \frac{H}{c}$$

$$f_2 > f_1$$

$$\tau_2 < \tau_1$$

$$\Delta t = \tau_1 - \tau_2 = \frac{1}{2} \frac{H \cancel{f_p^2}}{c} \left(\frac{1}{f_1^2} - \frac{1}{f_2^2} \right)$$

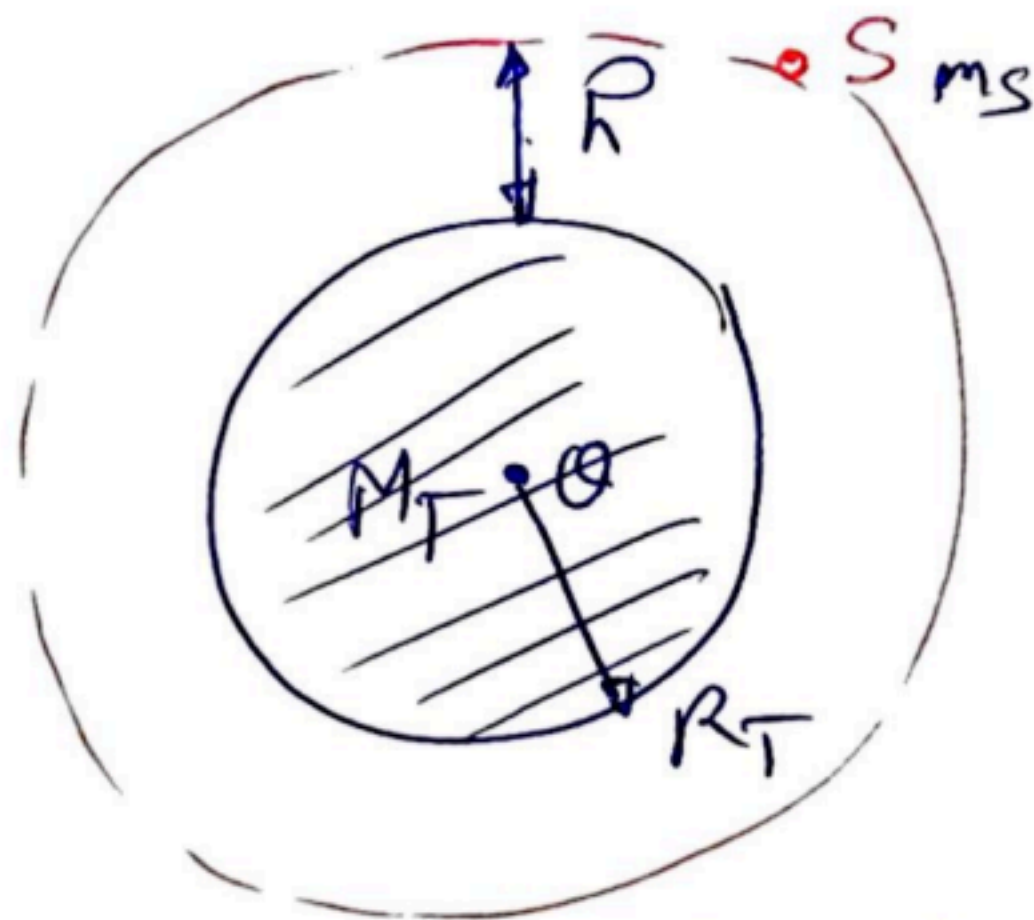
$$\lambda = \frac{c}{f}, \quad \omega_p = 2\pi f_p$$

$$\Delta t = \frac{H}{2c} \frac{\omega_p^2}{4\pi^2} \left(\frac{\lambda_2^2 - \lambda_1^2}{c^2} \right)$$

$$\Delta t = \frac{H}{8\pi^2 c} K'' (\lambda_2^2 - \lambda_1^2)$$

Force centrale

$$\vec{F}_G = - \frac{GM_T m_s}{r^2} \vec{e}_r$$
$$= m_s \vec{g}$$



$$\vec{g}(M) = - \frac{GM_T}{(R_T + h)^2} \vec{e}_r \quad h \ll R_T$$

$$= - \frac{GM_T}{R_T^2 \left(1 + \frac{h}{R_T}\right)^2} \vec{e}_r$$

$$\vec{g}(M) = \vec{g}_0 \left(1 - \frac{2h}{R_T}\right)$$

2) géocentrique : centre Terre

trois axes vers 3 étoiles fixes

3) a) $m \frac{d\vec{v}}{dt} = \vec{F}_G$

$$\vec{OM} = r \vec{e}_r \Rightarrow \vec{v} = \dot{r} \vec{e}_r + r \dot{\theta} \vec{e}_\theta$$

circulaire $\Rightarrow \vec{v} = (R_T + h) \dot{\theta} \vec{e}_\theta$

$$\frac{d\vec{v}}{dt} = \frac{d}{dt}[(r\dot{\theta})\vec{e}_{\theta}]$$

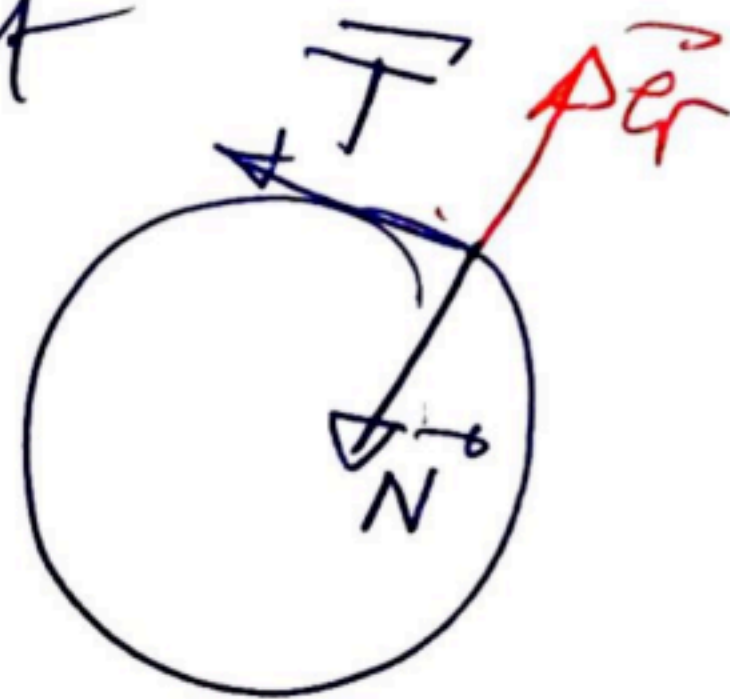
$$= r\ddot{\theta}\vec{e}_{\theta} + r\dot{\theta}(-\dot{\theta})\vec{e}_r$$

$$= -r\dot{\theta}^2\vec{e}_r + r\ddot{\theta}\vec{e}_{\theta}$$

$$\boxed{v = r\dot{\theta}} \longrightarrow \dot{\theta} = \frac{v}{r}; \quad \ddot{\theta} = \frac{1}{r} \frac{dv}{dt}$$

$$\frac{d\vec{v}}{dt} = \vec{a} = -\frac{v^2}{r}\vec{e}_r + \frac{dv}{dt}\vec{e}_{\theta}$$

$$\vec{a} = \underbrace{\frac{v^2}{r}}_{a_N} \vec{N} + \underbrace{\frac{dv}{dt}}_{a_T} \vec{T}$$

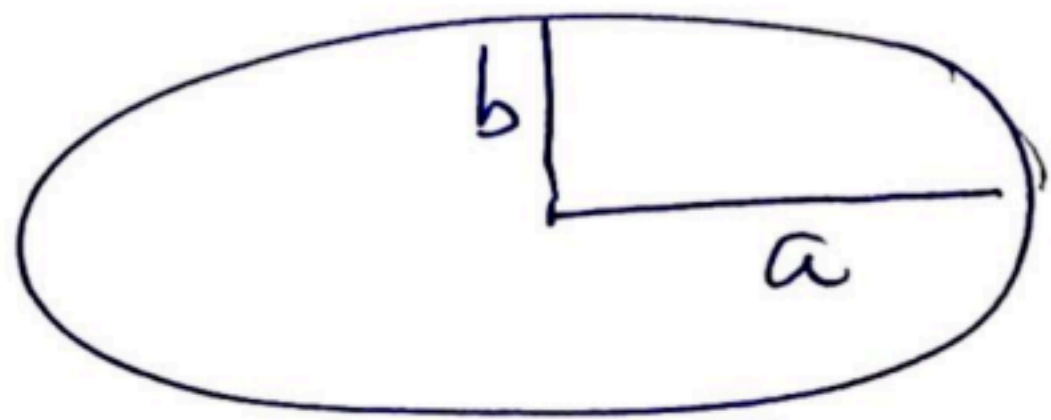


R.F.D $m \frac{v^2}{r} = \frac{G M_T m}{r^2}$

$m \frac{dv}{dt} = 0 \Rightarrow v = \text{const}$

$$v = \sqrt{\frac{G M_T}{(R_T + m)}}$$

$$\frac{T^2}{a^3} = \text{cte}$$



$$v = r \dot{\theta} = r \omega = r \frac{2\pi}{T} = \sqrt{\frac{GM}{r}}$$

$$\frac{4\pi^2 r^2}{T^2} = \frac{GM}{r} \Rightarrow \frac{T^2}{r^3} = \frac{4\pi^2}{GM}$$

$$\frac{T^2}{(R_T + h)^3} = \frac{4\pi^2}{GM}$$

$$4) \vec{\sigma}_\theta = \vec{OM} \wedge m \vec{v} = r \vec{e}_r \wedge m [r \dot{\theta} \vec{e}_\theta]$$

$$\vec{\sigma}_\theta = m r^2 \dot{\theta} \vec{k}$$

$$\frac{d\vec{\sigma}_\theta}{dt} = \frac{d}{dt} (\vec{OM} \wedge m \vec{v}) = \vec{OM} \wedge m \frac{d\vec{v}}{dt} = \vec{OM} \wedge m \vec{F}_G = \vec{0}$$

$$\vec{\sigma}_\theta = \text{cte}$$

$$|\vec{\sigma}_\theta| = m r^2 \dot{\theta} = \text{cte} :$$

$$r^2 \dot{\theta} = C$$

$$\left| \frac{d\vec{A}}{dt} \right| = \frac{1}{2} |\vec{r} \wedge \vec{v}| \text{ vitesse areolaire}$$

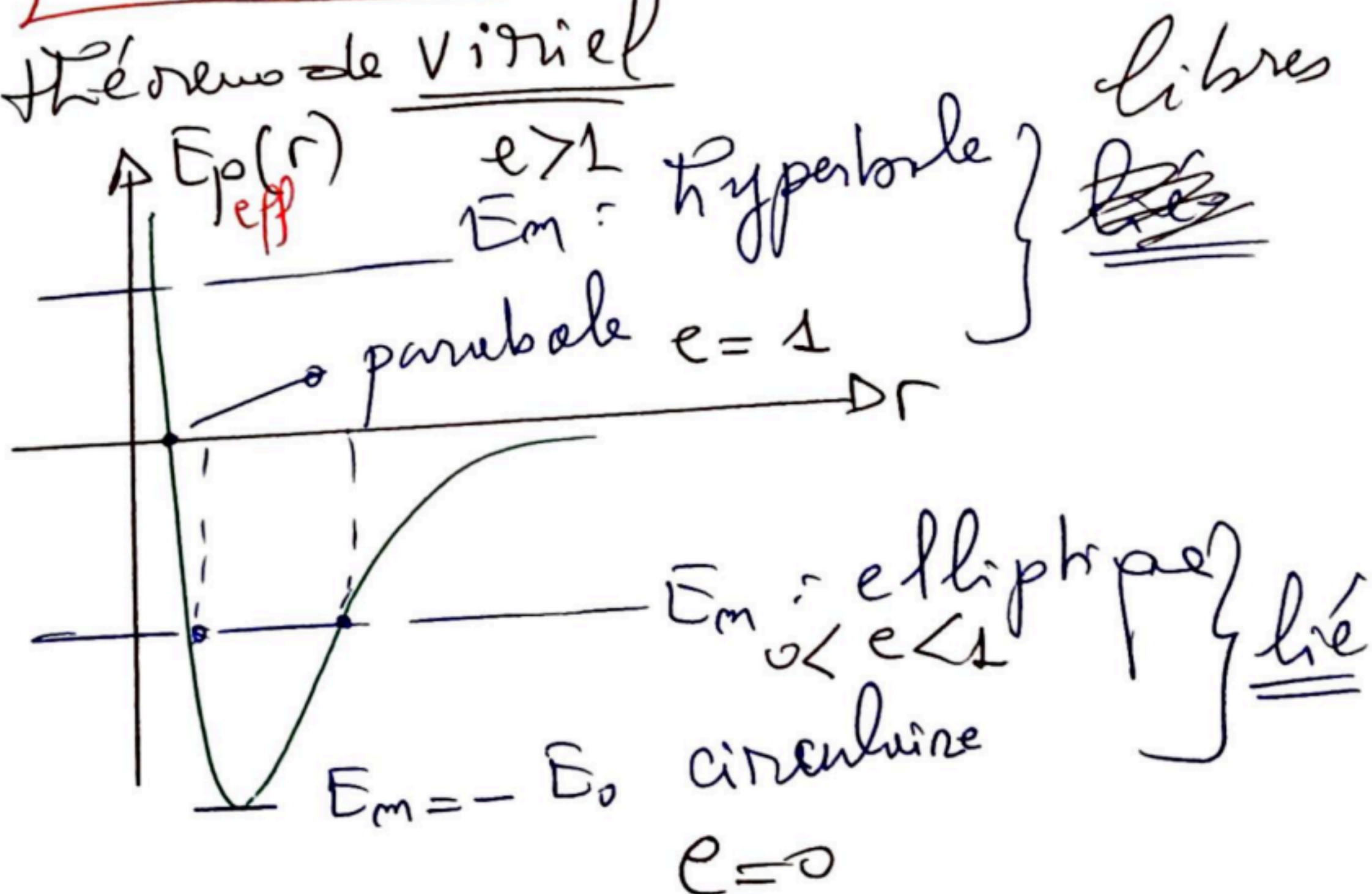
$$E_m = E_c + E_p = \frac{1}{2} m v^2 - \int \vec{F}_G \cdot d\vec{l}$$

$$E_p = + \int \frac{GMm}{r^2} dr = - \frac{GMm}{r} + \text{cte}$$

$$E_m = \frac{1}{2} m \frac{G^2 M^2}{r} - \frac{G M m}{r} = -\frac{1}{2} \frac{G^2 M m}{r} < 0$$

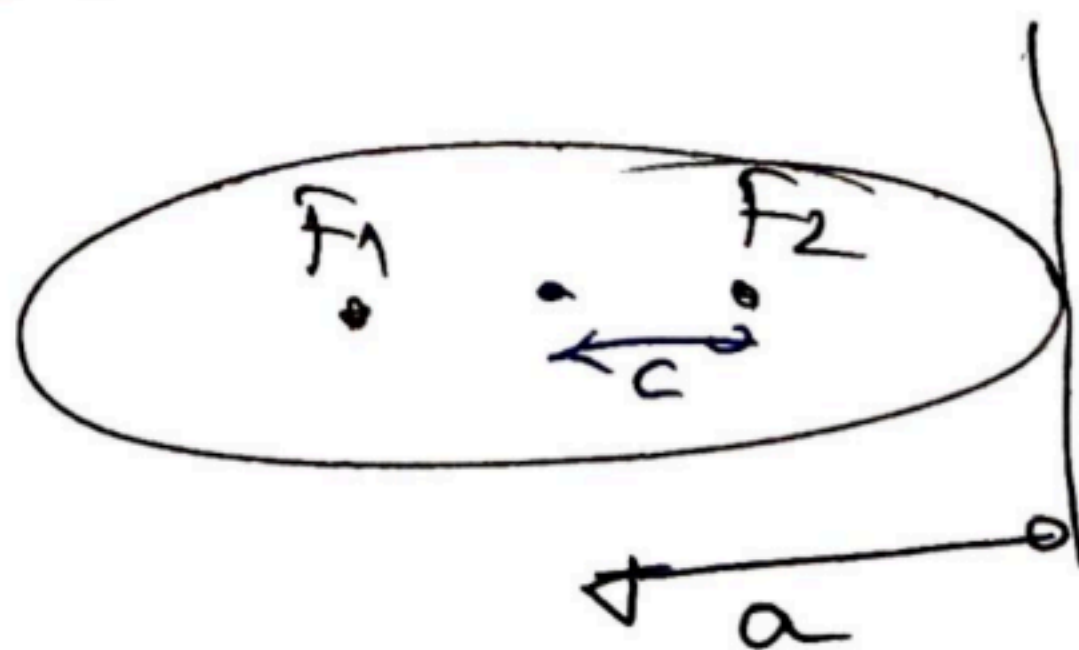
Pg: $\boxed{-2E_c = E_p}$ mvt circulaire

théorème de viriel



$$r = \frac{P}{1 + e \cos \theta}$$

$$e = \frac{c}{a}$$



Dipôle osculaire
PC2: 2022

By Phasor

$$m\ddot{r} = -eE - \frac{m}{\tau}\dot{r} - m\omega_0^2 r$$

$$\left[-\omega^2 + \omega_0^2 + \left(\frac{1}{\tau}\right)i\omega \right] \underline{r} = -\frac{e}{m} \underline{E}$$

$$\underline{r} = -\frac{e}{m} \frac{\underline{E}_0 e^{i\omega t}}{\left(\omega_0^2 - \omega^2\right) + \frac{i\omega}{\tau}}$$

$$\underline{\dot{r}} = -\frac{e}{m} \frac{i\omega \underline{E}_0}{\left(\omega_0^2 - \omega^2\right) + \frac{i\omega}{\tau}}$$

$$\underline{J} = -Ne \underline{\dot{r}} = \frac{e^2 N i\omega}{m \left(\omega_0^2 - \omega^2\right) + \frac{i\omega}{\tau}} \underline{E}$$

$$\underline{D} = \frac{i\epsilon\omega p^2}{\omega} \frac{1}{\left(\omega_0^2 - \omega^2\right) + \frac{i\omega}{\tau}}$$

$$k^2 = \frac{\omega^2}{c^2} \left(1 + \frac{iD}{\epsilon_0 \omega} \right)$$

$$= \frac{\omega^2}{c^2} \left[1 - \frac{\omega p^2}{\omega^2} \frac{1}{\left(\omega_0^2 - \omega^2\right) + \frac{i\omega}{\tau}} \right]$$