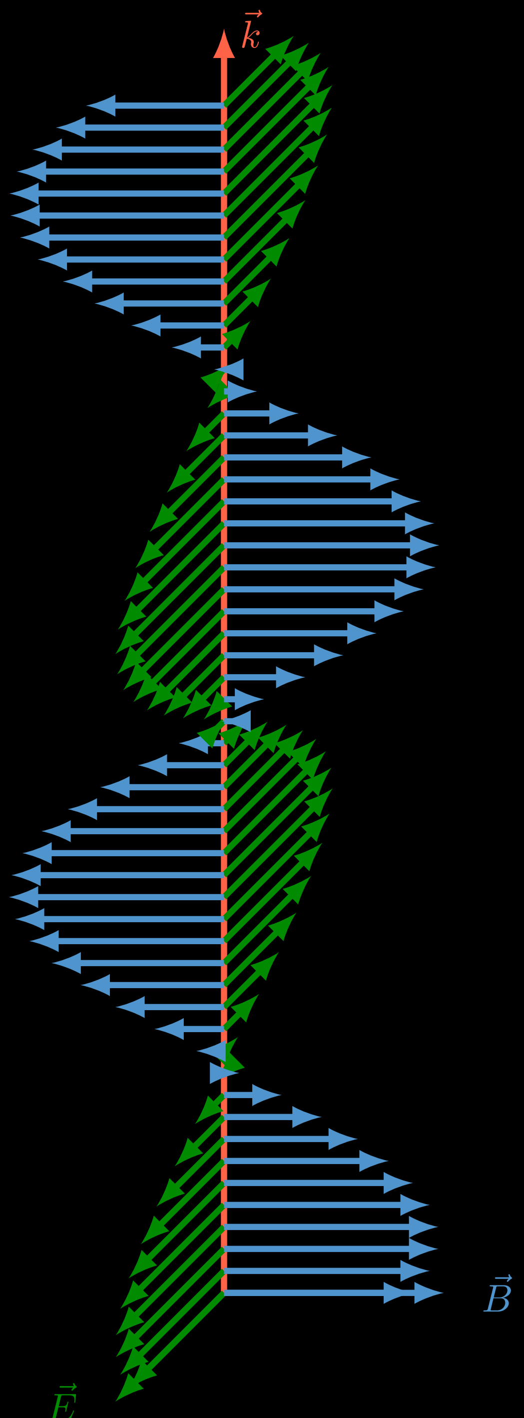


Física IV

06 outubro 2020

Equações de Maxwell

Espectro eletromagnético

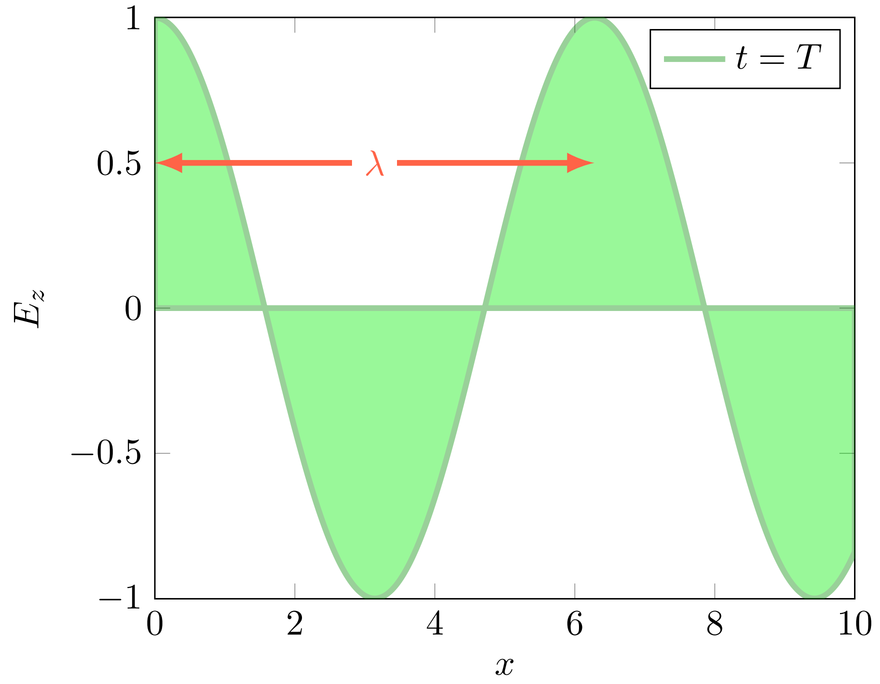
Equações de Maxwell
Radiação monocromática

$$\overrightarrow{E}(\vec{r},t) = E_0 \cos(\overrightarrow{k} \cdot \vec{r} - \omega t)\,\hat{z}$$

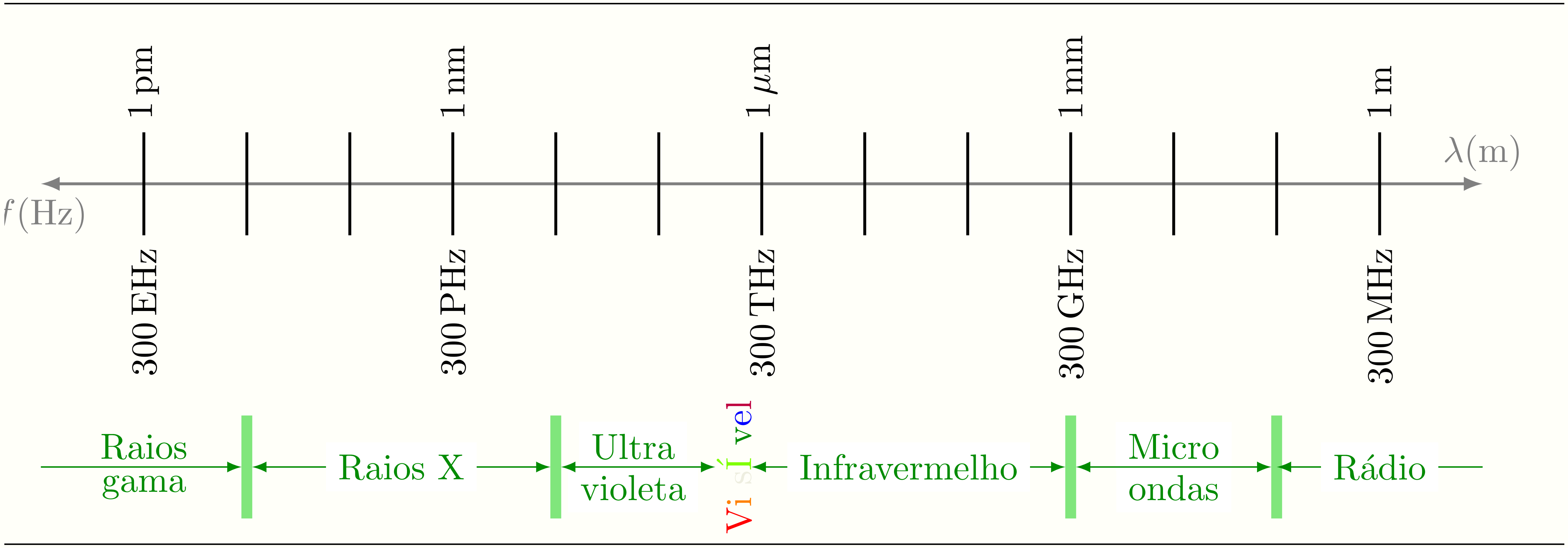
$$\omega = ck \qquad \lambda = cT$$

$$k = \frac{2\pi}{\lambda} \qquad \omega = \frac{2\pi}{T}$$

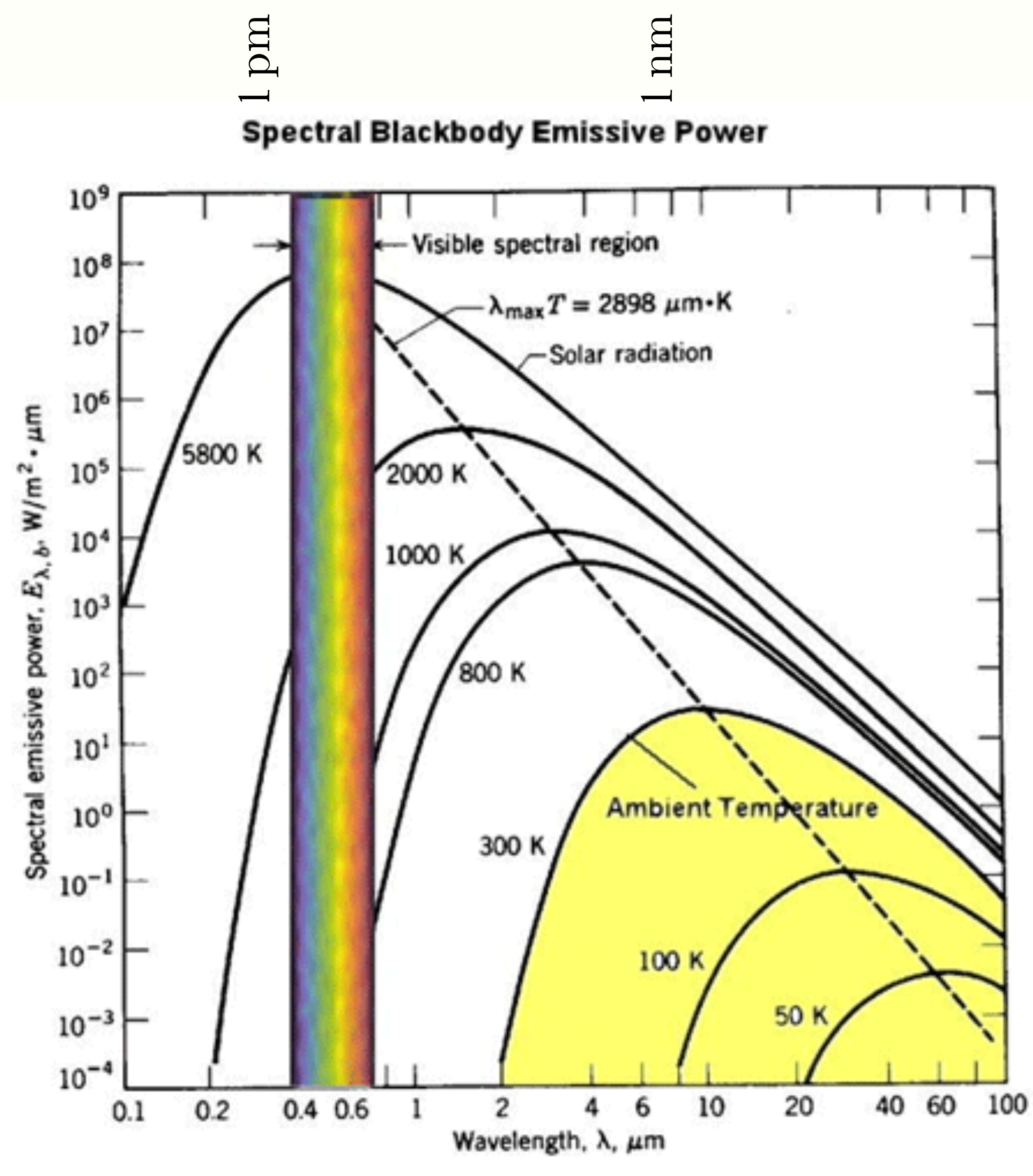
$$f = \frac{1}{T} \qquad \omega = 2\pi f$$

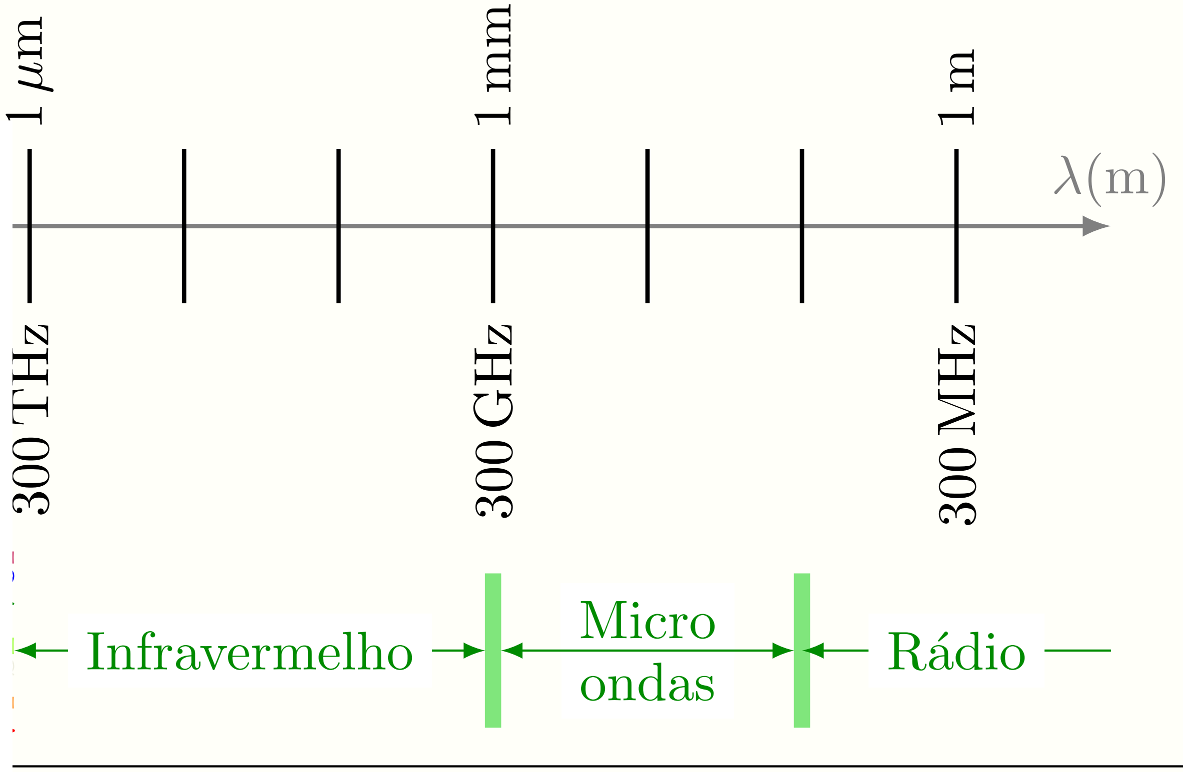


Equações de Maxwell
Espaço livre
Espectro eletromagnético

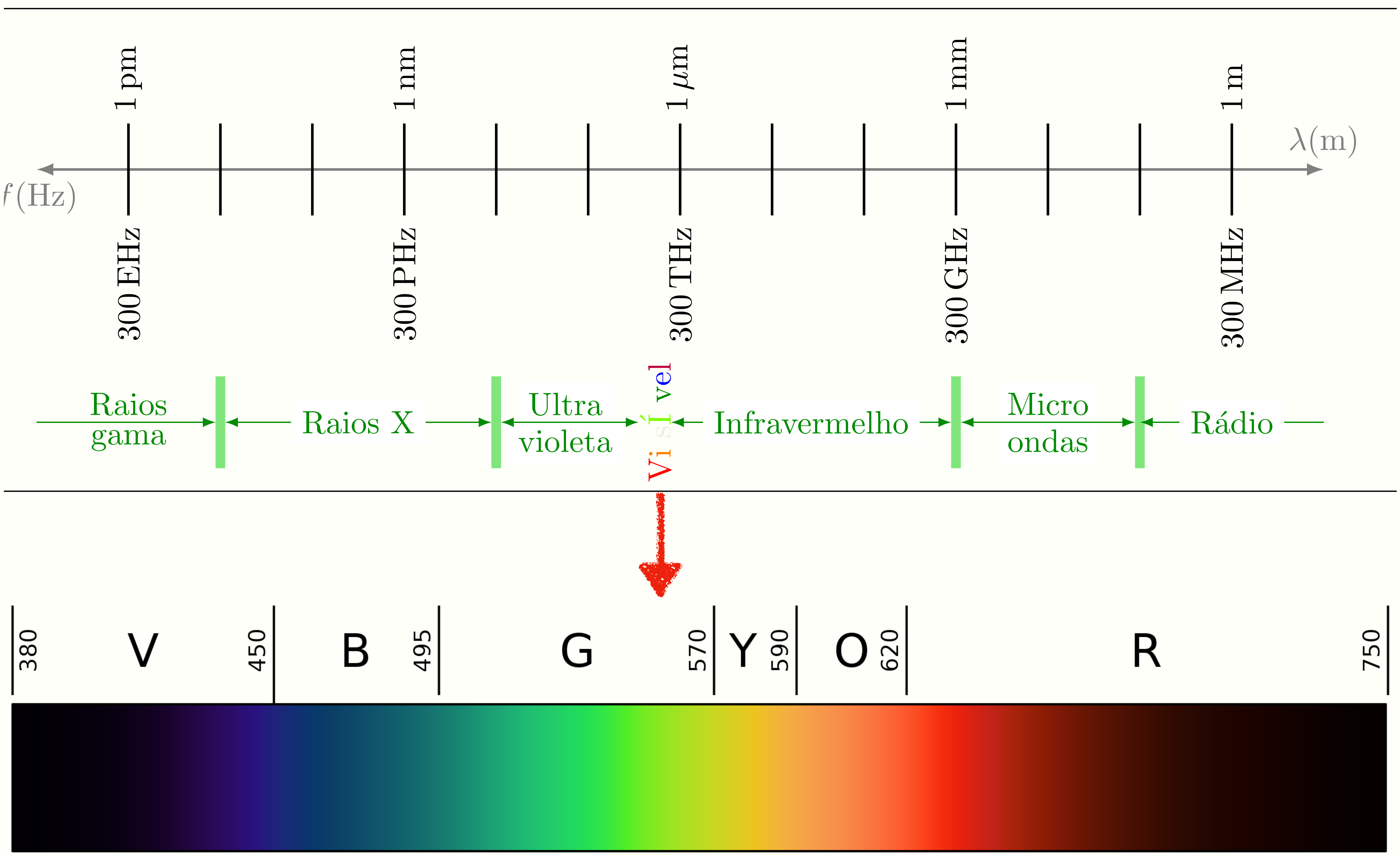


Equações de Maxwell
Espaço livre
Espectro eletromagnético

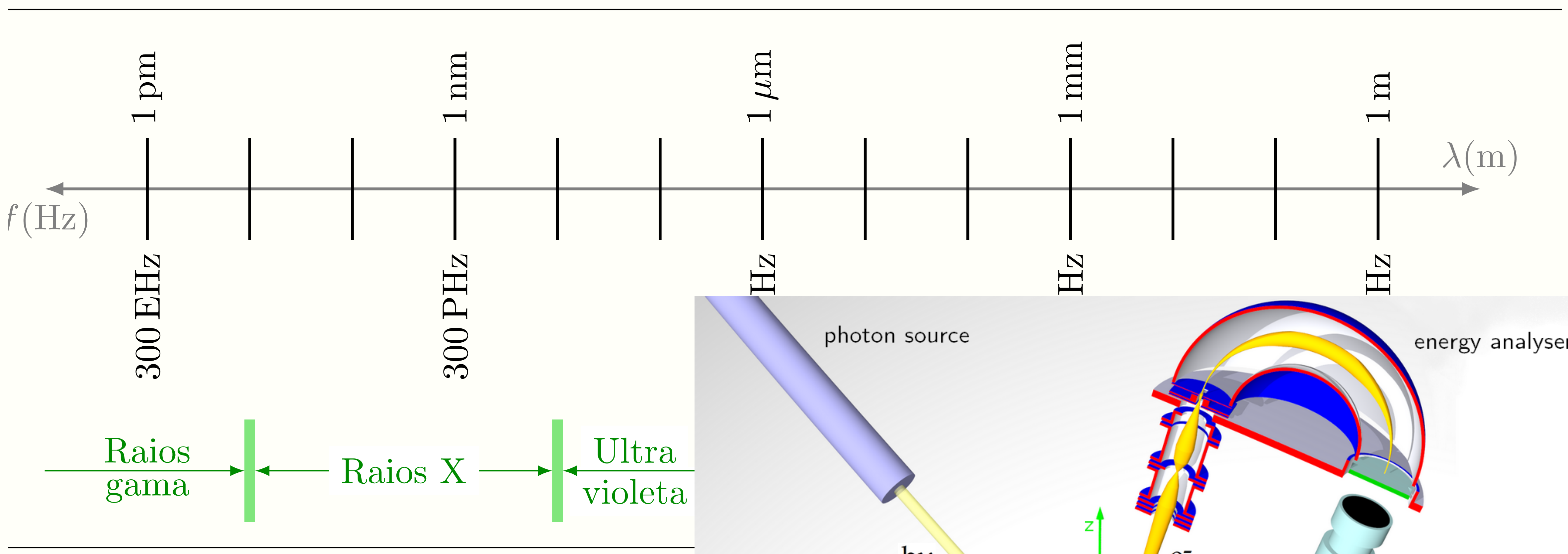


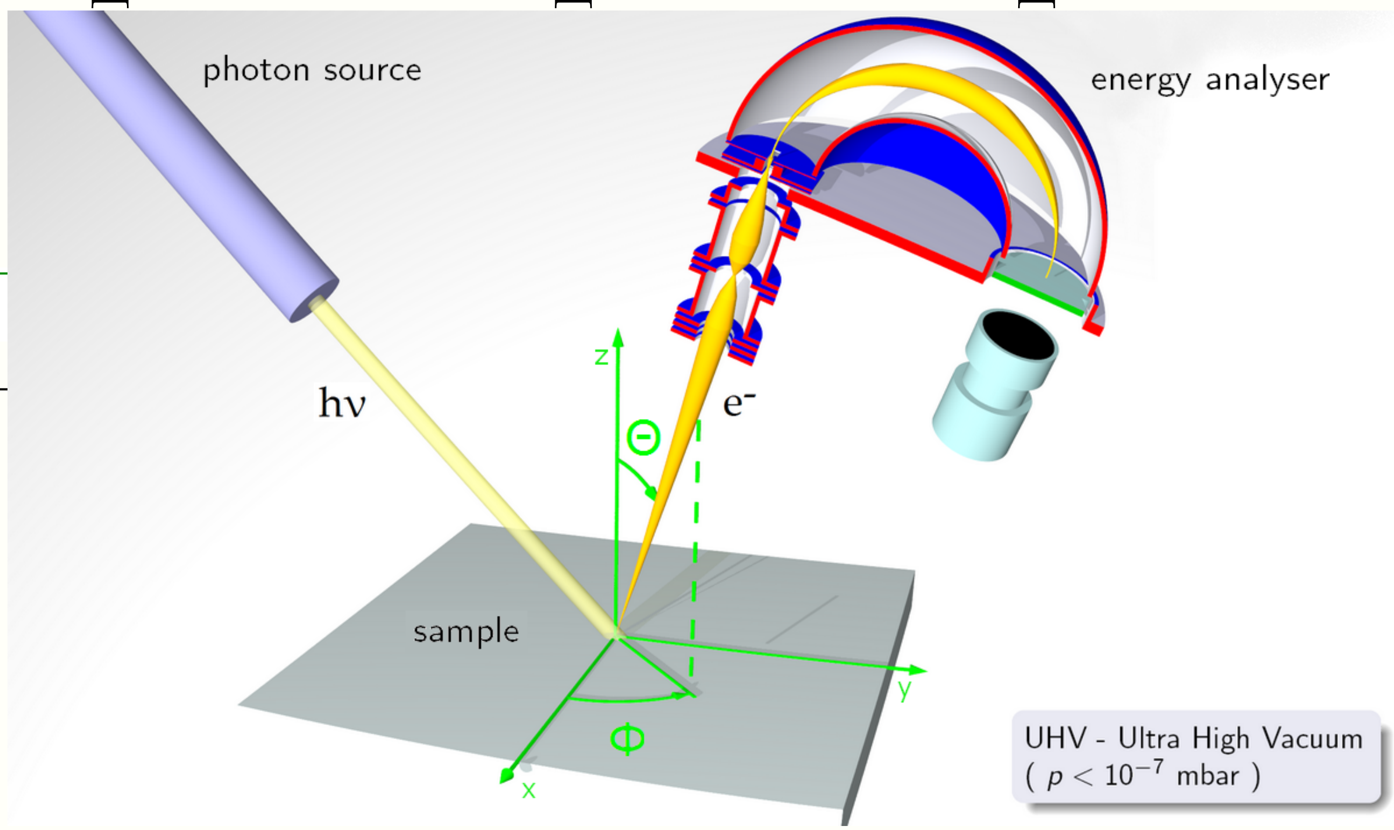


Equações de Maxwell
Espaço livre
Espectro eletromagnético

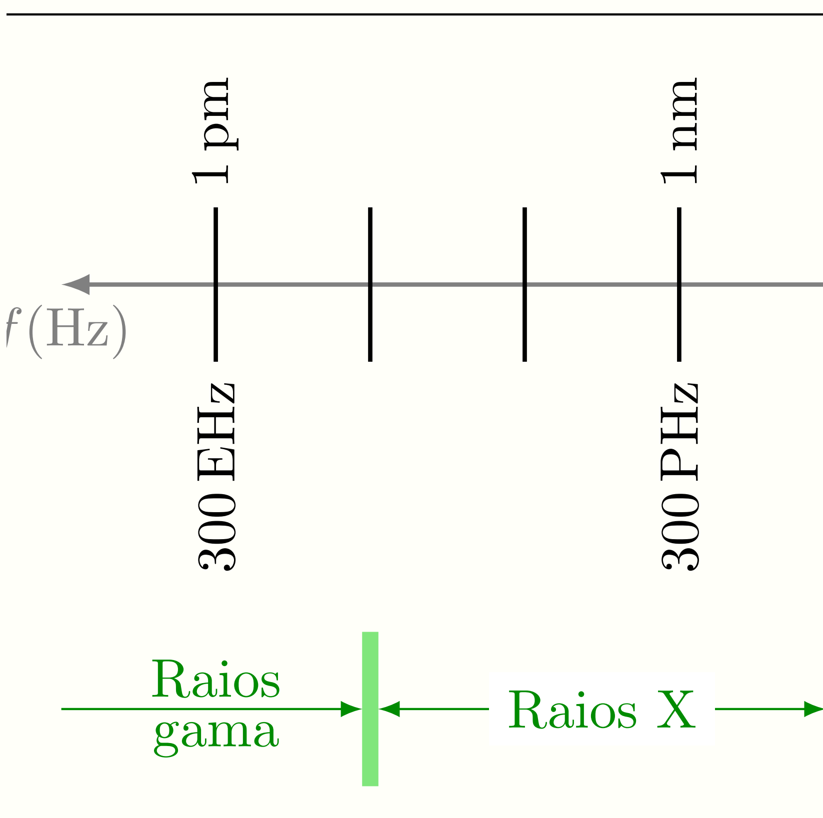


Equações de Maxwell
Espaço livre
Espectro eletromagnético



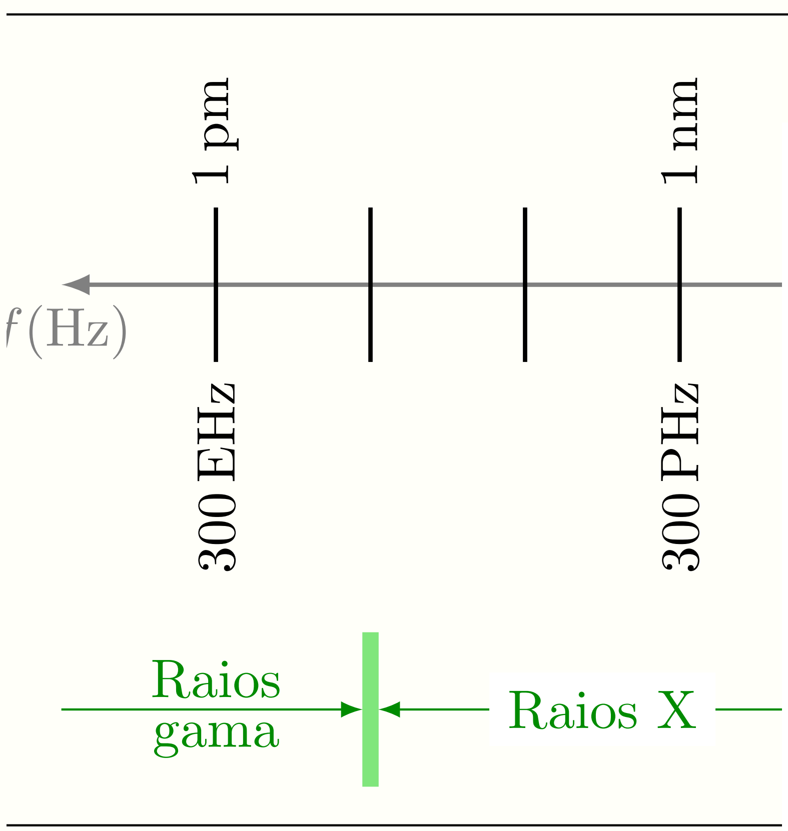


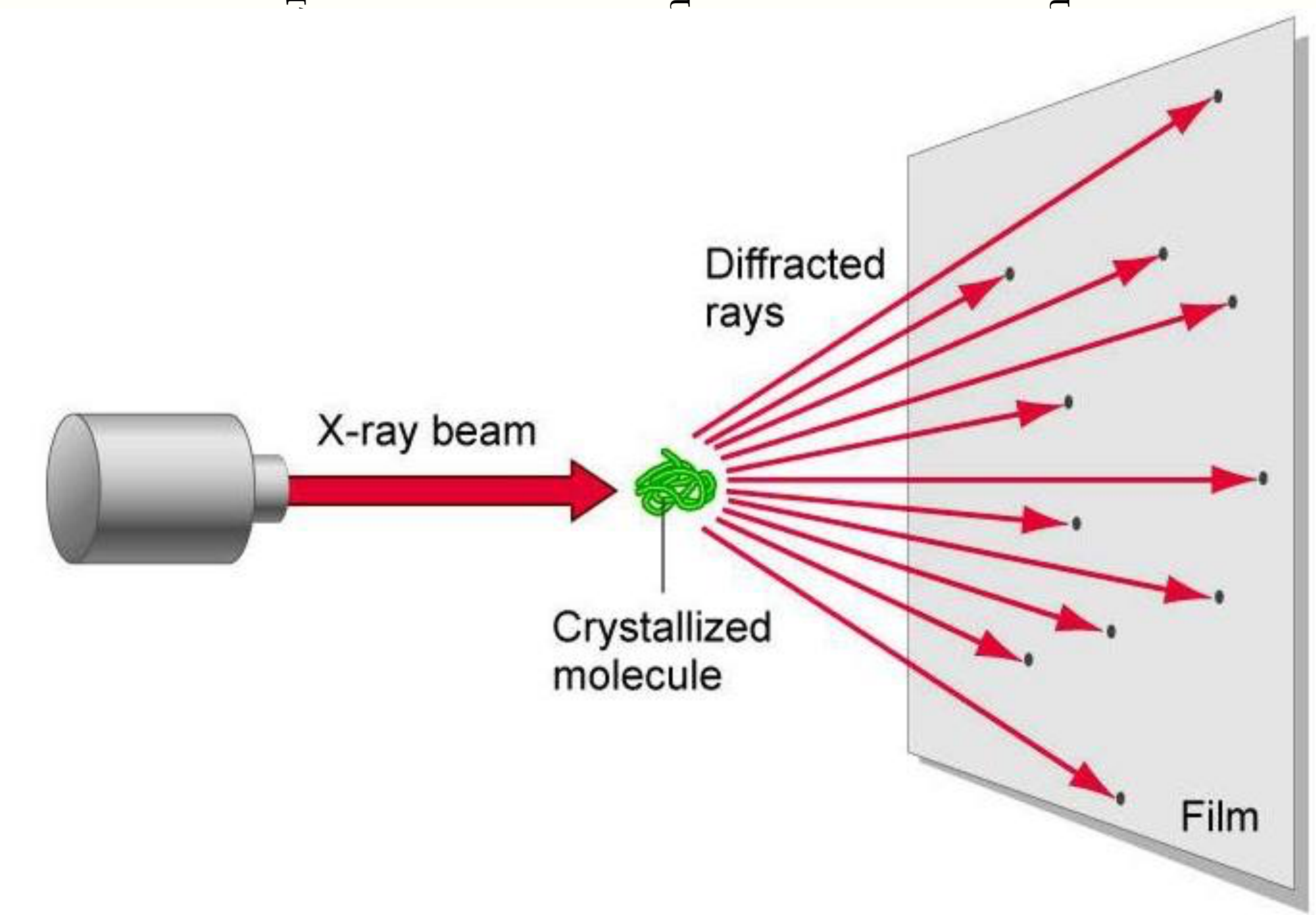
Equações de Maxwell
Espaço livre
Espectro eletromagnético



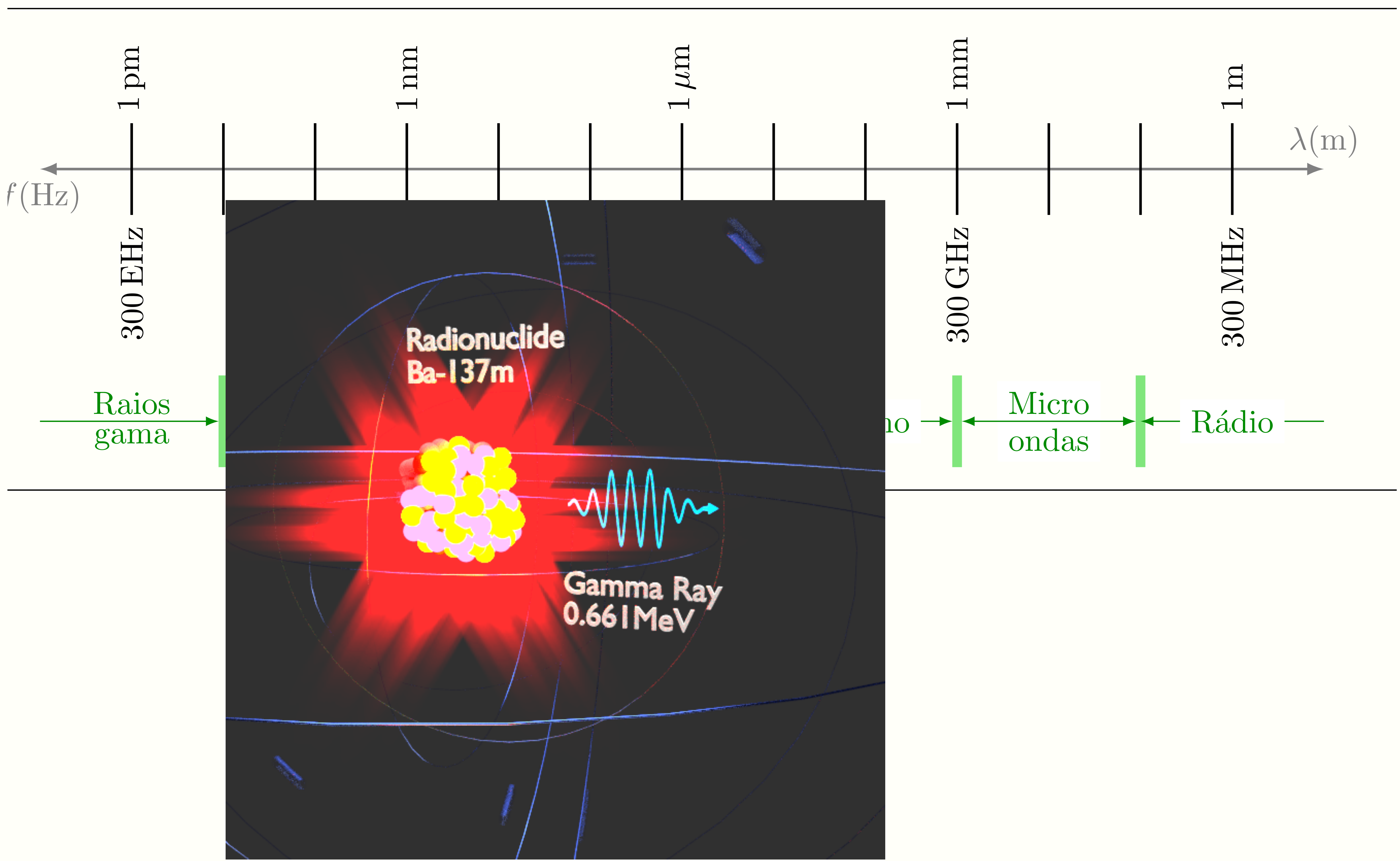
Anna Ludwig

Equações de Maxwell
Espaço livre
Espectro eletromagnético





Equações de Maxwell
Espaço livre
Espectro eletromagnético



Equações de Maxwell
Campos elétrico e magnético

$$\vec{E}(\vec{r},t) = E_0 \cos(kx - \omega t)\hat{z}$$

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

Equações de Maxwell
Campos elétrico e magnético

$$\vec{E}(\vec{r}, t) = E_0 \cos(kx - \omega t)\hat{z}$$

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

$$\frac{\partial E_z}{\partial y} = -\frac{\partial B_x}{\partial t} \qquad \Rightarrow B_x = 0$$

Equações de Maxwell
Campos elétrico e magnético

$$\vec{E}(\vec{r},t) = E_0 \cos(kx - \omega t)\hat{z}$$

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

$$\left(\vec{\nabla} \times \vec{E}\right)_x = \frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z}$$

$$\frac{\partial E_z}{\partial y} = -\frac{\partial B_x}{\partial t}$$

$$\Rightarrow B_x = 0$$

Equações de Maxwell
Campos elétrico e magnético

$$\vec{E}(\vec{r}, t) = E_0 \cos(kx - \omega t)\hat{z}$$

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

$$\left(\vec{\nabla} \times \vec{E}\right)_y = \frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x}$$

$$\frac{\partial E_z}{\partial x} = \frac{\partial B_y}{\partial t}$$

$$\Rightarrow \frac{\partial B_y}{\partial t} = -kE_0 \sin(kx - \omega t)$$

Equações de Maxwell
Campos elétrico e magnético

$$\vec{E}(\vec{r},t) = E_0 \cos(kx - \omega t)\hat{z}$$

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

$$\left(\vec{\nabla} \times \vec{E}\right)_y = \frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x}$$

$$\frac{\partial E_z}{\partial x} = \frac{\partial B_y}{\partial t}$$

$$\Rightarrow \frac{\partial B_y}{\partial t} = -kE_0 \sin(kx - \omega t)$$

$$B_y = -\frac{k}{\omega} E_0 \cos(kx - \omega t)$$

Equações de Maxwell
Campos elétrico e magnético

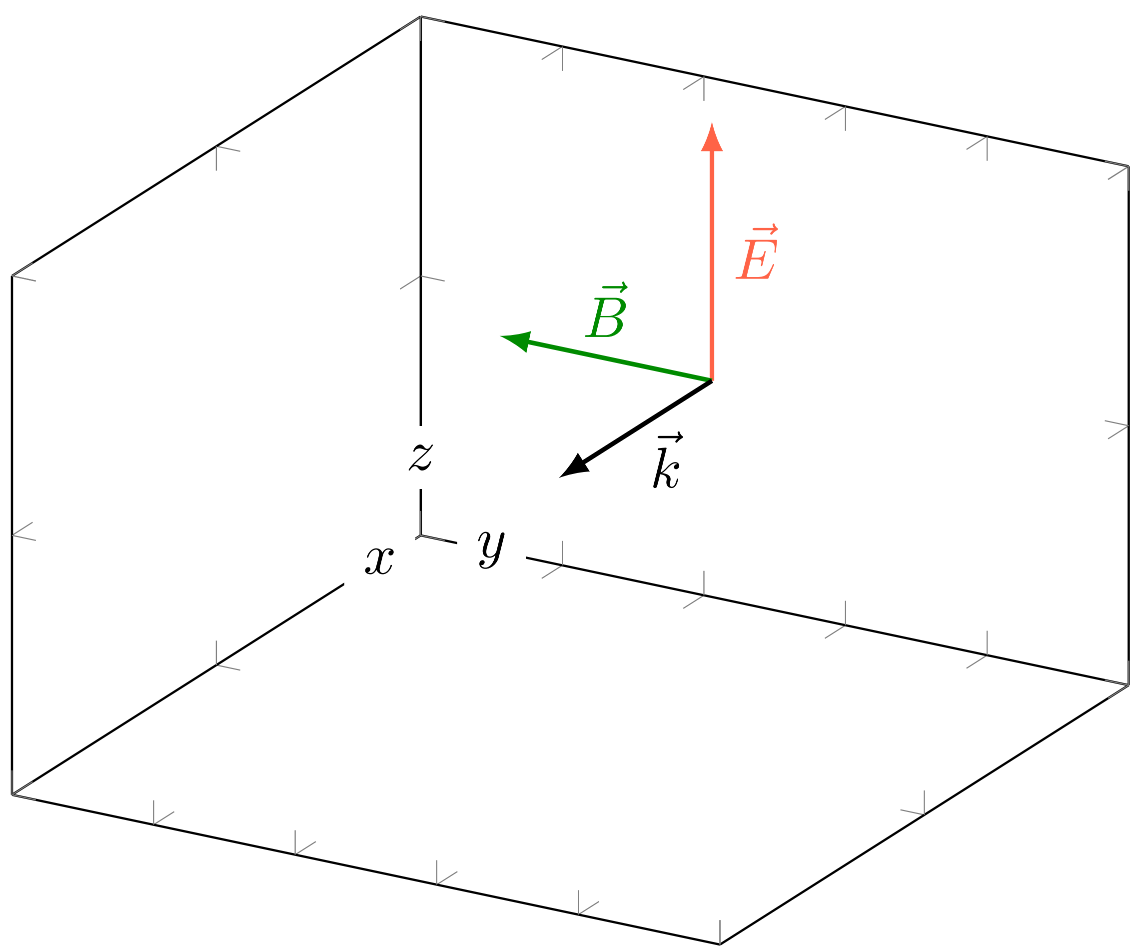
$$\overrightarrow{E}(\vec{r}, t) = E_0 \cos(kx - \omega t)\hat{z}$$

$$B_y = -\frac{k}{\omega} E_0 \cos(kx - \omega t) = -\frac{E_z}{c}$$

Equações de Maxwell
Campos elétrico e magnético

$$\vec{E}(\vec{r}, t) = E_0 \cos(kx - \omega t)\hat{z}$$

$$B_y = -\frac{k}{\omega} E_0 \cos(kx - \omega t) = -\frac{E_z}{c}$$



Pratique o que aprendeu

$$\vec{B}(\vec{r},t) = \cos\Big(2\pi(x+2y) - \omega t\Big)\,\hat{z}$$

$$\omega, \quad \vec{k}, \quad \vec{E} = ?$$

$$\omega, \quad \vec{k}, \quad \vec{E} = ?$$

Pratique o que aprendeu

$$\vec{B}(\vec{r},t) = \cos\Big(2\pi(x+2y) - \omega t\Big)\,\hat{z}$$

$$\vec{k}\cdot\vec{r} = 2\pi x + 4\pi y$$

$$\omega, \quad \vec{k}, \quad \vec{E} = ?$$

Pratique o que aprendeu

$$\overrightarrow{B}(\vec{r},t) = \cos\Big(2\pi(x+2y) - \omega t\Big)\,\hat{z}$$

$$\overrightarrow{k}\cdot\vec{r} = 2\pi x + 4\pi y \qquad \Rightarrow \begin{cases} k_x = 2\pi \\ k_y = 4\pi \end{cases}$$

$$\omega, \quad \vec{k}, \quad \vec{E} = ?$$

Pratique o que aprendeu

$$\vec{B}(\vec{r},t) = \cos\Big(2\pi(x+2y) - \omega t\Big)\,\hat{x}$$

$$\vec{k}\cdot\vec{r} = 2\pi x + 4\pi y \qquad \Rightarrow \begin{cases} k_x & = 2\pi \\ k_y & = 4\pi \end{cases}$$

$$k = \sqrt{(2\pi)^2 + (4\pi)^2} = 2\pi\sqrt{5}$$

$$\omega, \quad \vec{k}, \quad \vec{E} = ?$$

Pratique o que aprendeu

$$\vec{B}(\vec{r},t) = \cos\Big(2\pi(x+2y) - \omega t\Big)\,\hat{z}$$

$$\vec{k}\cdot\vec{r} = 2\pi x + 4\pi y \qquad \Rightarrow \begin{cases} k_x & = 2\pi \\ k_y & = 4\pi \end{cases}$$

$$k = \sqrt{(2\pi)^2 + (4\pi)^2} = 2\pi\sqrt{5} \qquad \Rightarrow \omega = 2\pi\sqrt{5}c$$

$$\omega, \quad \vec{k}, \quad \vec{E} = ?$$

Pratique o que aprendeu

$$\vec{k} = 2\pi\hat{x} + 4\pi\hat{y}$$

$$\overrightarrow{B}(\vec{r}, t) = \cos\Big(2\pi(x + 2y) - \omega t\Big)\,\hat{z}$$

$$\omega = 2\pi\sqrt{5}c$$

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

$$\omega, \quad \vec{k}, \quad \vec{E} = ?$$

Pratique o que aprendeu

$$\vec{k} = 2\pi\hat{x} + 4\pi\hat{y}$$

$$\omega = 2\pi\sqrt{5}c$$

$$\overrightarrow{B}(\vec{r}, t) = \cos\Big(2\pi(x + 2y) - \omega t\Big)\,\hat{z}$$

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

$$\vec{\boldsymbol{\nabla}} \times \vec{B} = \left(\frac{\partial B_z}{\partial y} - \frac{\partial B_y}{\partial z}\right)\hat{x} + \left(\frac{\partial B_x}{\partial z} - \frac{\partial B_z}{\partial x}\right)\hat{y} + \left(\frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y}\right)\hat{z}$$

$$\omega, \quad \vec{k}, \quad \vec{E} = ?$$

Pratique o que aprendeu

$$\vec{k} = 2\pi\hat{x} + 4\pi\hat{y}$$

$$\omega = 2\pi\sqrt{5}c$$

$$\vec{B}(\vec{r},t) = \cos\Big(2\pi(x+2y) - \omega t\Big)\,\hat{z}$$

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

$$\vec{\nabla} \times \vec{B} = \left(\frac{\partial B_z}{\partial y} - \cancel{\frac{\partial B_y}{\partial z}}\right)\hat{x} + \left(\cancel{\frac{\partial B_x}{\partial z}} - \frac{\partial B_z}{\partial x}\right)\hat{y} + \cancel{\left(\frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y}\right)}\hat{z}$$

$$-2\pi\sin\Big(2\pi(x+2y) - \omega t\Big)(2\hat{x} - \hat{y}) = \mu_0\epsilon_0 \frac{\partial \vec{E}}{\partial t}$$

$$\omega, \quad \vec{k}, \quad \vec{E} = ?$$

Pratique o que aprendeu

$$\vec{k} = 2\pi\hat{x} + 4\pi\hat{y}$$

$$\omega = 2\pi\sqrt{5}c$$

$$\vec{B}(\vec{r},t) = \cos\Big(2\pi(x+2y) - \omega t\Big)\,\hat{z}$$

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

$$-2\pi\sin\Big(2\pi(x+2y) - \omega t\Big)(2\hat{x} - \hat{y}) = \mu_0\epsilon_0\frac{\partial\vec{E}}{\partial t}$$

$$\vec{E} = -\frac{2\pi}{\omega\mu_0\epsilon_0}\cos\Big(2\pi(x+2y) - \omega t\Big)(2\hat{x} - \hat{y})$$

$$\omega, \quad \vec{k}, \quad \vec{E} = ?$$

Pratique o que aprendeu

$$\vec{k} = 2\pi\hat{x} + 4\pi\hat{y}$$

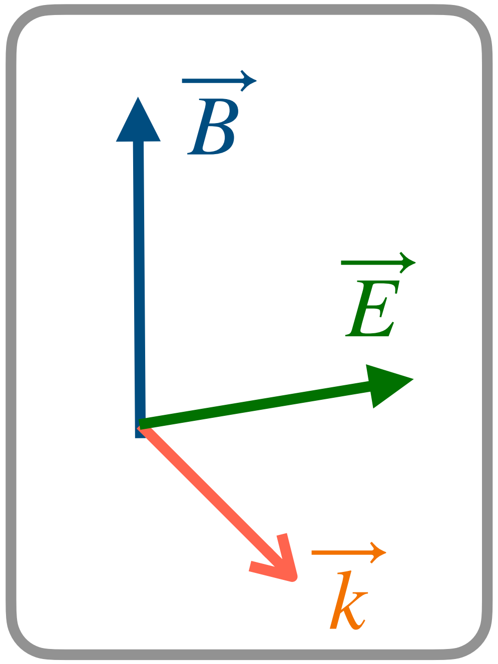
$$\omega = 2\pi\sqrt{5}c$$

$$\vec{B}(\vec{r},t) = \cos\Big(2\pi(x+2y) - \omega t\Big)\,\hat{z}$$

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

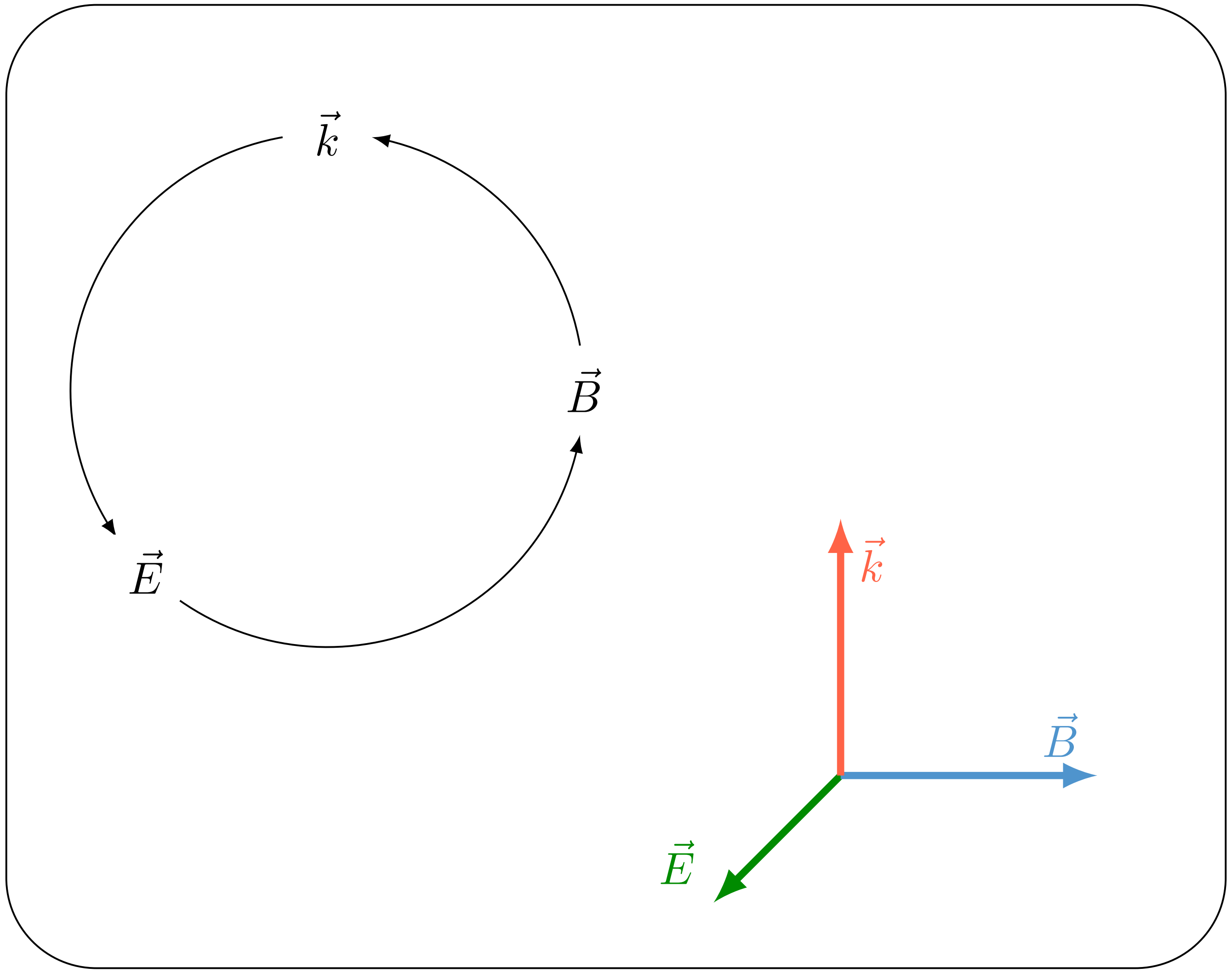
$$-2\pi\sin\Big(2\pi(x+2y) - \omega t\Big)(2\hat{x} - \hat{y}) = \mu_0\epsilon_0 \frac{\partial \vec{E}}{\partial t}$$

$$\vec{E} = -c\cos\Big(2\pi(x+2y) - \omega t\Big)\frac{2\hat{x} - \hat{y}}{\sqrt{5}}$$



Equações de Maxwell
Campos elétrico e magnético

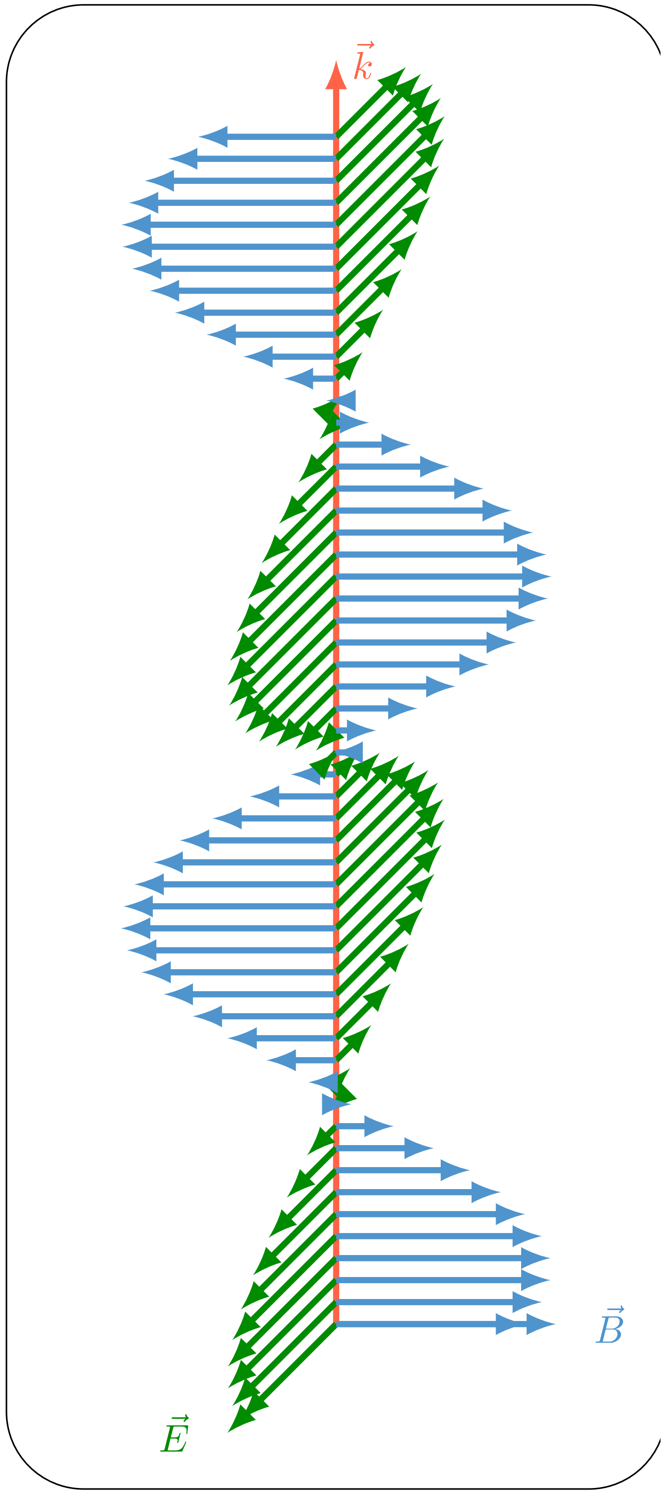
$$c\overrightarrow{B} = \hat{k} \times \overrightarrow{E}$$



Equações de Maxwell
Campos elétrico e magnético

$$\vec{E}(\vec{r},t) = A\cos(kz - \omega t)\,\hat{x}$$

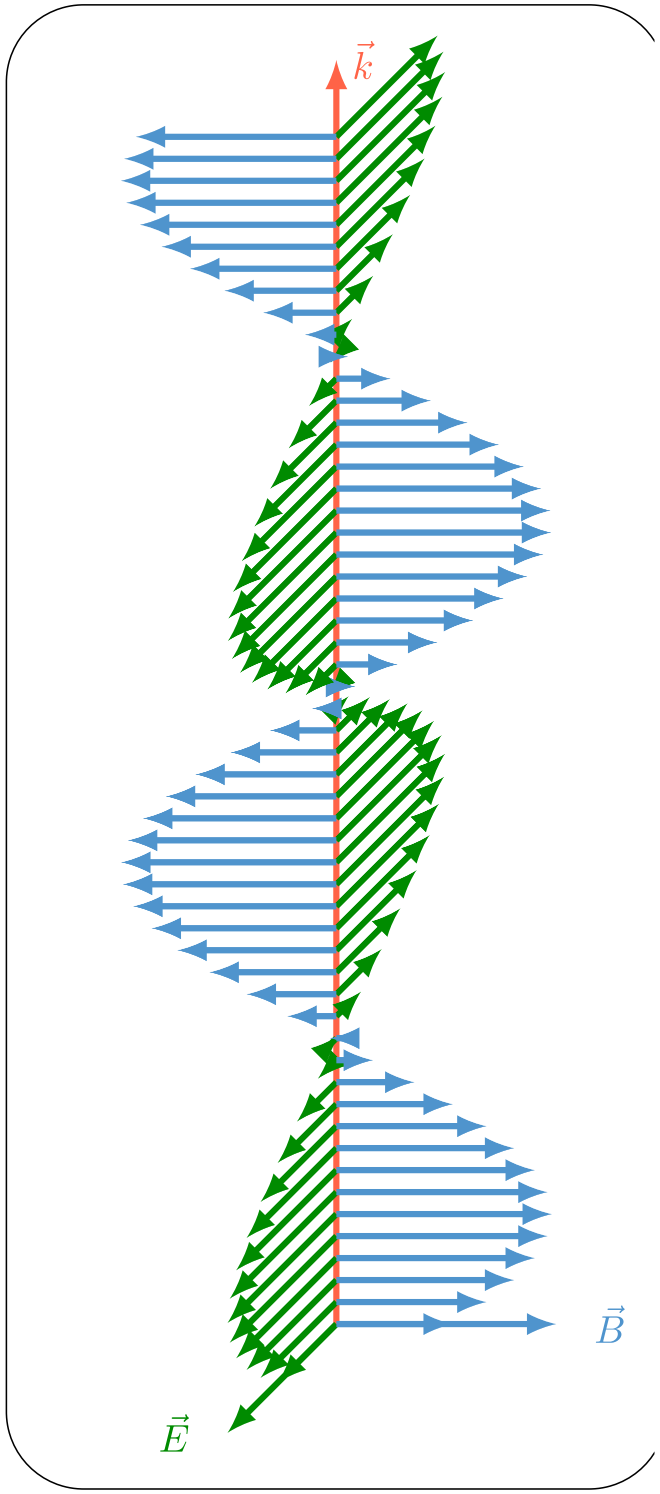
$$\vec{B}(\vec{r},t) = \frac{A}{c}\cos(kz - \omega t)\,\hat{y}$$



Equações de Maxwell
Campos elétrico e magnético

$$\overrightarrow{E}(\vec{r},t) = A\cos(kz - \omega t)\,\hat{x}$$

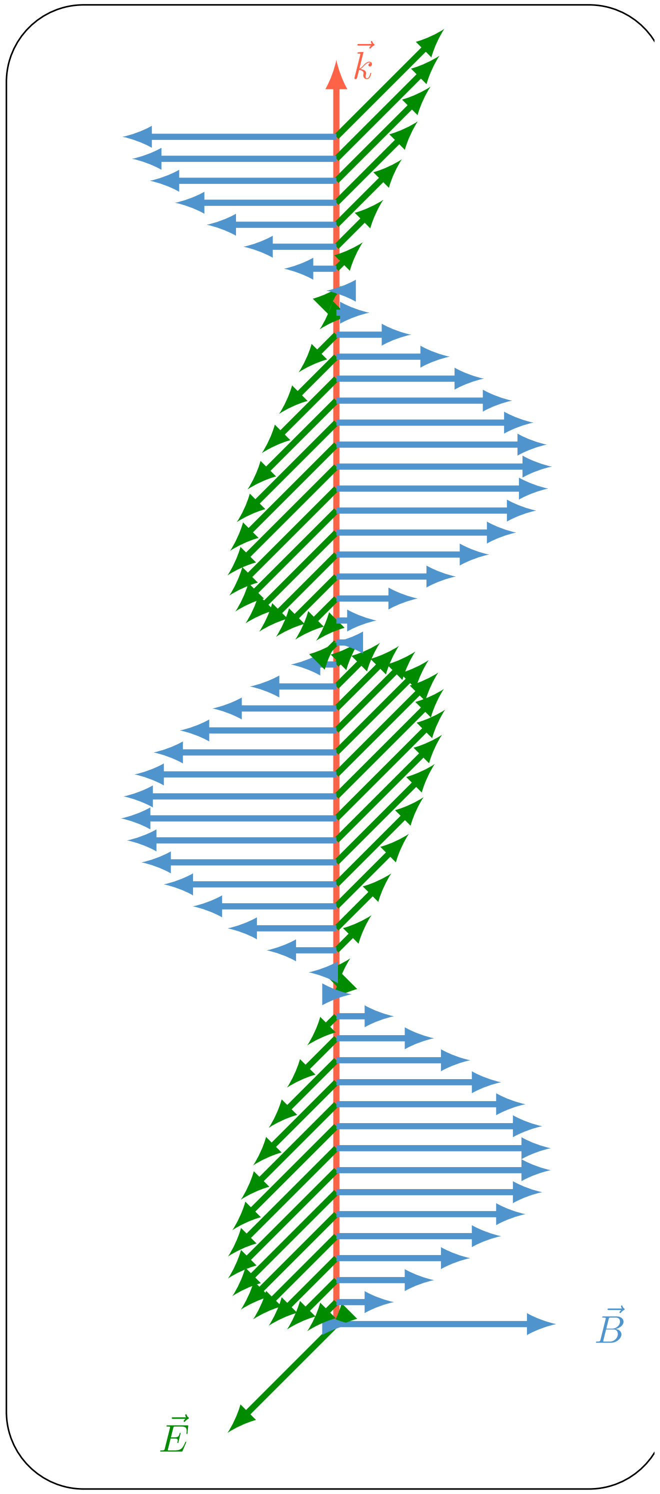
$$\overrightarrow{B}(\vec{r},t) = \frac{A}{c}\cos(kz - \omega t)\,\hat{y}$$



Equações de Maxwell
Campos elétrico e magnético

$$\overrightarrow{E}(\vec{r}, t) = A\cos(kz - \omega t)\,\hat{x}$$

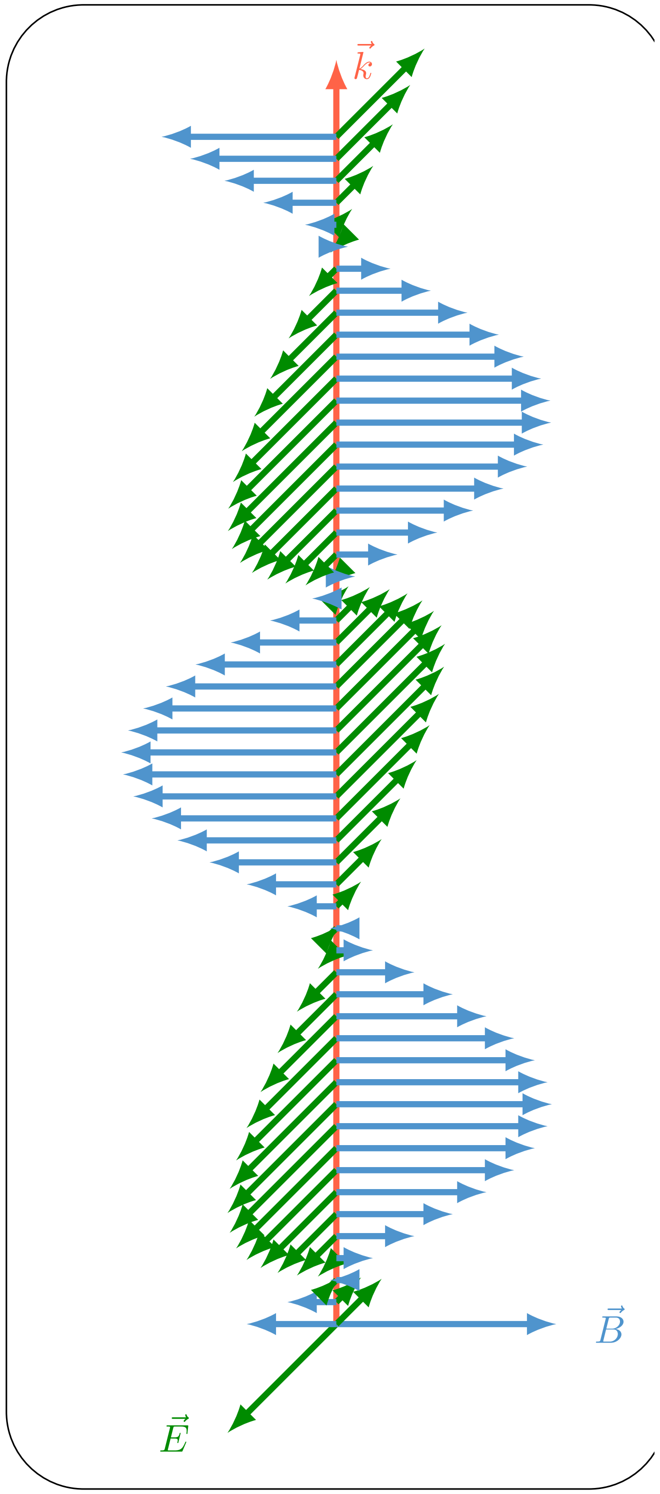
$$\overrightarrow{B}(\vec{r}, t) = \frac{A}{c}\cos(kz - \omega t)\,\hat{y}$$



Equações de Maxwell
Campos elétrico e magnético

$$\overrightarrow{E}(\vec{r},t) = A\cos(kz-\omega t)\,\hat{x}$$

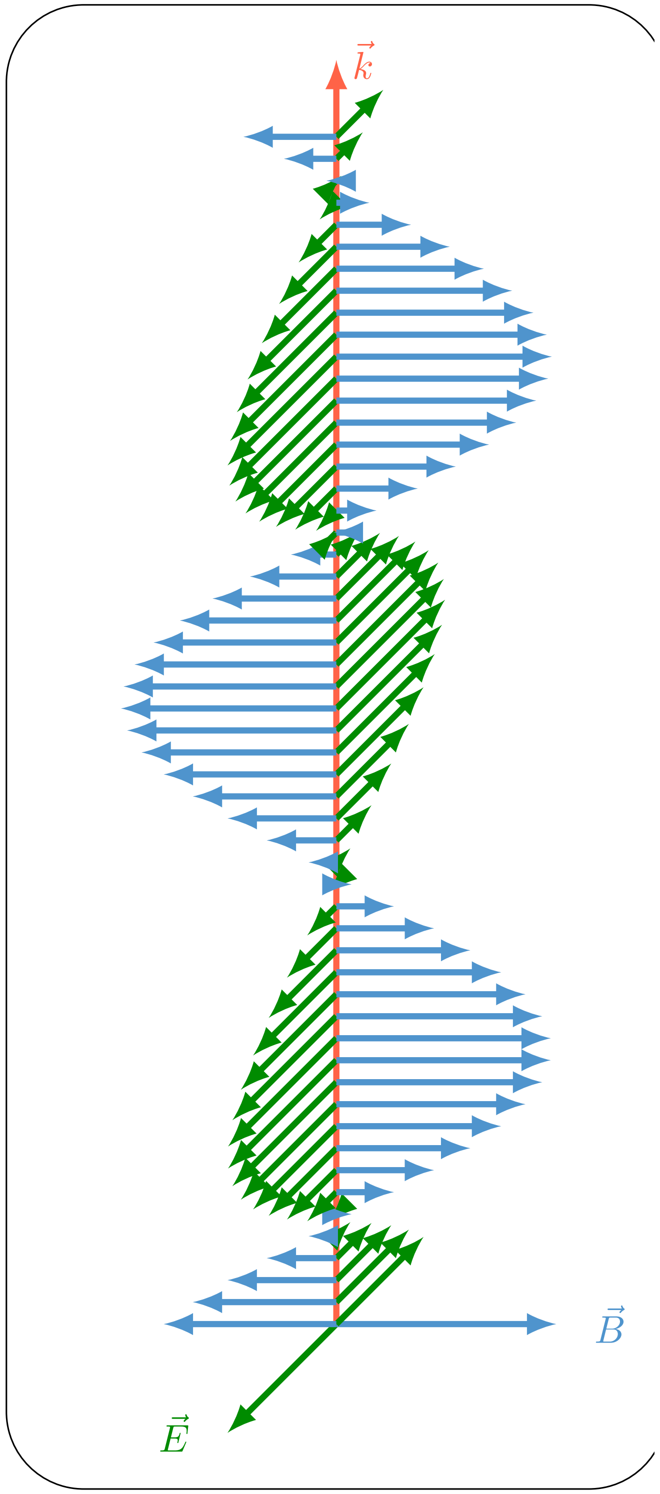
$$\overrightarrow{B}(\vec{r},t) = \frac{A}{c}\cos(kz-\omega t)\,\hat{y}$$



Equações de Maxwell
Campos elétrico e magnético

$$\overrightarrow{E}(\vec{r},t) = A\cos(kz - \omega t)\,\hat{x}$$

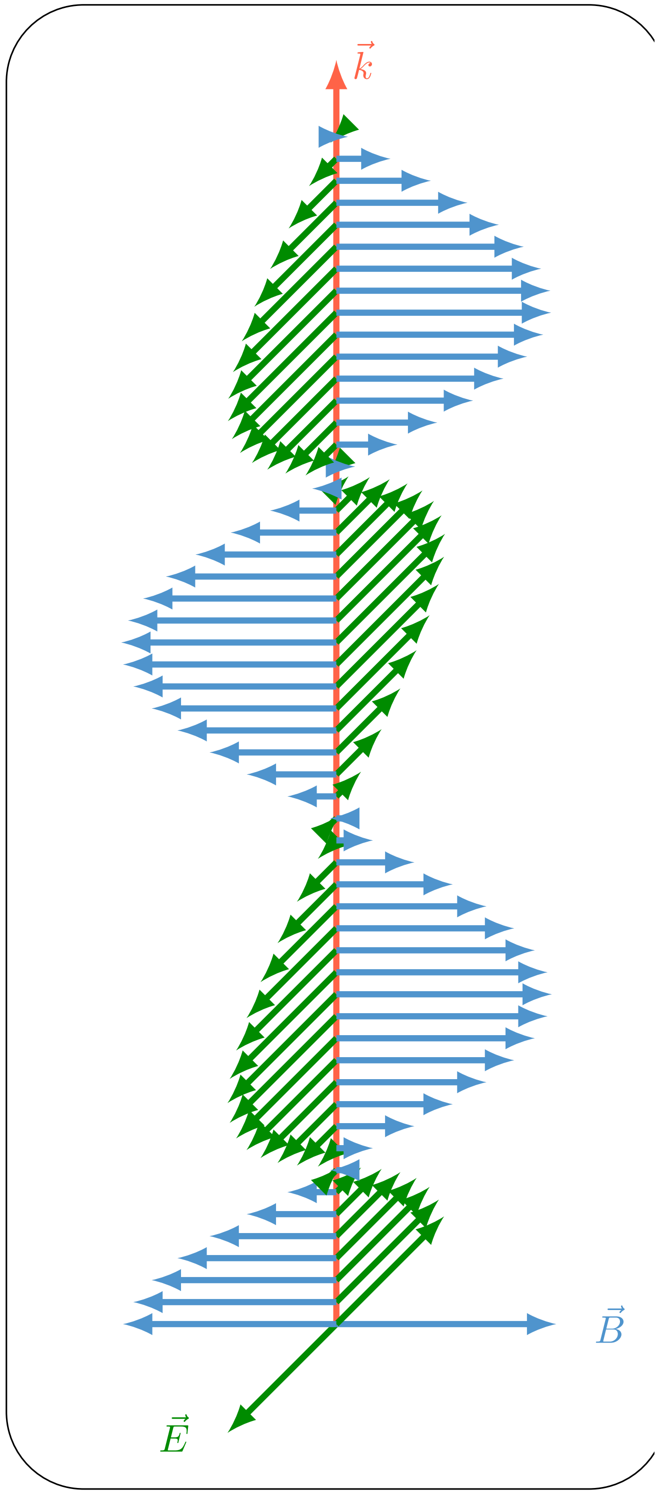
$$\overrightarrow{B}(\vec{r},t) = \frac{A}{c}\cos(kz - \omega t)\,\hat{y}$$



Equações de Maxwell
Campos elétrico e magnético

$$\overrightarrow{E}(\vec{r},t) = A\cos(kz-\omega t)\,\hat{x}$$

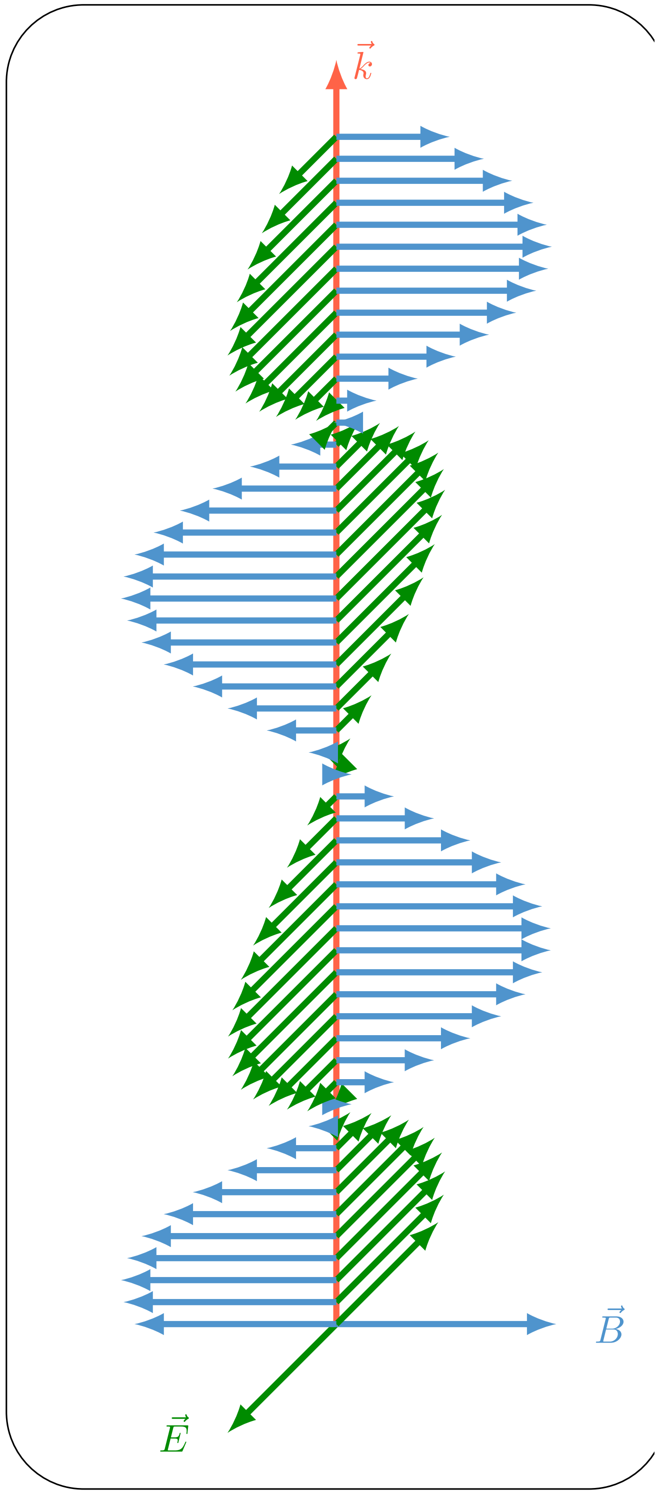
$$\overrightarrow{B}(\vec{r},t) = \frac{A}{c}\cos(kz-\omega t)\,\hat{y}$$



Equações de Maxwell
Campos elétrico e magnético

$$\vec{E}(\vec{r},t) = A\cos(kz-\omega t)\,\hat{x}$$

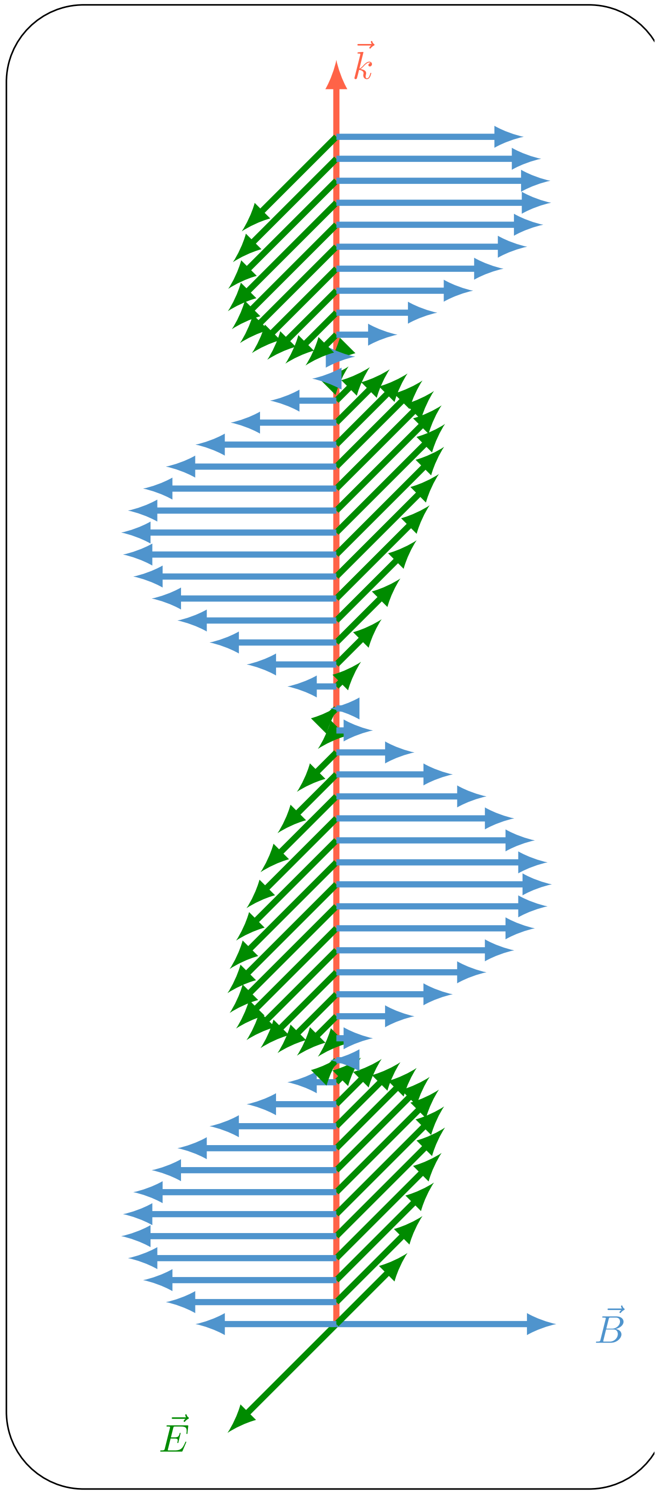
$$\vec{B}(\vec{r},t) = \frac{A}{c}\cos(kz-\omega t)\,\hat{y}$$



Equações de Maxwell
Campos elétrico e magnético

$$\vec{E}(\vec{r},t) = A\cos(kz-\omega t)\,\hat{x}$$

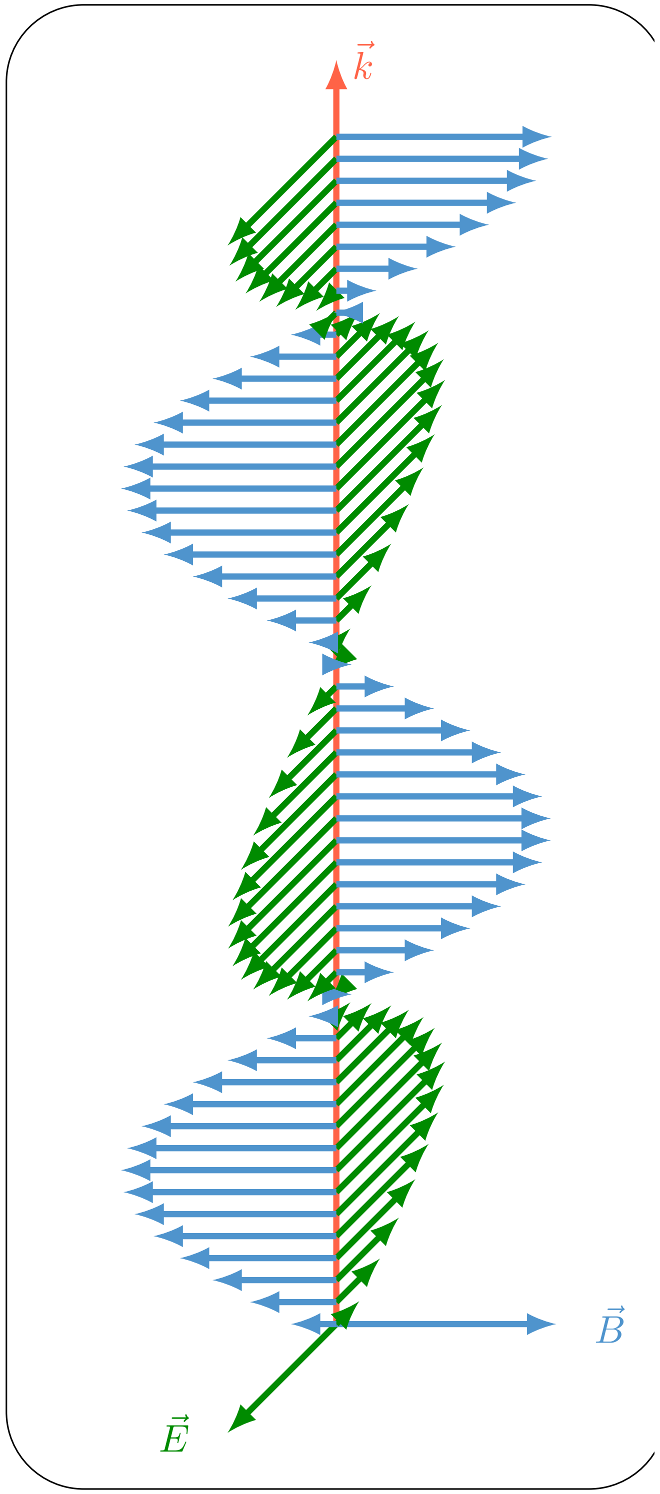
$$\vec{B}(\vec{r},t) = \frac{A}{c}\cos(kz-\omega t)\,\hat{y}$$



Equações de Maxwell
Campos elétrico e magnético

$$\vec{E}(\vec{r},t) = A\cos(kz-\omega t)\,\hat{x}$$

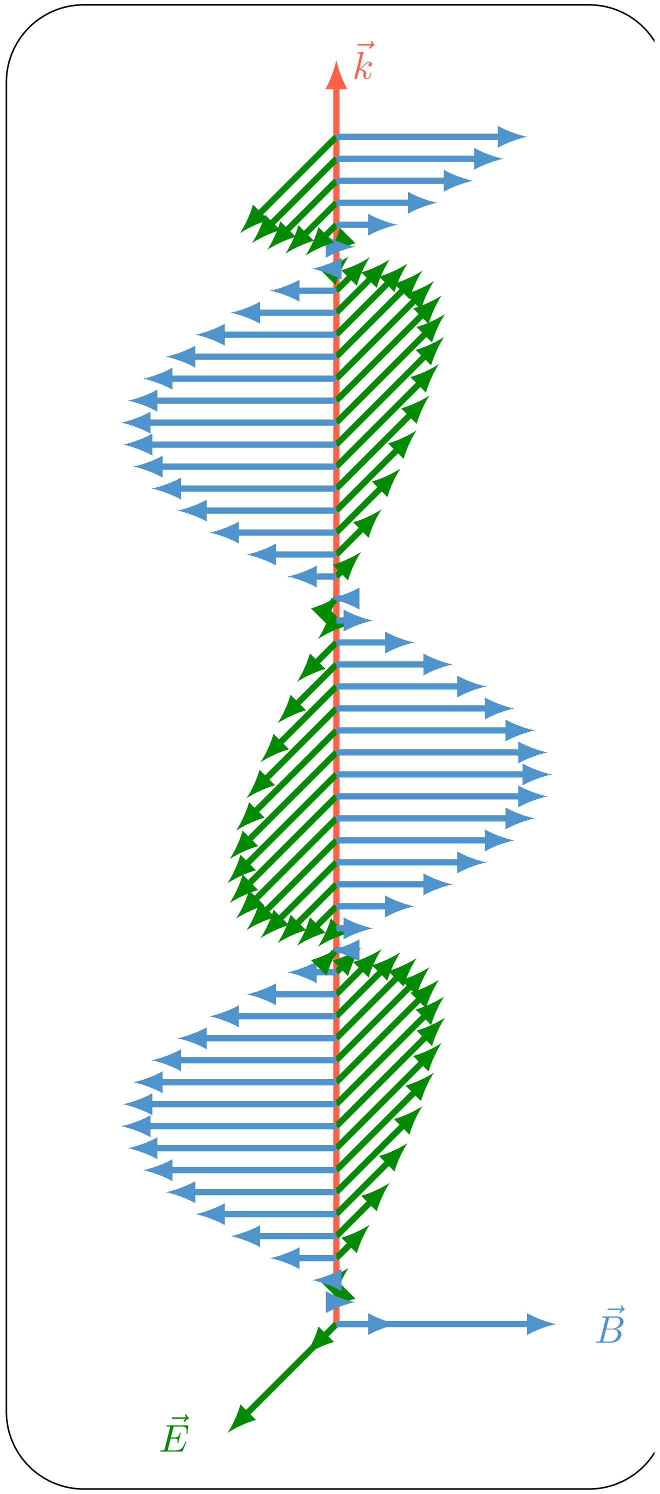
$$\vec{B}(\vec{r},t) = \frac{A}{c}\cos(kz-\omega t)\,\hat{y}$$



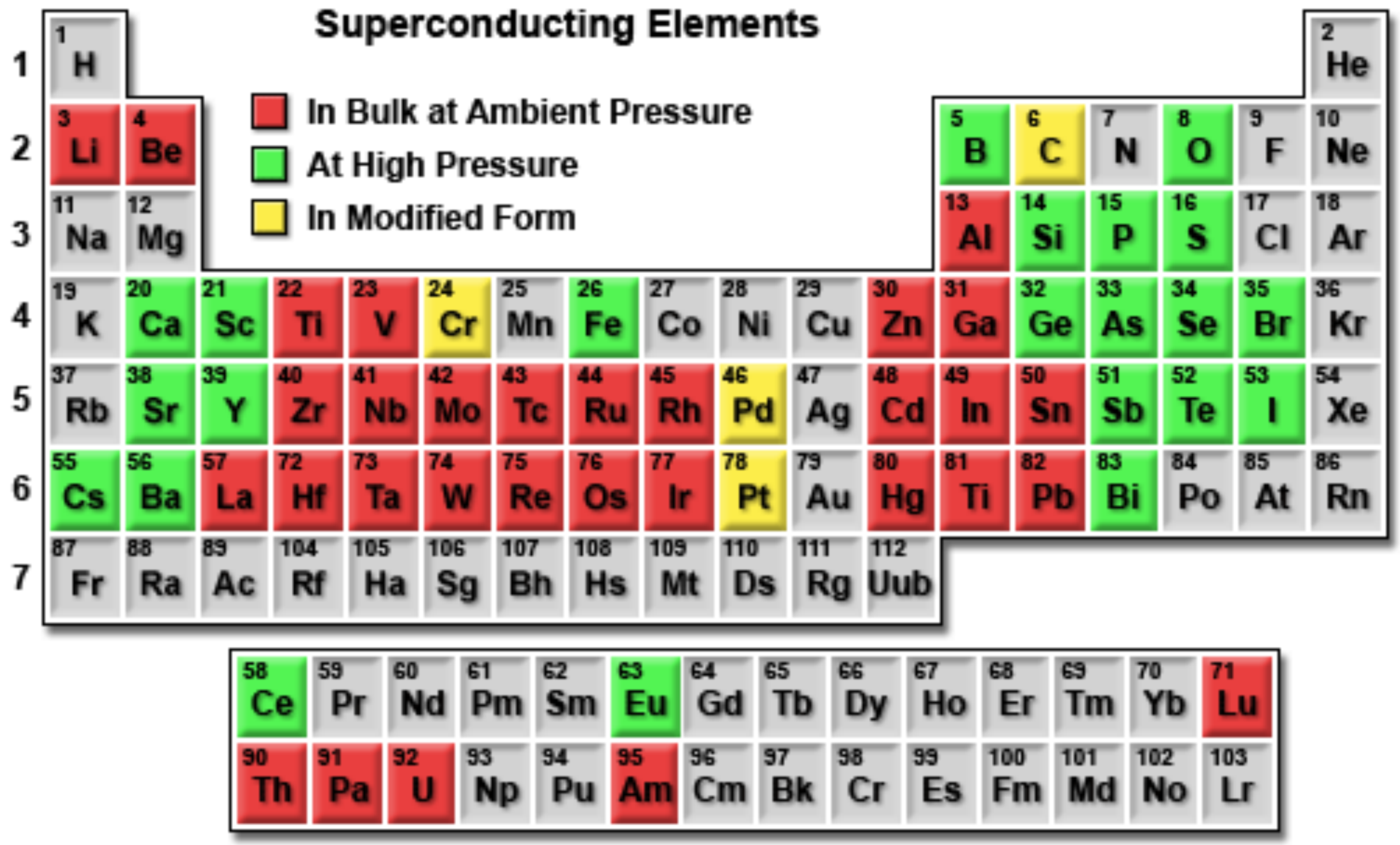
Equações de Maxwell
Campos elétrico e magnético

$$\vec{E}(\vec{r},t) = A\cos(kz - \omega t)\,\hat{x}$$

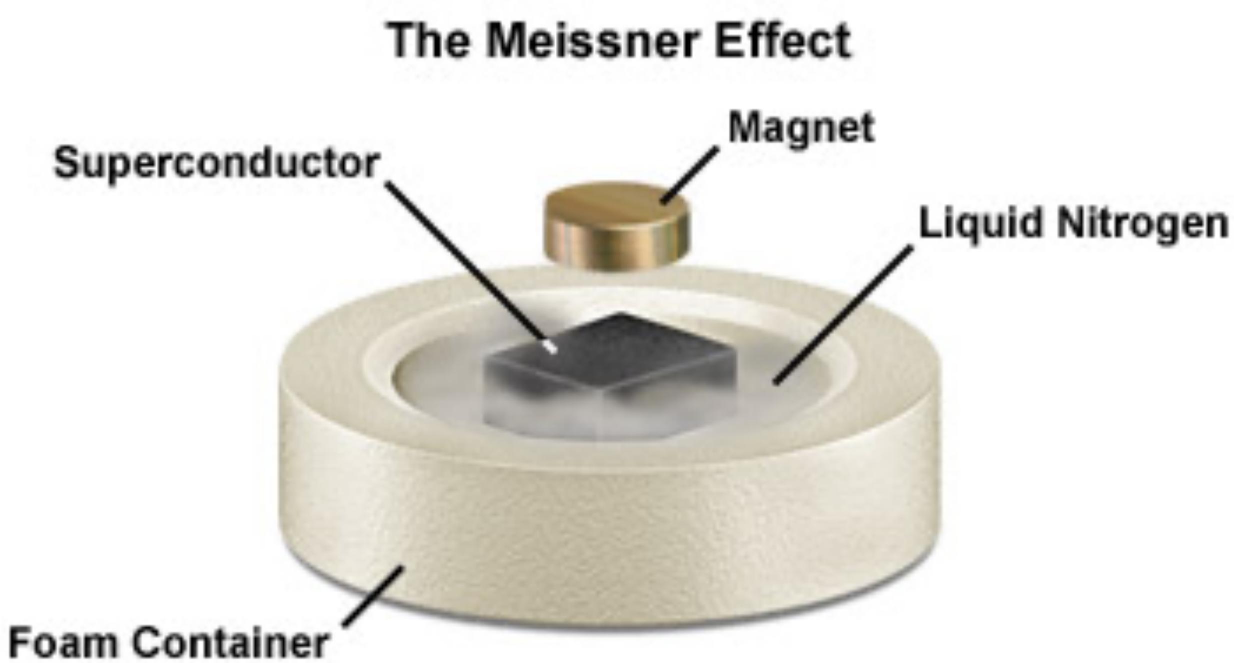
$$\vec{B}(\vec{r},t) = \frac{A}{c}\cos(kz - \omega t)\,\hat{y}$$



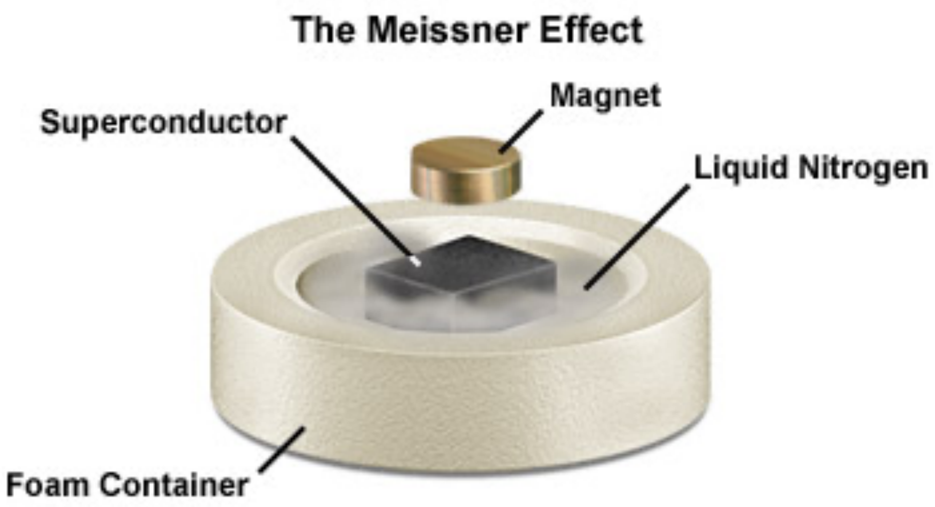
Supercondutividade



Supercondutividade

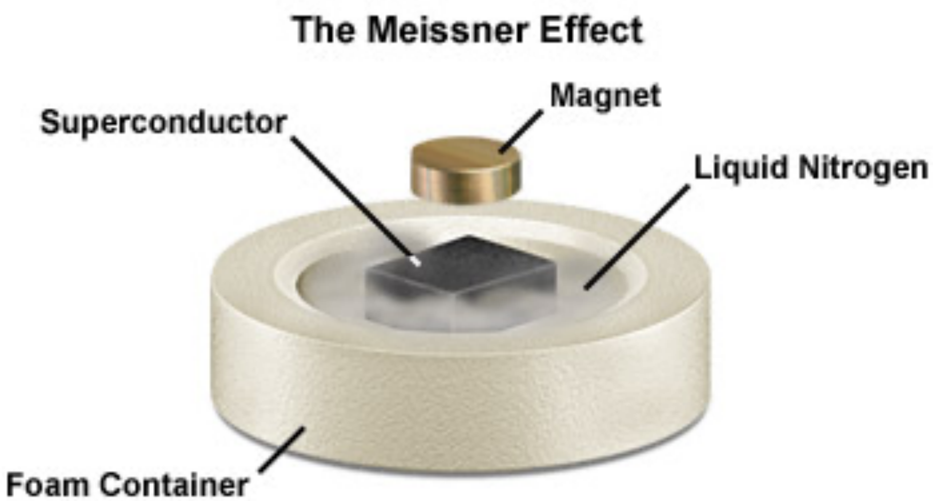


Supercondutividade



$$\vec{j} = \sigma \vec{E}$$

Supercondutividade



$$\cancel{\vec{j} = \sigma \vec{E}}$$

$$\vec{j} = \alpha \vec{A}$$