ONDE

- SONO PERTURBAZIONI DI UN MEZZO*
- HANNO UNA VELOCITÀ BEN DEFINITA

* NON VALE PER LE O.E.M.

ONDE ELETTROMAGNETICHE

no sorgenti di campo

$$\vec{\nabla}\cdot\vec{E} = 0 \qquad \vec{\nabla}\times\vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\vec{\nabla}\cdot\vec{B} = 0 \qquad \vec{\nabla}\times\vec{B} = \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t}$$

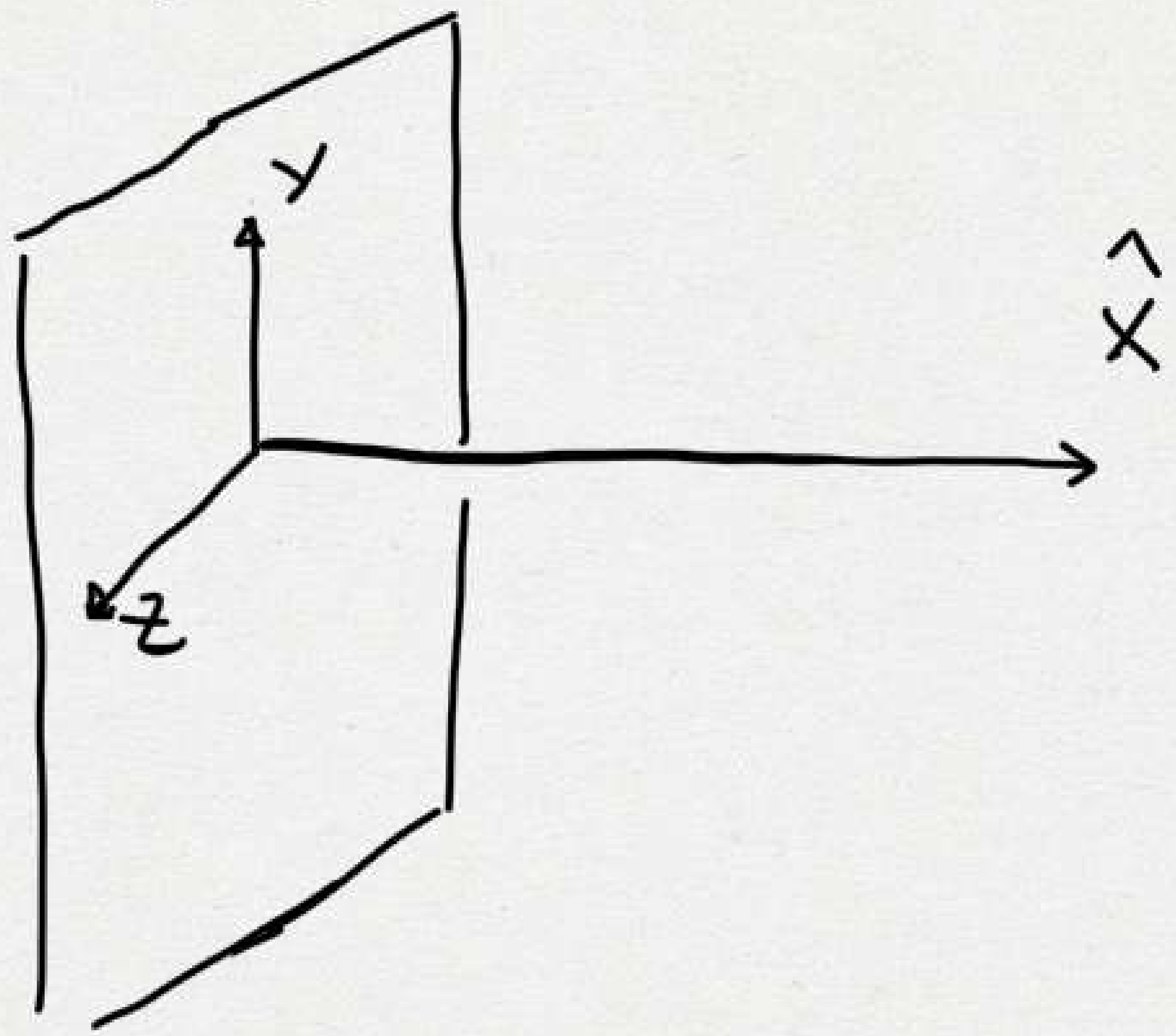
$\vec{E} = (E_x, E_y, E_z)$

$\vec{B} = (B_x, B_y, B_z)$

$E_\alpha = E_\alpha(x, y, z, t)$, $B_\alpha = B_\alpha(x, y, z, t)$

1. $\vec{E} = \vec{B} = 0$
2. i campi sono $\neq 0$ e variano nello spazio e nel tempo

↳ LE ONDE E.M.



1. l'onda si propaga lungo $\hat{x}$
2. i campi sono costanti sul piano $\hat{y}\,\hat{z}$

$$\boxed{\frac{\partial E_\alpha}{\partial y} = \frac{\partial E_\alpha}{\partial z} = 0} \qquad \boxed{\frac{\partial B_\alpha}{\partial y} = \frac{\partial B_\alpha}{\partial z} = 0} \qquad \alpha = x, y, z$$

$$\frac{\partial E_y}{\partial y} = \frac{\partial E_z}{\partial z} = 0 \quad , \quad \vec{\nabla}\cdot\vec{E} = \frac{\partial E_x}{\partial x} + \cancel{\frac{\partial E_y}{\partial x}} + \cancel{\frac{\partial E_z}{\partial z}} = 0 \Rightarrow \boxed{\frac{\partial E_x}{\partial x} = 0 \ , \ \frac{\partial B_x}{\partial x} = 0}$$

$$\vec{\nabla}\times\vec{E} = \left(\cancel{\frac{\partial E_z}{\partial x}} - \cancel{\frac{\partial E_y}{\partial z}}, \cancel{\frac{\partial E_x}{\partial z}} - \frac{\partial E_z}{\partial x}, \frac{\partial E_y}{\partial x} - \cancel{\frac{\partial E_x}{\partial x}}\right) = \left(0, -\frac{\partial E_z}{\partial x}, \frac{\partial E_y}{\partial x}\right) = -\frac{\partial \vec{B}}{\partial t}$$

$$\vec{\nabla}\times\vec{B} = \left(0, -\frac{\partial B_z}{\partial x}, \frac{\partial B_y}{\partial x}\right) = \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t}$$

$$\boxed{\begin{array}{l} 0 = \dfrac{\partial B_x}{\partial t} \\[2em] 0 = \dfrac{\partial E_x}{\partial t} \end{array}} \qquad \frac{\partial E_z}{\partial x} = \frac{\partial B_y}{\partial t} \qquad \frac{\partial E_y}{\partial x} = -\frac{\partial B_z}{\partial t}$$

$$\frac{\partial B_z}{\partial x} = -\varepsilon_0\mu_0 \frac{\partial E_y}{\partial t} \qquad \frac{\partial B_y}{\partial x} = \varepsilon_0\mu_0 \frac{\partial E_z}{\partial t}$$

E_x, B_x costanti e uniformi $\Rightarrow$ $E_x = 0$, $B_x = 0$

$$\frac{\partial E_y}{\partial x} = -\frac{\partial B_z}{\partial t} \qquad \frac{\partial B_z}{\partial x} = -\varepsilon_0 \mu_0 \frac{\partial E_y}{\partial t}$$

$$\downarrow \partial x \qquad \downarrow \partial t$$

$$\frac{\partial^2 E_y}{\partial x^2} = -\boxed{\frac{\partial^2 B_z}{\partial x \partial t}} \qquad \boxed{\frac{\partial^2 B_z}{\partial x \partial t}} = -\varepsilon_0 \mu_0 \frac{\partial^2 E_y}{\partial t^2} \Rightarrow$$

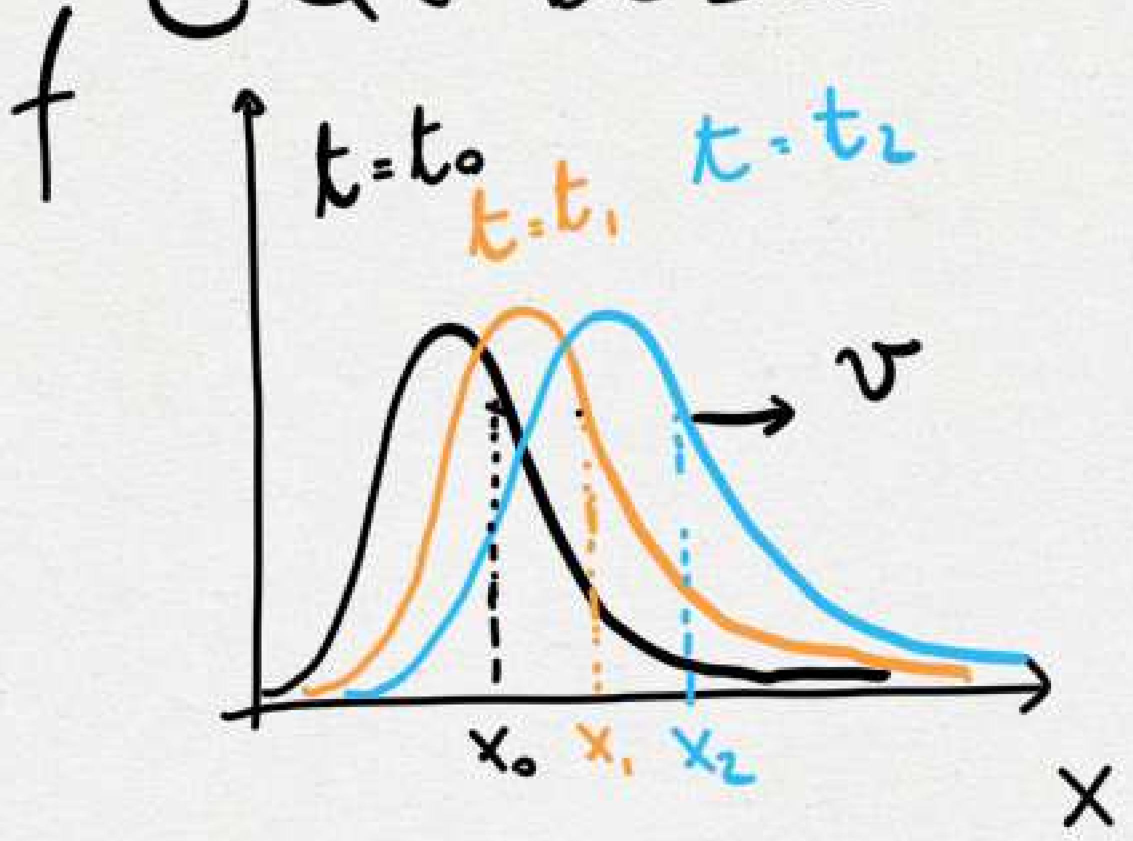
$$\frac{\partial^2 E_y}{\partial x^2} = \varepsilon_0 \mu_0 \frac{\partial^2 E_y}{\partial t^2}$$ eq. equivalenti per E_z, B_y, B_z

$$\frac{\partial^2 f}{\partial x^2} = \frac{1}{\boxed{v^2}} \frac{\partial^2 f}{\partial t^2}$$ EQUAZIONE DELLE ONDE (O DI D'ALEMBERT)

$\rightarrow$ velocità di propagazione dell'onda

$$\varepsilon_0 \mu_0 = \frac{1}{c^2}$$

EQ. DELLE ONDE PIANE



$$\frac{\partial^2 f}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 f}{\partial t^2}$$

SONO SOLUZIONI TUTTE LE FUNZIONI DEL TIPO

$$f(x,t) = f(x \pm vt) \quad , \quad \frac{\partial f}{\partial x} = \frac{df}{d(x \pm vt)} \; / \; \frac{\partial f}{\partial t} = v\frac{df}{d(x \pm vt)}$$

se $f(x - vt)$

$$x_0 - vt_0 = x_1 - vt_1 \Rightarrow f(x_0 - vt_0) = f(x_1 - vt_1)$$

$$\Downarrow$$

$$\boxed{x_1 = x_0 + v(t_1 + t_0)}$$ MOTO UNIFORME

ONDE PIANE

ONDE ARMONICHE

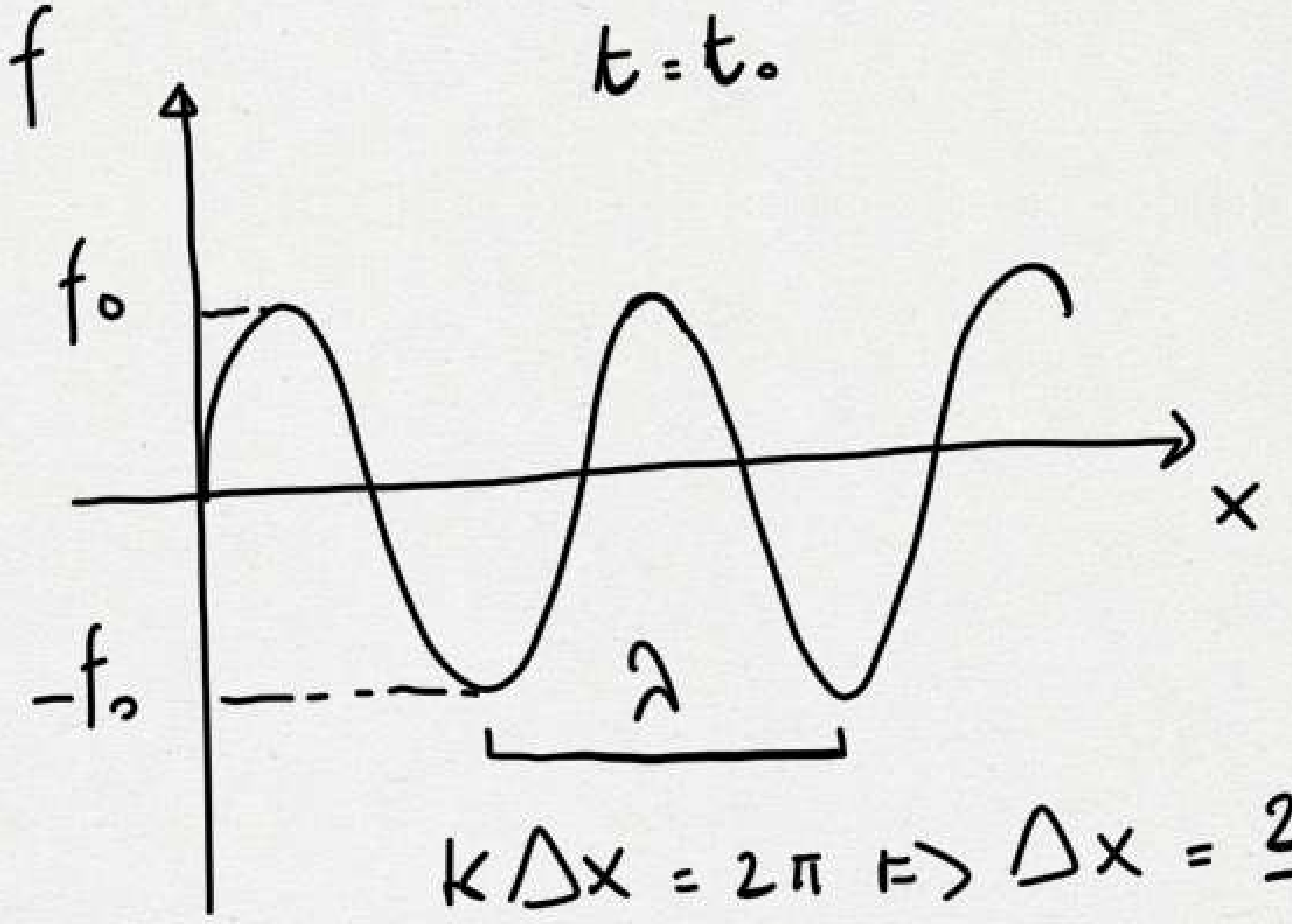
$f(x,t) = f(x - vt)$, $\underbrace{g(x,t) = x - vt \ , \ (x-vt)^{\alpha} \ , \ e^{-\frac{(x-vt)}{\beta}}}_{\text{ESEMPI}}$

$f(x,t) = f_0 \sin[k(x-vt)]$

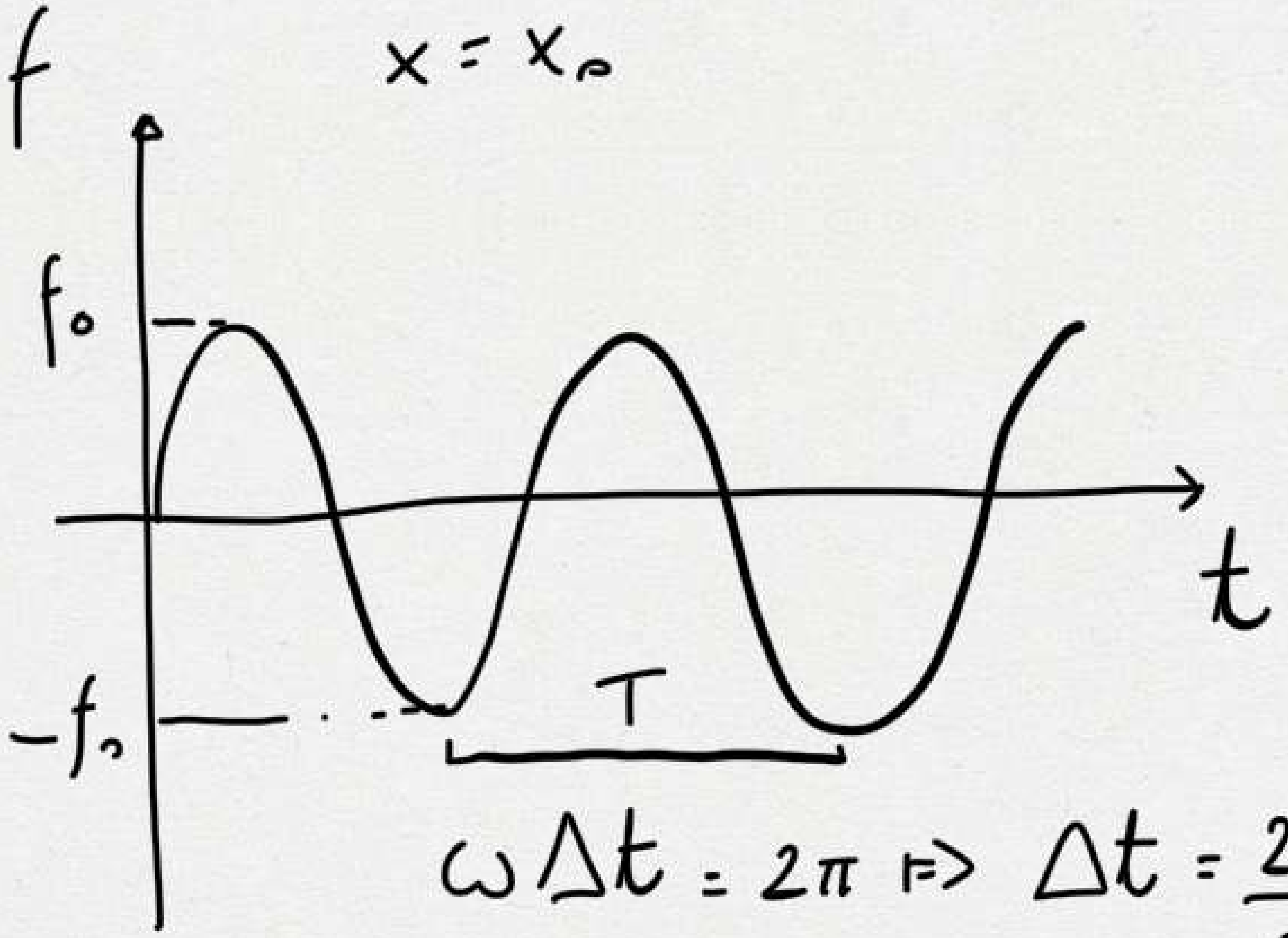
VETTORE D'ONDA — $\omega = kv$ PULSAZIONE DELL'ONDA

$f(x,t) = f_0 \cos[k(x-vt)] = f_0 \cos[kx - \omega t]$

AMPIEZZA



$k\Delta x = 2\pi \Rightarrow \Delta x = \frac{2\pi}{k} = \lambda$ LUNGHEZZA D'ONDA



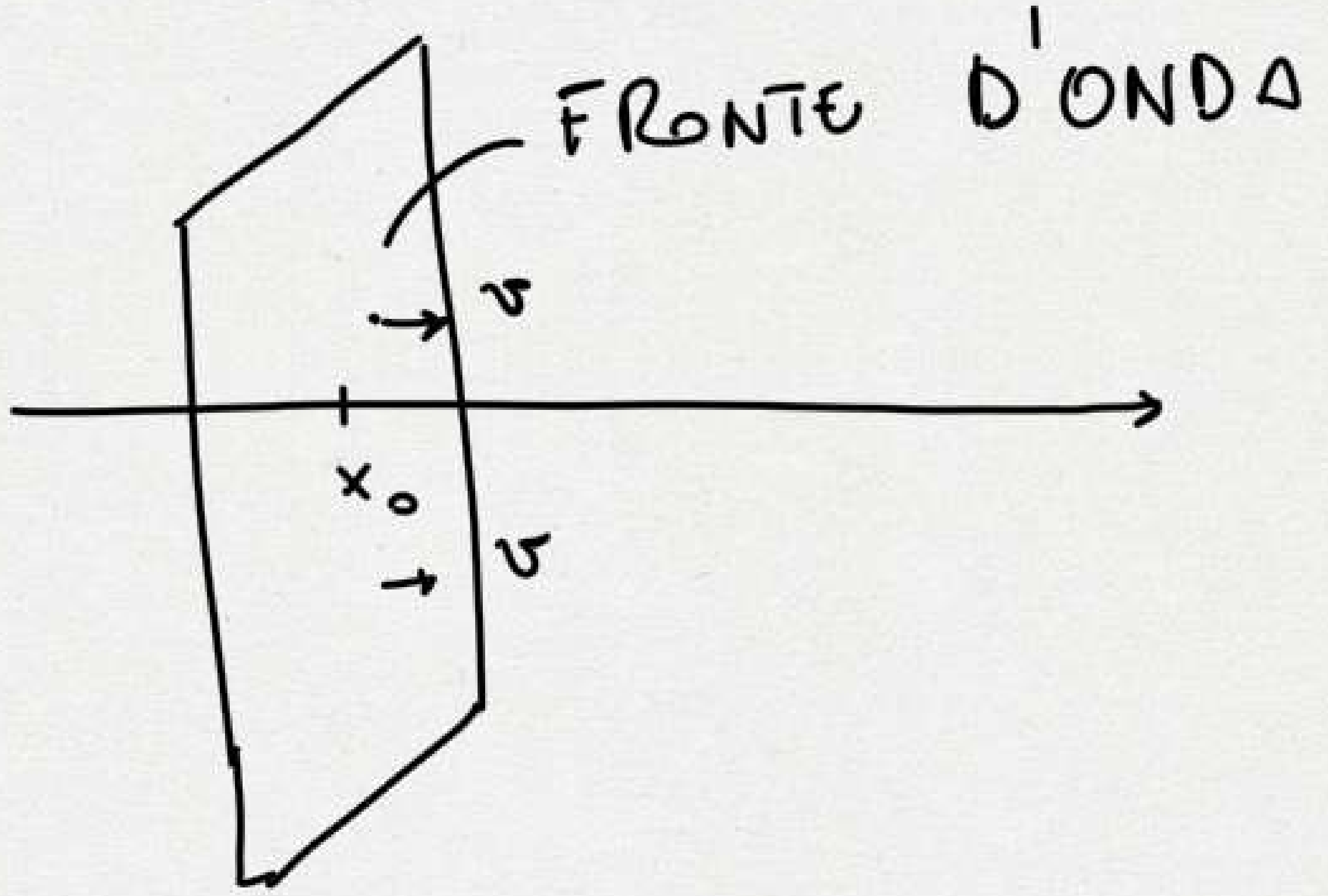
$\omega \Delta t = 2\pi \Rightarrow \Delta t = \frac{2\pi}{\omega} = T$ PERIODO

$\nu = \frac{1}{T}$

① $f = f_0 \cos[\underbrace{kx - \omega t}_{\delta}]$ FASE DELL'ONDA

$f = f_0 \cos[kx - \omega t + \delta_0]$ $\longrightarrow$ FASE INTRINSECA

② il FRONTE D'ONDA è l'insieme dei punti su cui l'onda ha una fase costante



ONDE ELETTROMAGNETICHE PIANE

$$\frac{\partial^2 E_y}{\partial x^2} = \frac{1}{c^2}\frac{\partial^2 E_y}{\partial t^2}$$

$$\vec{E} = E_y\hat{y} + E_z\hat{z} = E_{y0}\cos(kx-\omega t)\hat{y} + E_{z0}\cos(kx-\omega t)\hat{z}$$

$$\vec{B} = B_y\hat{y} + B_z\hat{z} = B_{y0}\cos(kx-\omega t)\hat{y} + B_{z0}\cos(kx-\omega t)\hat{z}$$

$$\frac{\partial E_z}{\partial x} = \frac{\partial B_y}{\partial t} \Rightarrow -kE_{z0}\cancel{\sin(kx-\omega t)} = \omega B_{y0}\cancel{\sin(kx-\omega t)} \Rightarrow$$

$$E_{z0} = -\frac{\omega B_{y0}}{k} = -cB_{y0} \Rightarrow \boxed{B_{y0} = -\frac{E_{z0}}{c}} \Rightarrow$$

$$B_{z0} = \frac{E_{y0}}{c}$$

$$B^2 = B_y^2 + B_z^2 = \frac{E_y^2}{c^2} + \frac{E_z^2}{c^2} = \frac{E^2}{c^2} \Rightarrow B = \frac{E}{c}$$

$$\vec{E} \cdot \vec{B} = E_y B_y + E_z B_z = -\cancel{\frac{E_y E_z}{c}} + \cancel{\frac{E_y E_z}{c}} = 0$$

$$\vec{E} \times \vec{B} = (E_y \hat{y} + E_z \hat{z}) \times (B_y \hat{y} + B_z \hat{z}) = E_y B_z \hat{y} \times \hat{z} + E_z B_y \hat{z} \times \hat{y} =$$

$$= E_y B_z \hat{x} - E_z B_y \hat{x} = \frac{E_y^2}{c} \hat{x} + \frac{E_z^2}{c} \hat{x} = \frac{E^2}{c} \hat{x}$$

$$u = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0} = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2\mu_0}\frac{E^2}{c^2} = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\varepsilon_0 E^2 = \varepsilon_0 E^2$$

$$p = \frac{U}{c}$$

$p_{RAD} = \frac{I}{c}$, I è l'intensità dell'onda