Física IV

28 setembro 2020

Equações de Maxwell

Radiação eletromagnética

Equações de Maxwell

$$\vec{\nabla} \cdot \vec{D} = \frac{\rho}{\epsilon_0}$$

$$\vec{D} = \kappa \vec{E}$$

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

$$\vec{\nabla} \cdot \vec{B} = 0$$

$$\vec{B} = \mu \vec{H}$$

$$\vec{\nabla} \times \vec{H} = \vec{j} + \epsilon_0 \frac{\partial \vec{D}}{\partial t}$$

Equações de Maxwell
Espaço livre

$$\overrightarrow{\nabla} \cdot \overrightarrow{E} = 0$$

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

$$\overrightarrow{\nabla} \cdot \overrightarrow{B} = 0$$

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

Equações de Maxwell
Espaço livre

$$\nabla^2 \overrightarrow{E} = \mu_0 \epsilon_0 \frac{\partial^2 \overrightarrow{E}}{\partial t^2}$$

$$\nabla^2 \overrightarrow{B} = \mu_0 \epsilon_0 \frac{\partial^2 \overrightarrow{B}}{\partial t^2}$$

Equações de Maxwell
Espaço livre

$$\nabla^2 \overrightarrow{E} = \mu_0 \epsilon_0 \frac{\partial^2 \overrightarrow{E}}{\partial t^2}$$

Equações de Maxwell
Espaço livre

$$\nabla^2 \overrightarrow{E} = \mu_0 \epsilon_0 \frac{\partial^2 \overrightarrow{E}}{\partial t^2}$$

$$\nabla^2 F = \frac{1}{v^2} \frac{\partial^2 F}{\partial t^2} \qquad (F = E_x, E_y, E_z)$$

Equações de Maxwell
Espaço livre

$$\nabla^2 \overrightarrow{E} = \mu_0 \epsilon_0 \frac{\partial^2 \overrightarrow{E}}{\partial t^2}$$

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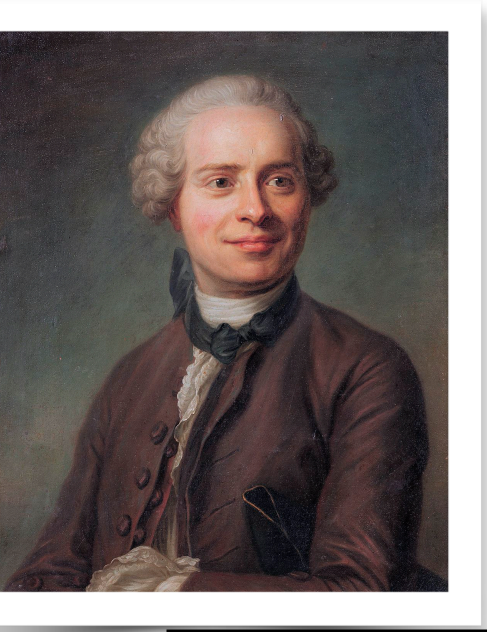
$$F(\vec{r}, t) = f(\hat{k} \cdot \vec{r} - vt)$$



D'Alembert

Equações de Maxwell
Espaço livre

$$\nabla^2 \vec{E} = \mu_0 \epsilon_0 \frac{\partial^2 \vec{E}}{\partial t^2}$$

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$$v = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 2.998 \times 10^8 \text{m/s}$$

Equações de Maxwell
Espaço livre

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Equações de Maxwell
Espaço livre

$$\nabla^2 \overrightarrow{E} = \mu_0 \epsilon_0 \frac{\partial^2 \overrightarrow{E}}{\partial t^2}$$

$$E_z = E_z(\hat{k} \cdot \vec{r} - vt)$$

Equações de Maxwell
Espaço livre

$$\nabla^2 \vec{E} = \mu_0 \epsilon_0 \frac{\partial^2 \vec{E}}{\partial t^2}$$

$$E_z(\vec{r}, t) = f(\hat{k} \cdot \vec{r} - vt)$$

$$\hat{k} = k_x \hat{x} + k_y \hat{y} + k_z \hat{z} \qquad (k_x^2 + k_y^2 + k_z^2 = 1)$$

$$\nabla^2 \overrightarrow{E} = \mu_0 \epsilon_0 \frac{\partial^2 \overrightarrow{E}}{\partial t^2}$$

$$E_z = f(\hat{k} \cdot \vec{r} - vt)$$

$$\nabla^2 \overrightarrow{E} = \mu_0 \epsilon_0 \frac{\partial^2 \overrightarrow{E}}{\partial t^2}$$

$$E_z = f(\hat{k} \cdot \vec{r} - vt) = f(u)$$

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$$E_z = f(\hat{k} \cdot \vec{r} - vt) = f(u)$$

$$\overrightarrow{\nabla} E_z = \frac{df}{du} \overrightarrow{\nabla} u$$

$$\nabla^2 \overrightarrow{E} = \mu_0 \epsilon_0 \frac{\partial^2 \overrightarrow{E}}{\partial t^2}$$

$$E_z = f(\hat{k} \cdot \vec{r} - vt) = f(u)$$

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$$\overrightarrow{\nabla} E_z = \frac{df}{du} (k_x \hat{x} + k_y \hat{y} + k_z \hat{z})$$

$$\nabla^2 \overrightarrow{E} = \mu_0 \epsilon_0 \frac{\partial^2 \overrightarrow{E}}{\partial t^2}$$

$$E_z = f(\hat{k} \cdot \vec{r} - vt) = f(u)$$

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$$E_z = f(\hat{k} \cdot \vec{r} - vt) = f(u)$$

$$\overrightarrow{\nabla} E_z = \hat{k} \, \frac{df}{du}$$

$$\nabla^2 \overrightarrow{E} = \mu_0 \epsilon_0 \frac{\partial^2 \overrightarrow{E}}{\partial t^2}$$

$$E_z = f(\hat{k} \cdot \vec{r} - vt) = f(u)$$

$$\overrightarrow{\nabla} E_z = \hat{k} \, \frac{df}{du}$$

$$\frac{\partial E_z}{\partial t} = - v \, \frac{df}{du}$$

$$\nabla^2 \overrightarrow{E} = \mu_0 \epsilon_0 \frac{\partial^2 \overrightarrow{E}}{\partial t^2}$$

$$E_z = f(\hat{k} \cdot \vec{r} - vt) = f(u)$$

$$\left.\begin{array}{l} \overrightarrow{\nabla} E_z = \hat{k}\,\dfrac{df}{du} \\[2em] \dfrac{\partial E_z}{\partial t} = -\,v\,\dfrac{df}{du} \end{array}\right\} \quad \hat{k}^2 \frac{d^2 f}{\partial u^2} = v^2 \mu_0 \epsilon_0 \frac{d^2 f}{du^2}$$

$$\nabla^2 \overrightarrow{E} = \mu_0 \epsilon_0 \frac{\partial^2 \overrightarrow{E}}{\partial t^2}$$

$$E_z = f(\hat{k} \cdot \vec{r} - vt) = f(u)$$

$$\left.\begin{aligned} \overrightarrow{\nabla} E_z &= \hat{k}\,\frac{df}{du} \\ \frac{\partial E_z}{\partial t} &= -\,v\,\frac{df}{du} \end{aligned}\right\} \quad \hat{k}^2 \frac{d^2 f}{du^2} = v^2 \mu_0 \epsilon_0 \frac{d^2 f}{du^2} \Rightarrow v^2 = \frac{1}{\mu_0 \epsilon_0}$$

Pratique o que aprendeu

$$\overrightarrow{E} = \overrightarrow{E}_0 f(\hat{k} \cdot \vec{r} - vt)$$

$$\overrightarrow{\nabla} \cdot \overrightarrow{E} = 0$$

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$$\overrightarrow{E} = \overrightarrow{E}_0 f(\hat{k} \cdot \vec{r} - vt)$$

$$\hat{k} \cdot \overrightarrow{E}_0 \frac{df}{du} = 0 \qquad \Rightarrow \qquad \hat{k} \perp \overrightarrow{E}_0$$

Pratique o que aprendeu

Exemplo: $\overrightarrow{E}$ na direção $\hat{z}$, versor $\hat{k}$ na direção $\hat{x}$

$$\overrightarrow{E} = \overrightarrow{E}_0 f(\hat{k} \cdot \vec{r} - vt)$$

$$\hat{k} \cdot \overrightarrow{E}_0 \frac{df}{du} = 0 \qquad \Rightarrow \qquad \hat{k} \perp \overrightarrow{E}_0$$

$$\overrightarrow{E} = f(\hat{k} \cdot \vec{r} - ct)\hat{z} \qquad (\hat{k} = \hat{x})$$

Pratique o que aprendeu

Exemplo: $\overrightarrow{E}$ na direção $\hat{z}$, versor $\hat{k}$ na direção $\hat{x}$

$$\overrightarrow{E} = \overrightarrow{E}_0 f(\hat{k} \cdot \vec{r} - vt)$$

$$\hat{k} \cdot \overrightarrow{E}_0 \frac{df}{du} = 0 \qquad \Rightarrow \qquad \hat{k} \perp \overrightarrow{E}_0$$

$$\overrightarrow{E} = f(\hat{k} \cdot \vec{r} - ct)\hat{z}$$

$$\overrightarrow{E} = f(x - ct)\hat{z}$$