Eletromagnetismo

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

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

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

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

30 de junho de 2021

Magnetostática

Potencial vetor

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

$$\vec{\nabla} \times \vec{B} = \mu_0 \vec{J}$$

$$\vec{B} = \vec{\nabla} \times \vec{A} \qquad \vec{\nabla} \cdot \vec{A} = 0$$

$$\nabla^2 \vec{A} = -\mu_0 \vec{J}$$

$$\left[\nabla^2 V = -\frac{\rho}{\epsilon_0} \right]$$

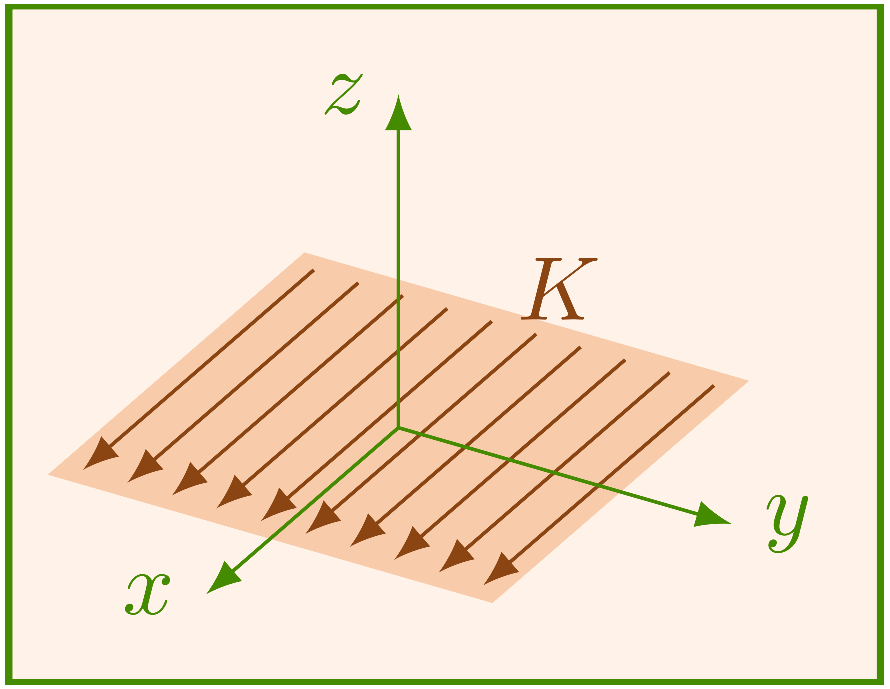
$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi} \int \frac{\vec{J}(\vec{r}\,')}{\mathscr{r}} \, \mathrm{d}\tau'$$

$$\left[V(\vec{r}) = \frac{1}{4\pi\epsilon_0} \int \frac{\rho(\vec{r}\,')}{\mathscr{r}} \, \mathrm{d}\tau' \right]$$

$$\vec{B} = \vec{\nabla} \times \vec{A}$$

Pratique o que aprendeu

$$\nabla^2 \vec{A} = -\mu_0 \vec{J}$$



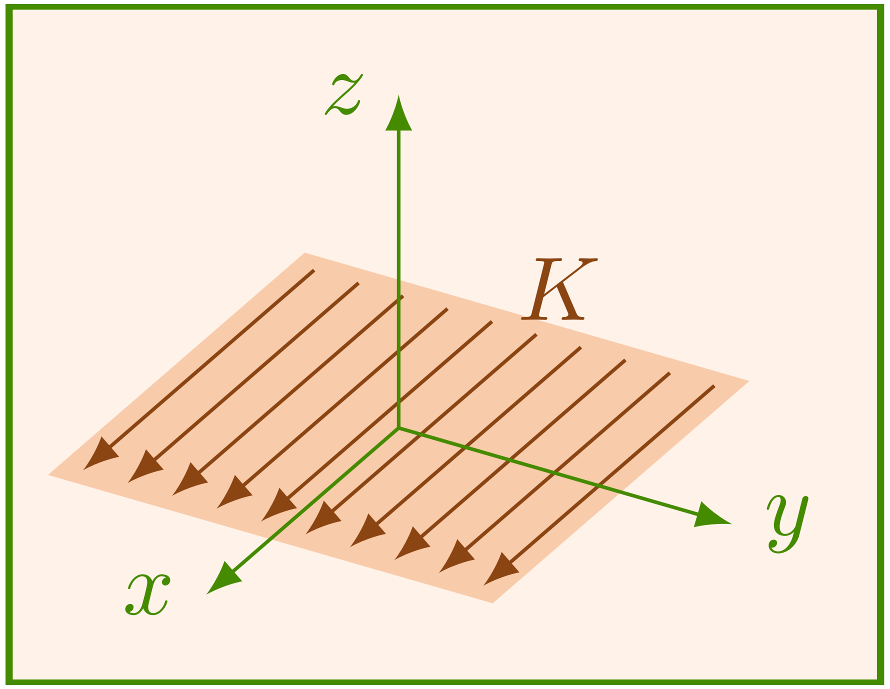
$$\vec{B} = \vec{\nabla} \times \vec{A}$$

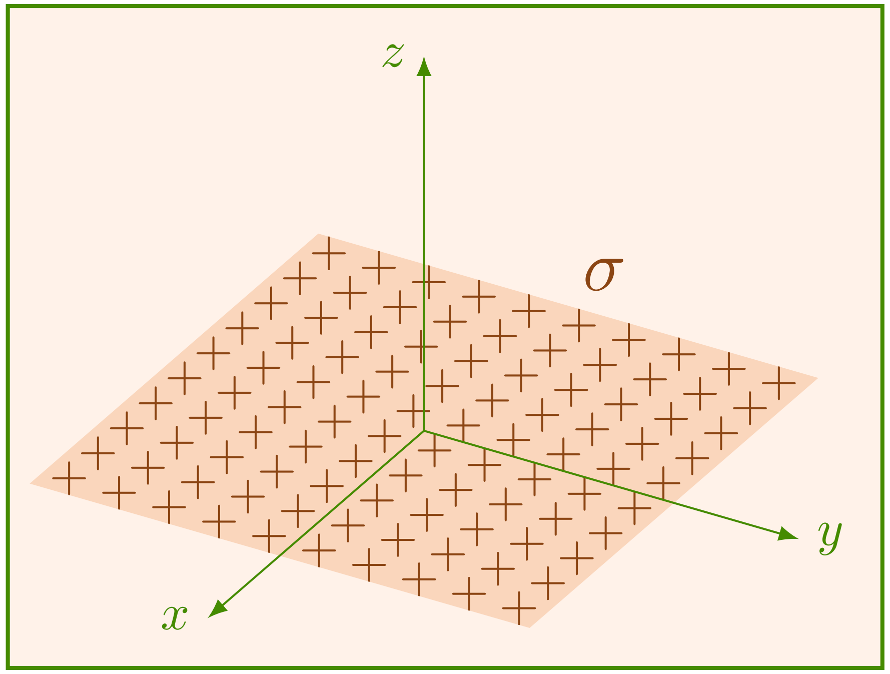
Pratique o que aprendeu

$$\nabla^2 \vec{A} = -\mu_0 \vec{J}$$

$$\vec{K} = K\hat{x}$$

$$A_x(\vec{r}) \leftrightarrow V(\vec{r})$$



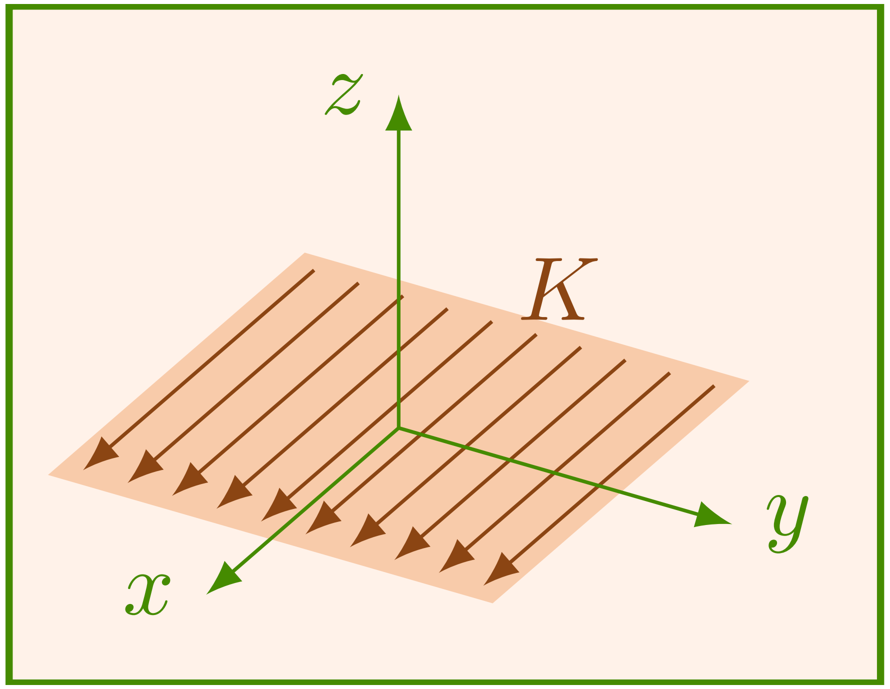


$$\vec{B} = \vec{\nabla} \times \vec{A}$$

Pratique o que aprendeu

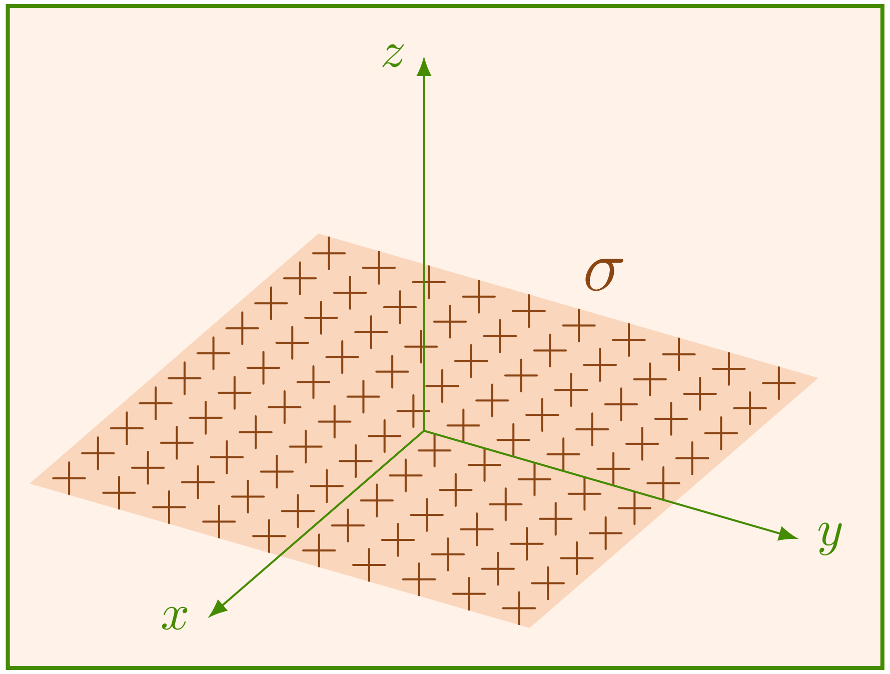
$$\nabla^2 \vec{A} = -\mu_0 \vec{J}$$

$$\vec{K} = K\hat{x}$$



$$A_x(\vec{r}) \leftrightarrow V(\vec{r})$$

$$V(\vec{r}) = -\frac{\sigma}{2\epsilon_0} z$$

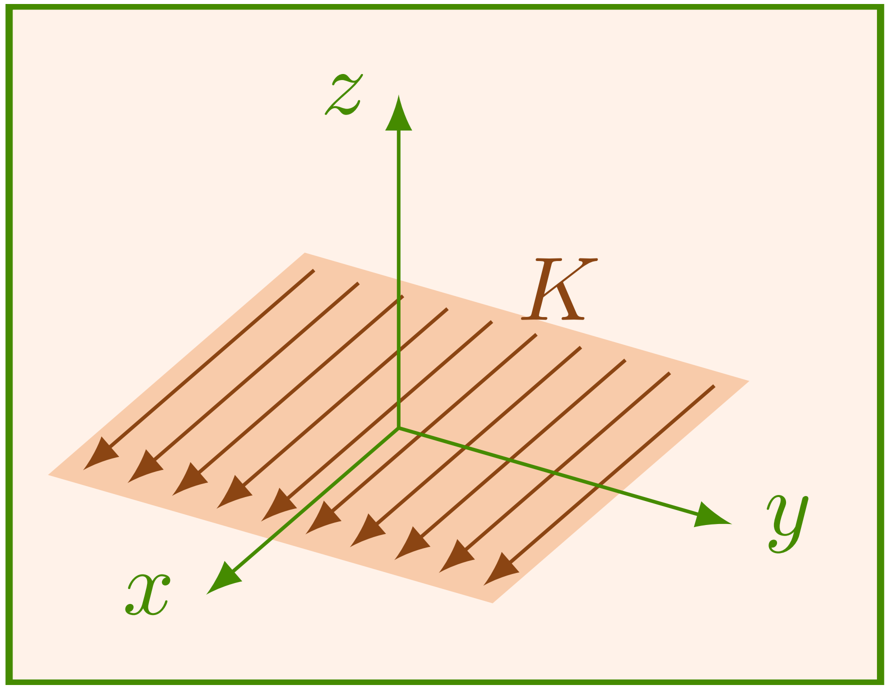


$$\vec{B} = \vec{\nabla} \times \vec{A}$$

Pratique o que aprendeu

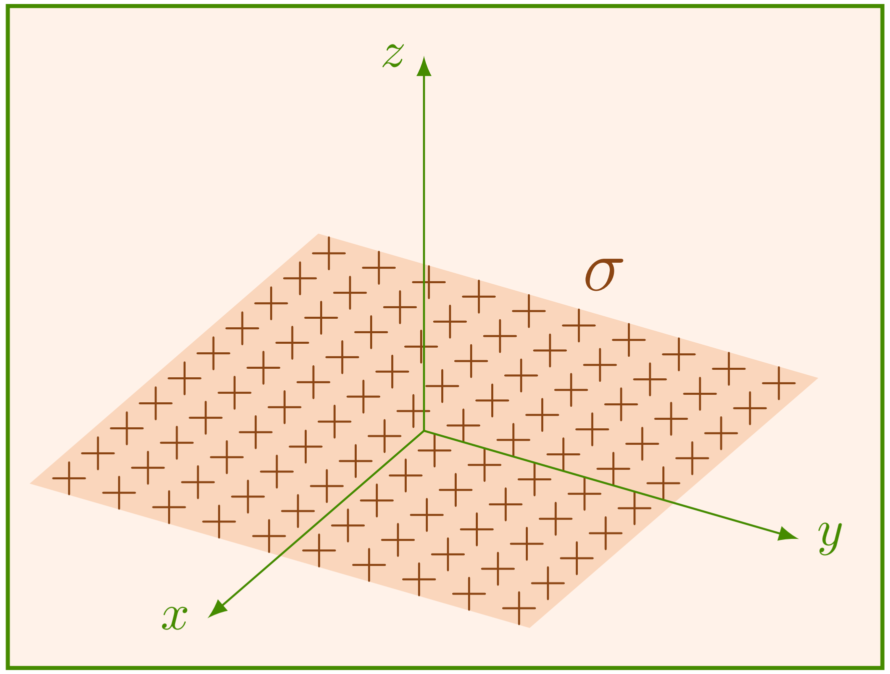
$$\nabla^2 \vec{A} = -\mu_0 \vec{J}$$

$$\vec{K} = K\hat{x}$$



$$A_x(\vec{r}) \leftrightarrow V(\vec{r})$$

$$V(\vec{r}) = -\frac{\sigma}{2\epsilon_0} z$$



$$\Rightarrow \quad A_x(\vec{r}) = -\mu_0 \frac{K}{2} z$$

$$\vec{B} = \vec{\nabla} \times \vec{A}$$

Pratique o que aprendeu

$$\nabla^2 \vec{A} = -\mu_0 \vec{J}$$

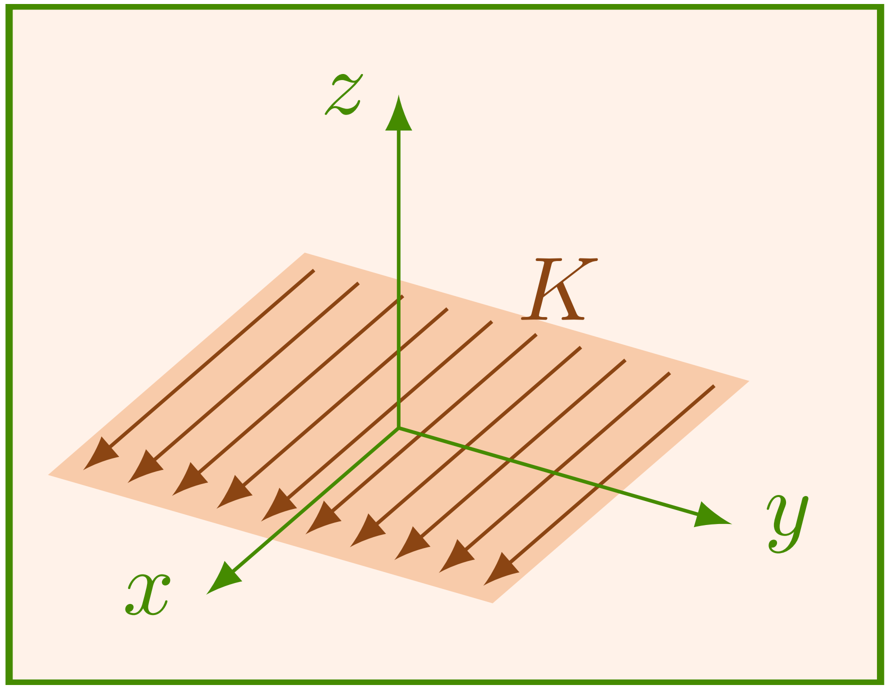
$$\vec{K} = K\hat{x}$$

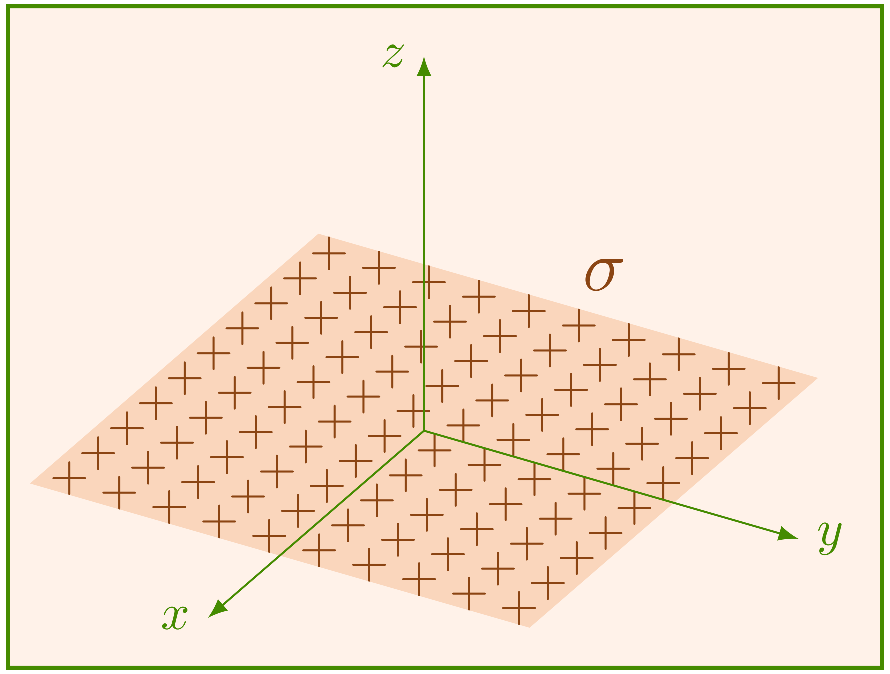
$$A_x(\vec{r}) \leftrightarrow V(\vec{r})$$

$$V(\vec{r}) = -\frac{\sigma}{2\epsilon_0} z$$

$$\Rightarrow \quad A_x(\vec{r}) = -\mu_0 \frac{K}{2} z$$

$$\vec{B} = -\mu_0 \frac{K}{2} \hat{y}$$

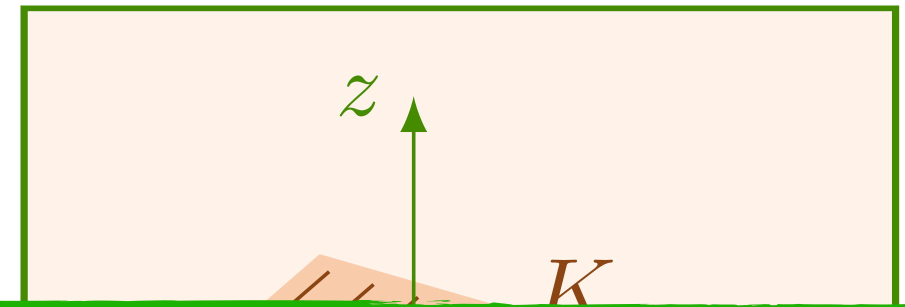




$$\vec{B} = \vec{\nabla} \times \vec{A}$$

$$\nabla^2 \vec{A} = -\mu_0 \vec{J}$$

Pratique o que aprendeu



$$\vec{K} = K\hat{x}$$

$$A_x(\vec{r}) \leftrightarrow V(\vec{r})$$

$$V(\vec{r}) = -\frac{\sigma}{2\epsilon_0} z$$

$$\Rightarrow \quad A_x(\vec{r}) = -\mu_0 \frac{K}{2} z$$

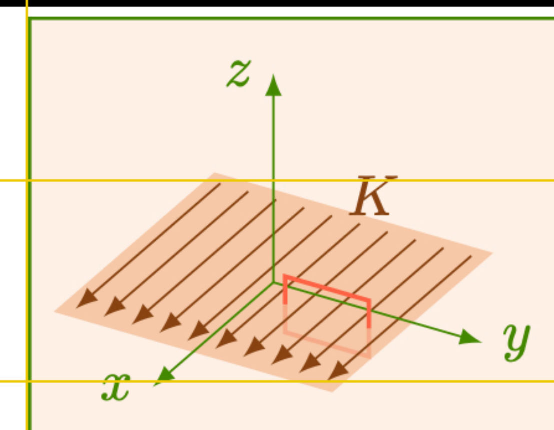
$$\vec{B} = -\mu_0 \frac{K}{2} \hat{y}$$

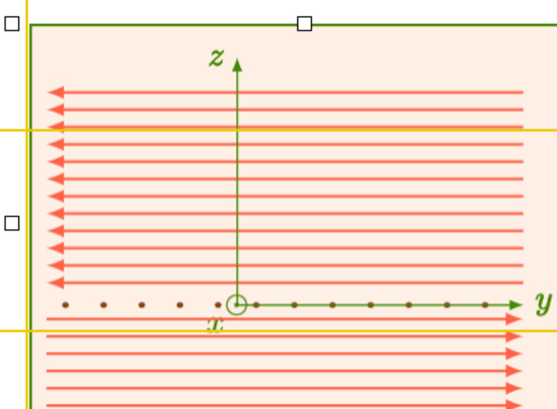
Pratique o que aprendeu

$$\oint \vec{B} \cdot \vec{d\ell} = \mu_0 I_{\text{int}}$$

$$B2\ell = \mu_0 K \ell$$

$$B = \mu_0 \frac{K}{2}$$



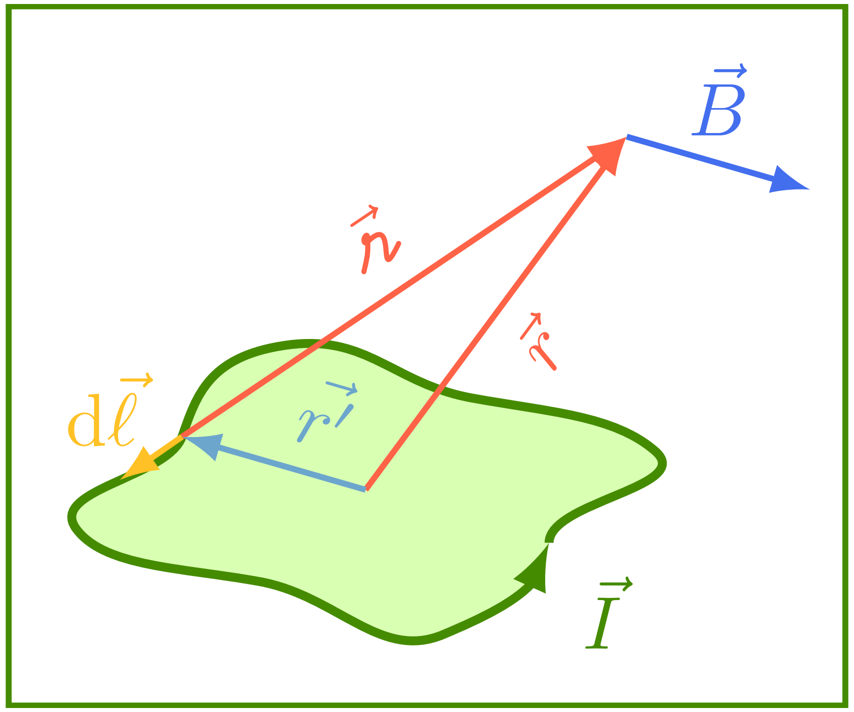


Expansão multipolar

$$\vec{B} = \vec{\nabla} \times \vec{A} \qquad \vec{\nabla} \cdot \vec{A} = 0$$

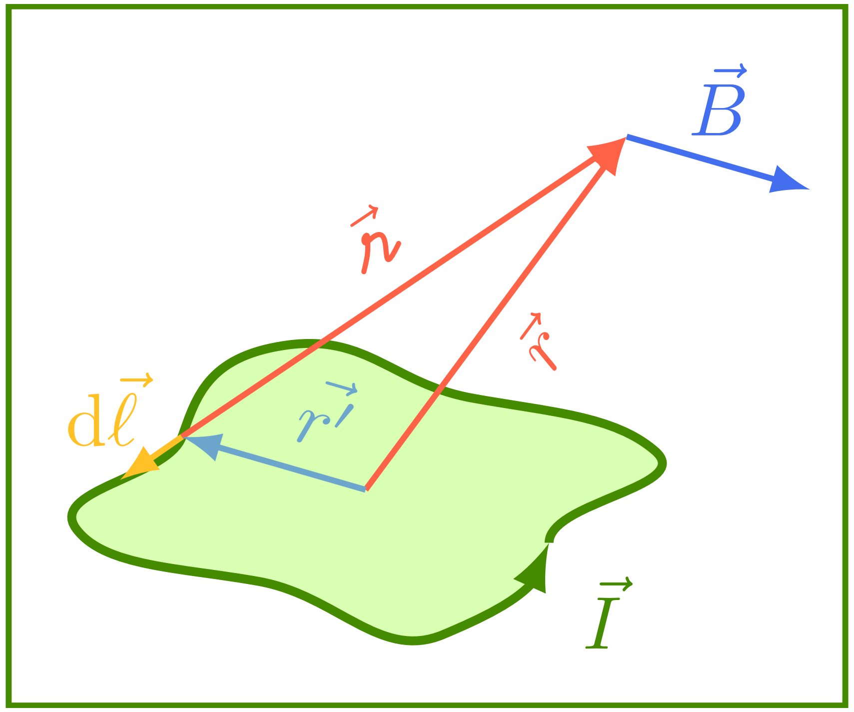
$$\nabla^2 \vec{A} = -\mu_0 \vec{J}$$

$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi} \int \frac{\vec{J}(\vec{r}\,')}{\mathscr{r}} \, \mathrm{d}\tau'$$



Expansão multipolar

$$\vec{B} = \vec{\nabla} \times \vec{A} \qquad \vec{\nabla} \cdot \vec{A} = 0$$



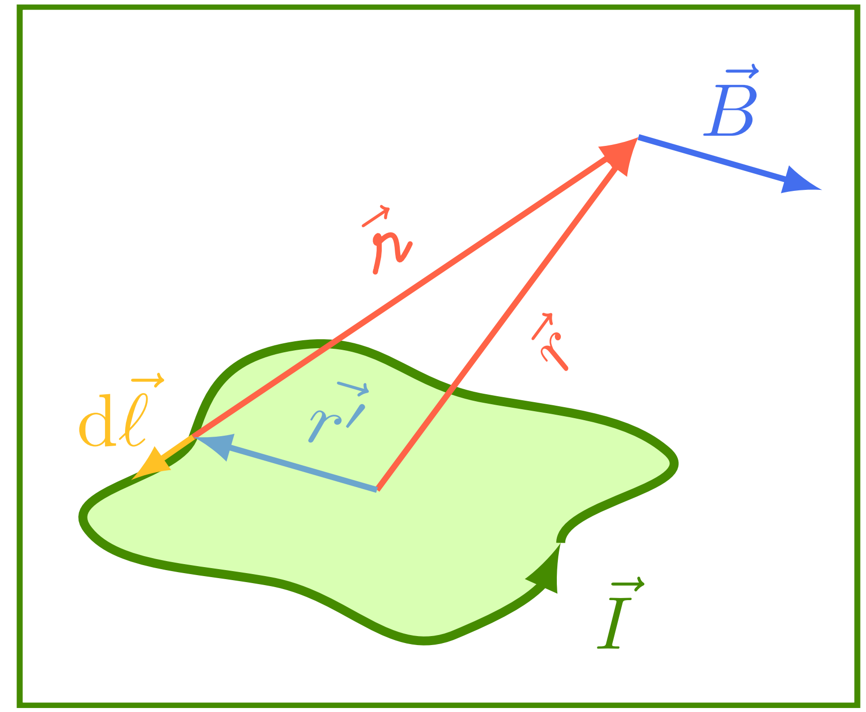
$$\nabla^2 \vec{A} = -\mu_0 \vec{J}$$

$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi} \int \frac{\vec{J}(\vec{r}\,')}{\mathscr{r}} \, \mathrm{d}\tau'$$

$$\frac{1}{\mathscr{r}} = \frac{1}{r} \sum_{\ell=0}^{\infty} \left(\frac{r'}{r}\right)^{\ell} P_\ell(\cos\theta')$$

Expansão multipolar

$$\vec{B} = \vec{\nabla} \times \vec{A} \qquad \vec{\nabla} \cdot \vec{A} = 0$$



$$\nabla^2 \vec{A} = -\mu_0 \vec{J}$$

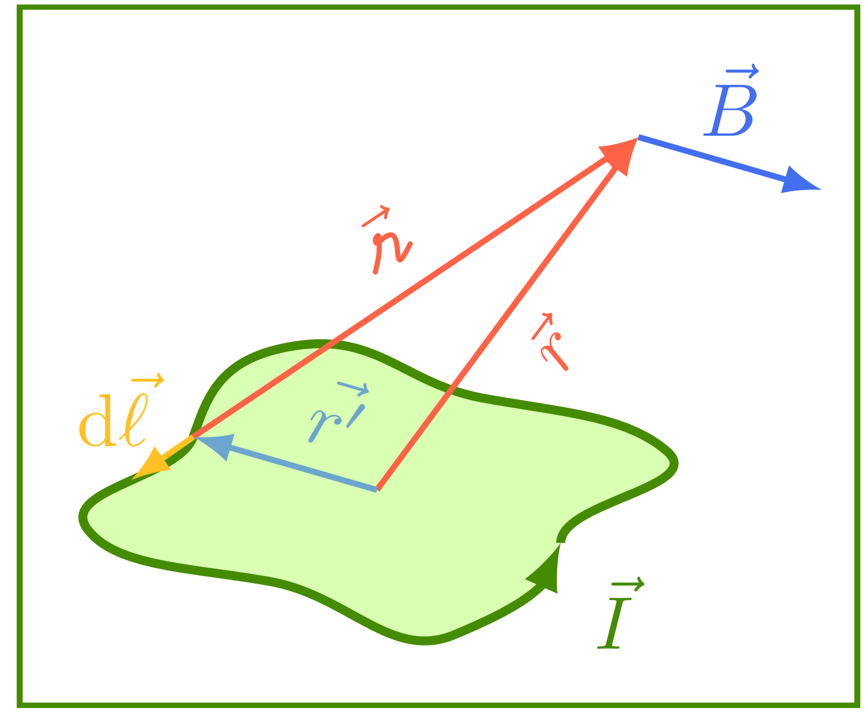
$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi} \int \frac{\vec{J}(\vec{r}\,')}{\mathscr{r}}\, \mathrm{d}\tau' = \frac{\mu_0}{4\pi} \int \frac{\vec{I}(\vec{r}\,')}{\mathscr{r}}\, \mathrm{d}\ell'$$

$$\frac{1}{\mathscr{r}} = \frac{1}{r} \sum_{\ell=0}^{\infty} \left(\frac{r'}{r}\right)^{\ell} P_\ell(\cos\theta')$$

$$\ell = 0 \quad \Rightarrow \quad \frac{1}{\mathscr{r}} \approx \frac{1}{r} \qquad \Rightarrow \qquad \vec{A}(\vec{r}) = \frac{\mu_0 I}{4\pi r} \oint \mathrm{d}\vec{\ell'}$$

Expansão multipolar

$$\vec{B} = \vec{\nabla} \times \vec{A} \qquad \vec{\nabla} \cdot \vec{A} = 0$$



$$\nabla^2 \vec{A} = -\mu_0 \vec{J}$$

$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi} \int \frac{\vec{J}(\vec{r}\,')}{\mathscr{r}}\, \mathrm{d}\tau' = \frac{\mu_0}{4\pi} \int \frac{\vec{I}(\vec{r}\,')}{\mathscr{r}}\, \mathrm{d}\ell'$$

$$\frac{1}{\mathscr{r}} = \frac{1}{r} \sum_{\ell=0}^{\infty} \left(\frac{r'}{r}\right)^{\ell} P_\ell(\cos\theta')$$

$$\ell \leq 1 \quad \Rightarrow \quad \frac{1}{\mathscr{r}} \approx \frac{1}{r} + \frac{r'}{r^2}\cos\theta \Rightarrow \vec{A}(\vec{r}) = \frac{\mu_0 I}{4\pi r} \oint \mathrm{d}\vec{\ell'} + \frac{\mu_0}{4\pi r^2} \oint r' \cos\theta' \mathrm{d}\vec{\ell}'$$

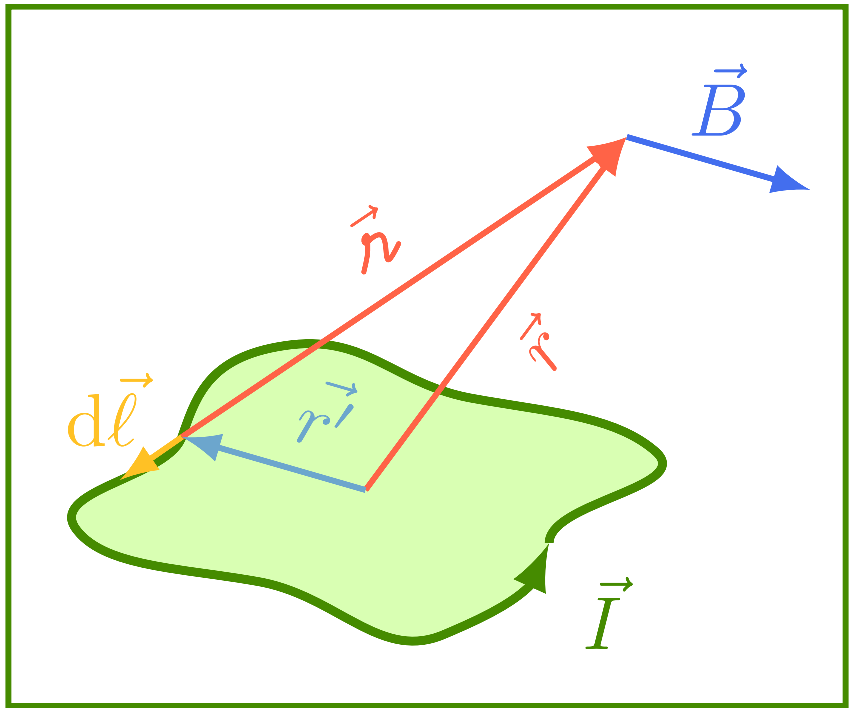
$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi} \frac{\vec{m} \times \hat{r}}{r^2}$$

Expansão multipolar

$$\vec{B} = \vec{\nabla} \times \vec{A} \qquad \vec{\nabla} \cdot \vec{A} = 0$$

$$\nabla^2 \vec{A} = -\mu_0 \vec{J}$$

$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi} \frac{\vec{m} \times \hat{r}}{r^2} \qquad \vec{m} = I\vec{a}$$



Pratique o que aprendeu

$$\vec{m} = I\vec{a}$$

$$\vec{m} = ?$$

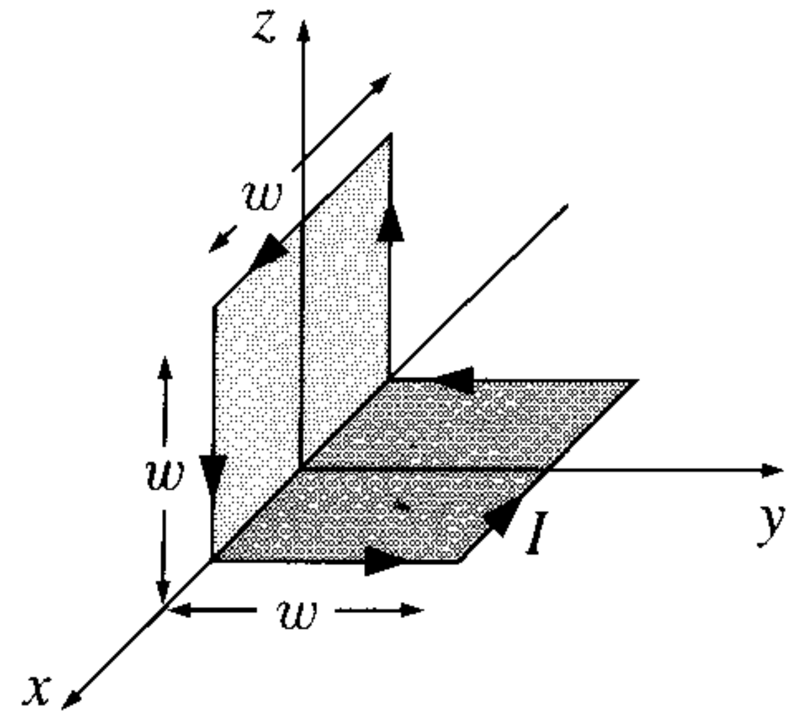


Figure 5.52

Pratique o que aprendeu

$$\vec{m} = I\vec{a}$$

$$\vec{m} = Iw^2(\hat{y} + \hat{z})$$

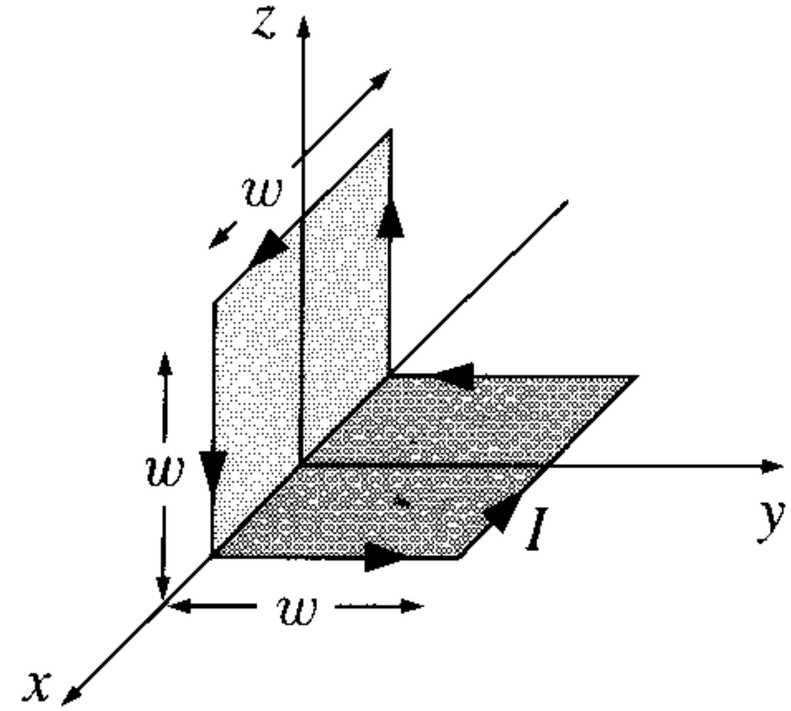
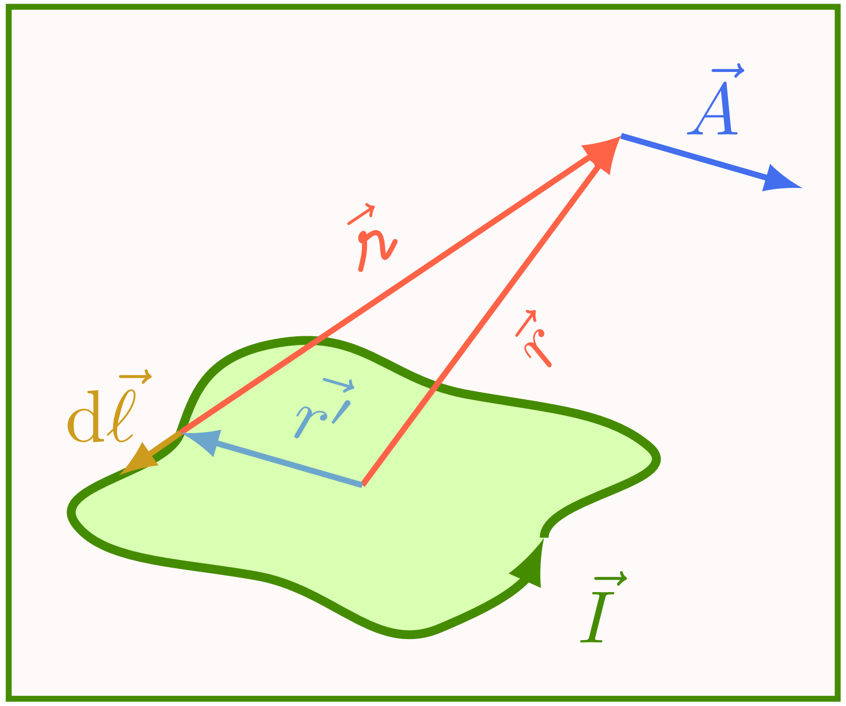


Figure 5.52

Expansão multipolar

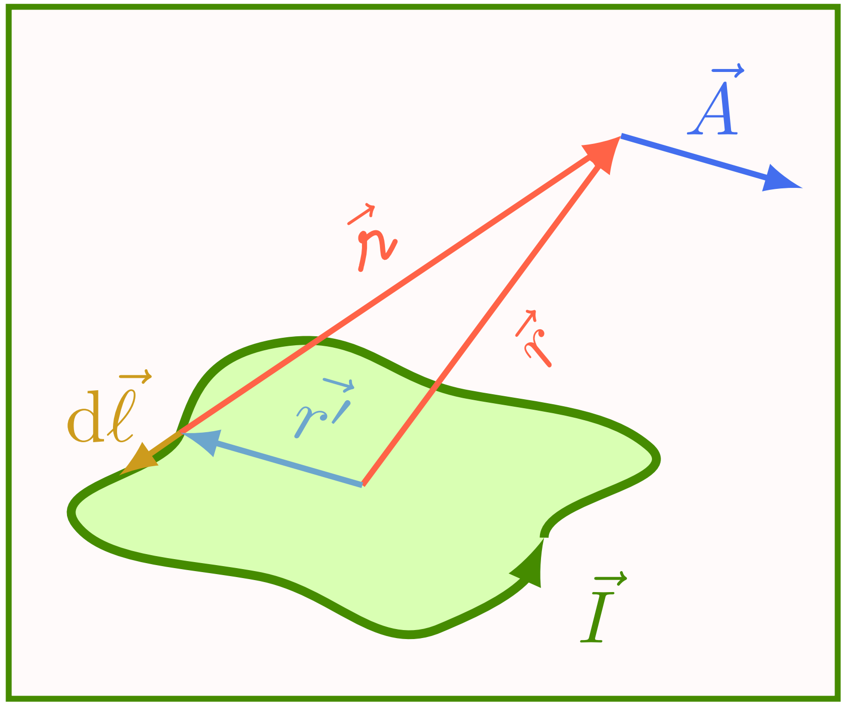
$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi}\frac{\vec{m}\times\hat{r}}{r^2}$$

$$\vec{m} = m\hat{z}$$



Expansão multipolar

$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi}\frac{\vec{m}\times\hat{r}}{r^2}$$



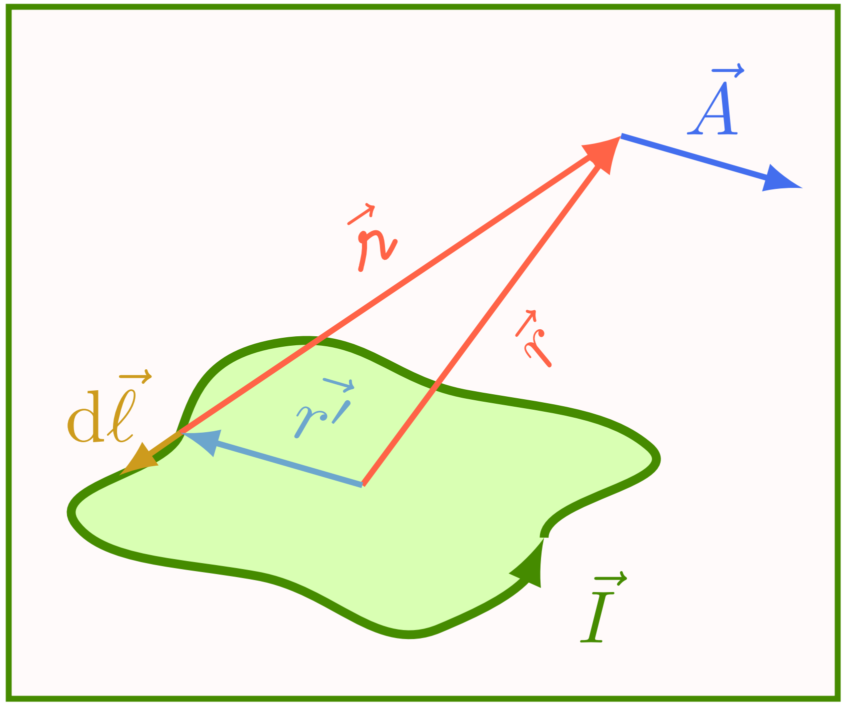
$$\vec{m} = m\hat{z}$$

$$\vec{r} = s\hat{s} + z\hat{z}$$

$$\vec{m}\times\hat{r} = s\vec{m}\times\hat{s}$$

Expansão multipolar

$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi}\frac{\vec{m}\times\hat{r}}{r^2}$$



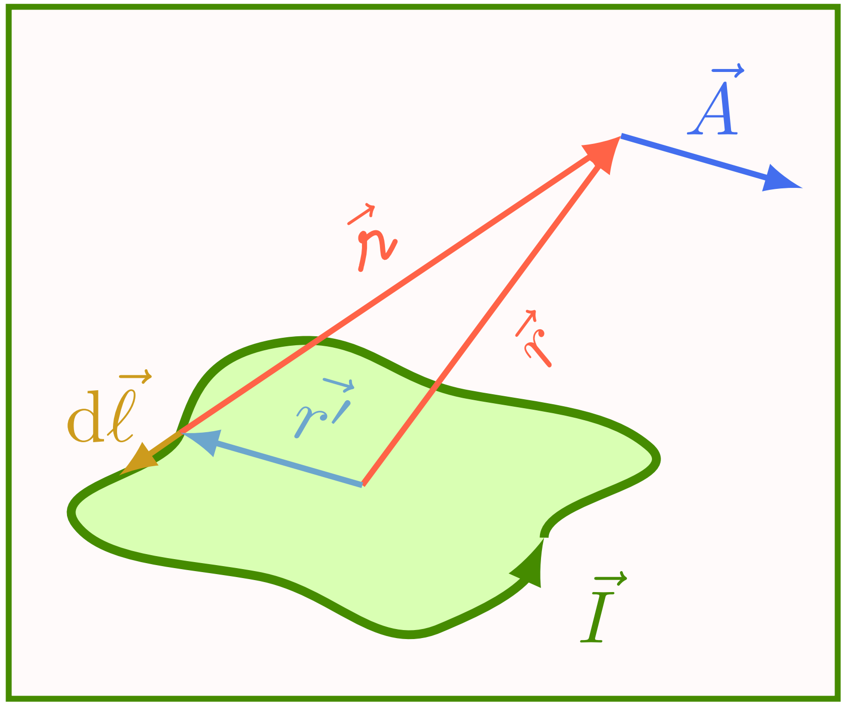
$$\vec{m} = m\hat{z}$$

$$\vec{r} = s\hat{s} + z\hat{z}$$

$$\vec{m}\times\hat{r} = s\vec{m}\times\hat{s} = sm\hat{\phi}$$

Expansão multipolar

$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi}\frac{\vec{m}\times\hat{r}}{r^2}$$



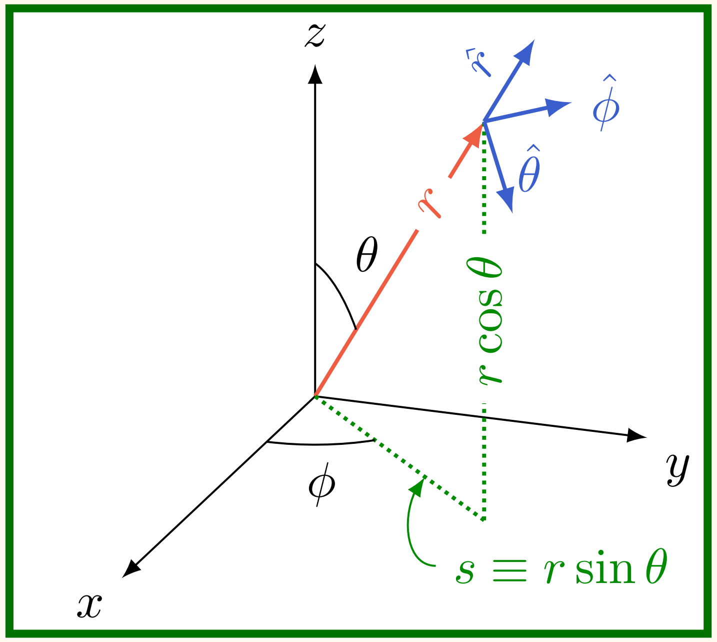
$$\vec{m} = m\hat{z}$$

$$\vec{r} = s\hat{s} + z\hat{z}$$

$$\vec{m}\times\hat{r} = s\vec{m}\times\hat{s} = sm\hat{\phi}$$

$$\vec{A} = \frac{\mu_0}{4\pi}\frac{m\sin\theta}{r^2}\hat{\phi}$$

Coordenadas esféricas



$$d\vec{\ell} = dr\,\hat{r} + r\,d\theta\,\hat{\theta} + r\sin\theta\,d\phi\,\hat{\phi}$$

$$\vec{\nabla}t = \frac{\partial t}{\partial r}\hat{r} + \frac{1}{r}\frac{\partial t}{\partial \theta}\hat{\theta} + \frac{1}{r\sin\theta}\frac{\partial t}{\partial \phi}\hat{\phi}$$

$$\vec{\nabla}\cdot\vec{v} = \frac{1}{r^2}\frac{\partial(r^2 v_r)}{\partial r} + \frac{1}{r\sin\theta}\frac{\partial(\sin\theta v_\theta)}{\partial\theta} + \frac{1}{r\sin\theta}\frac{\partial v_\phi}{\partial\phi}$$

$$\vec{\nabla}\times\vec{v} = \frac{1}{r\sin\theta}\left[\frac{\partial}{\partial\theta}\left(\sin\theta v_\phi\right) - \frac{\partial v_\theta}{\partial\phi}\right]\hat{r} + \frac{1}{r}\left[\frac{1}{\sin\theta}\frac{\partial v_r}{\partial\phi} - \frac{\partial}{\partial r}\left(r v_\phi\right)\right]\hat{\theta} + \frac{1}{r}\left[\frac{\partial}{\partial r}\left(r\,v_\theta\right) - \frac{\partial v_r}{\partial\theta}\right]\hat{\phi}$$

$$\nabla^2 t = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial t}{\partial r}\right) + \frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial t}{\partial\theta}\right) + \frac{1}{r^2\sin^2\theta}\frac{\partial^2 t}{\partial\phi^2}$$

Expansão multipolar

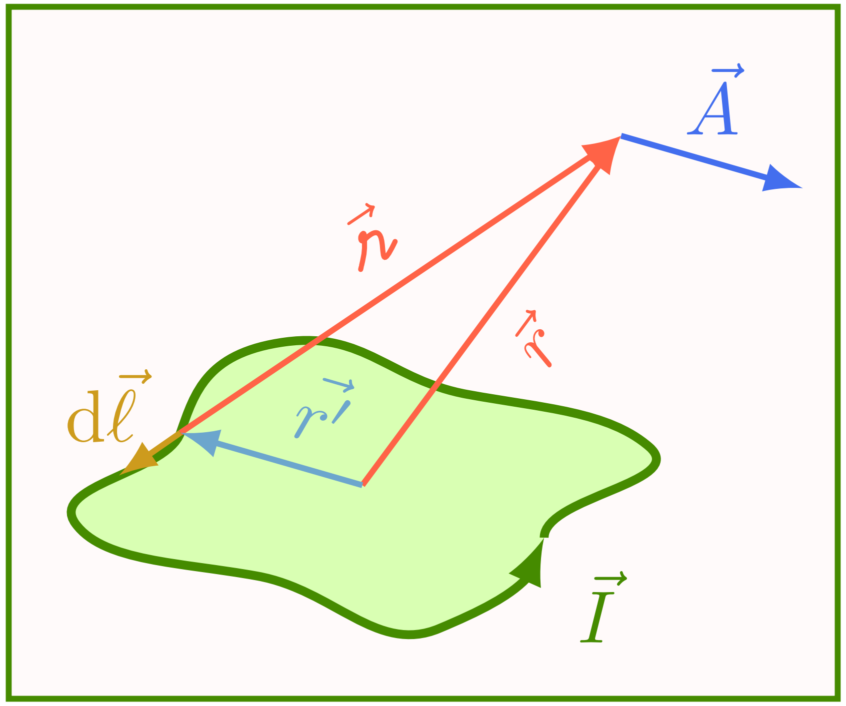
$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi}\frac{\vec{m}\times\hat{r}}{r^2}$$

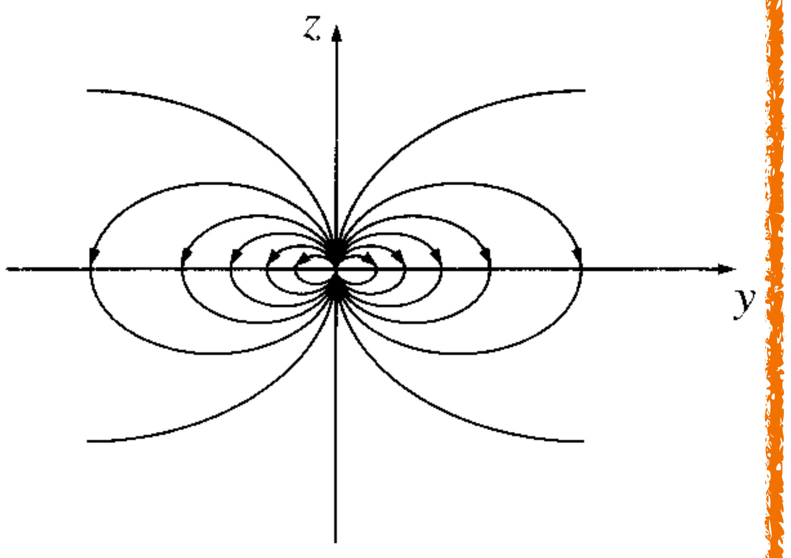
$$\vec{m} = m\hat{z}$$

$$\vec{r} = s\hat{s} + z\hat{z}$$

$$\vec{m}\times\hat{r} = s\vec{m}\times\hat{s} = sm\hat{\phi}$$

$$\vec{A} = \frac{\mu_0}{4\pi}\frac{m\sin\theta}{r^2}\hat{\phi}$$





(a) Field of a "pure" dipole

Eletromagnetismo

$$\overrightarrow{\nabla} \cdot \overrightarrow{D} = \rho$$

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

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

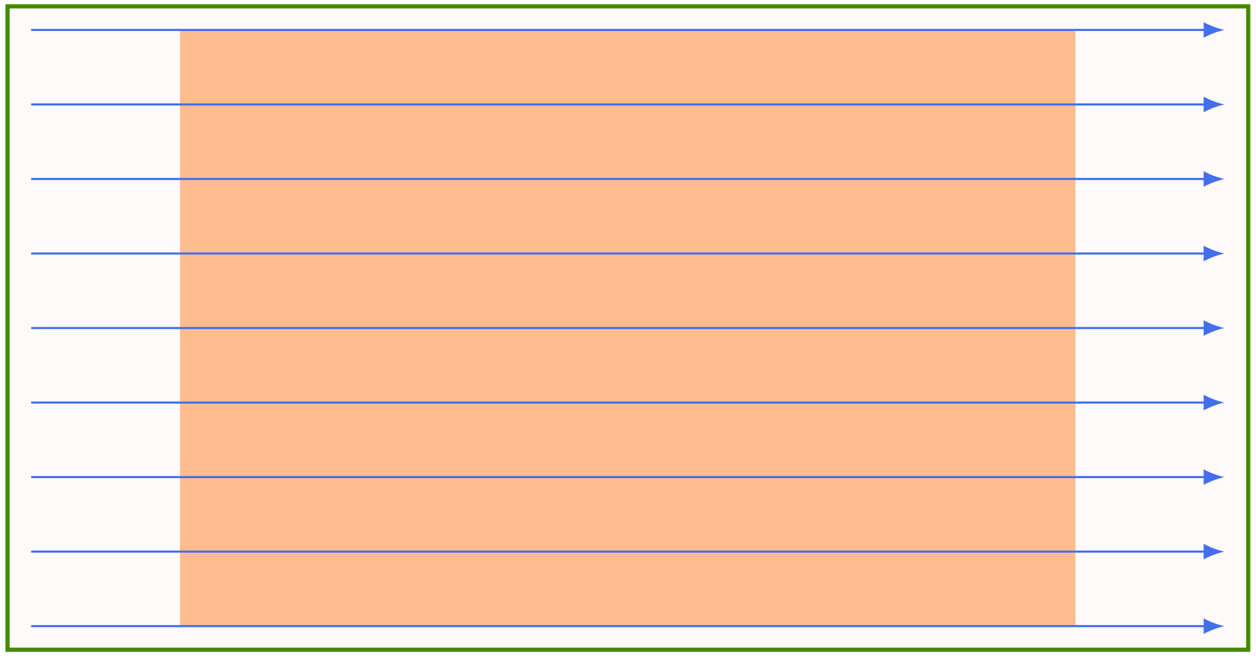
$$\overrightarrow{\nabla} \times \overrightarrow{H} = \vec{j} + \epsilon_0 \frac{\partial \overrightarrow{D}}{\partial t}$$

30 de junho de 2021

Magnetismo em materiais

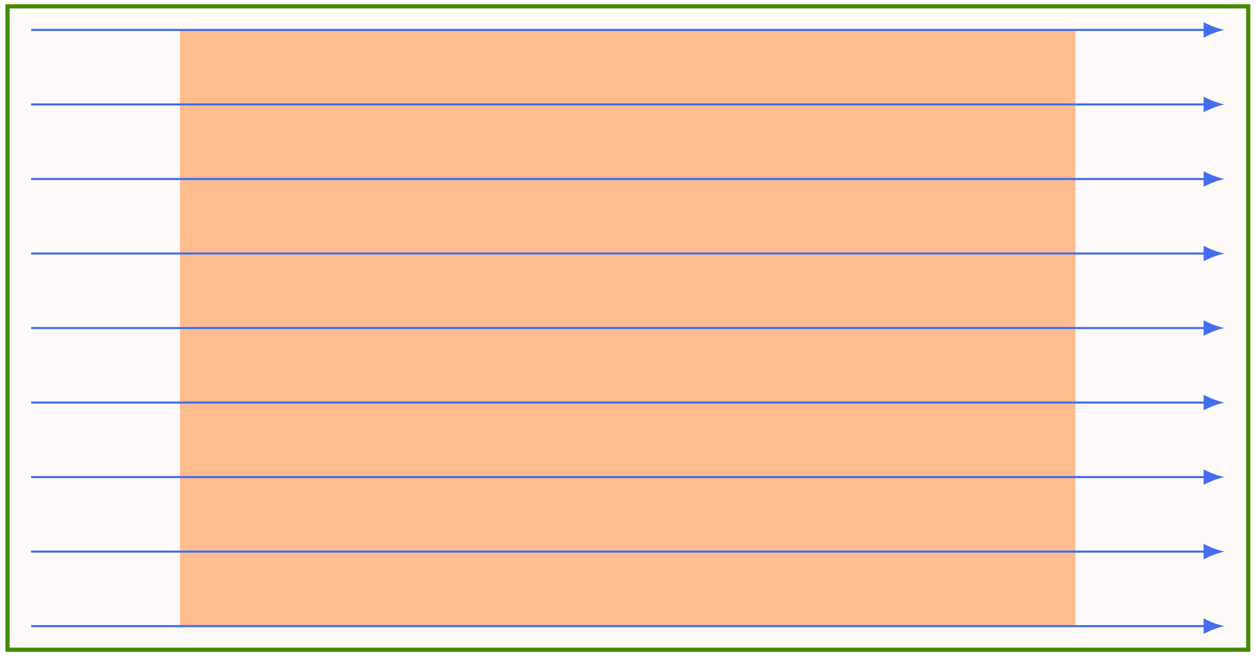
Magnetismo em materiais

- Paramagnéticos
- Diamagnéticos
- Ferromagnéticos
- Antiferromagnéticos



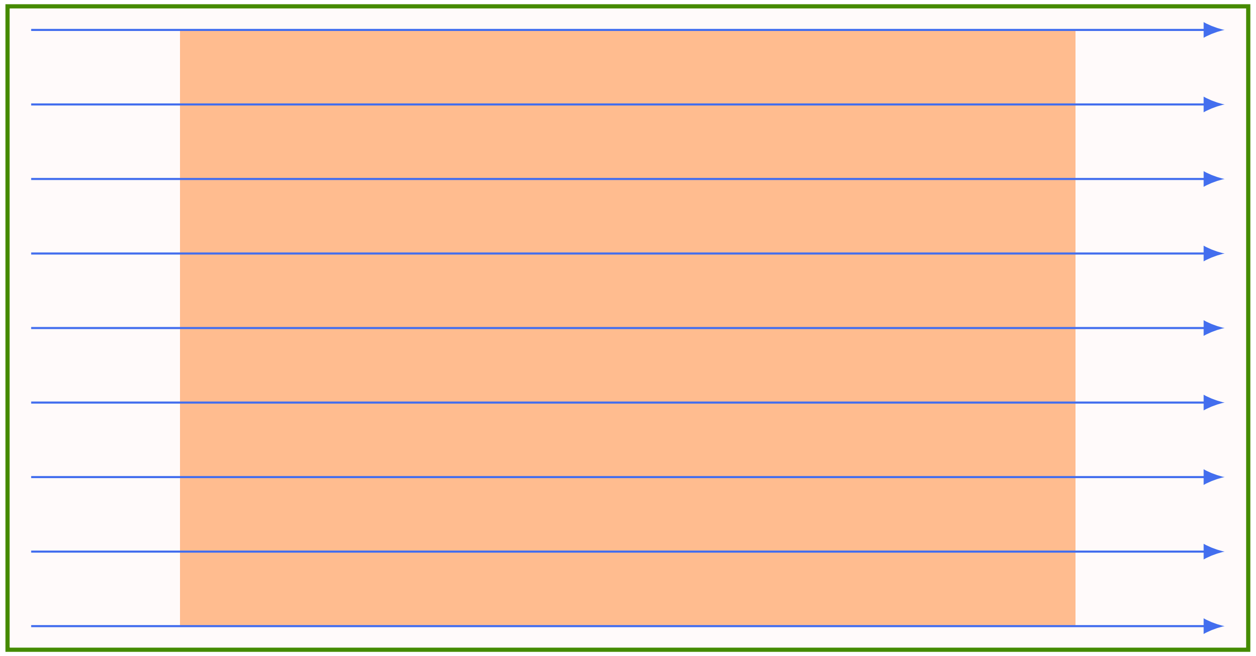
Magnetismo em materiais

- Paramagnéticos



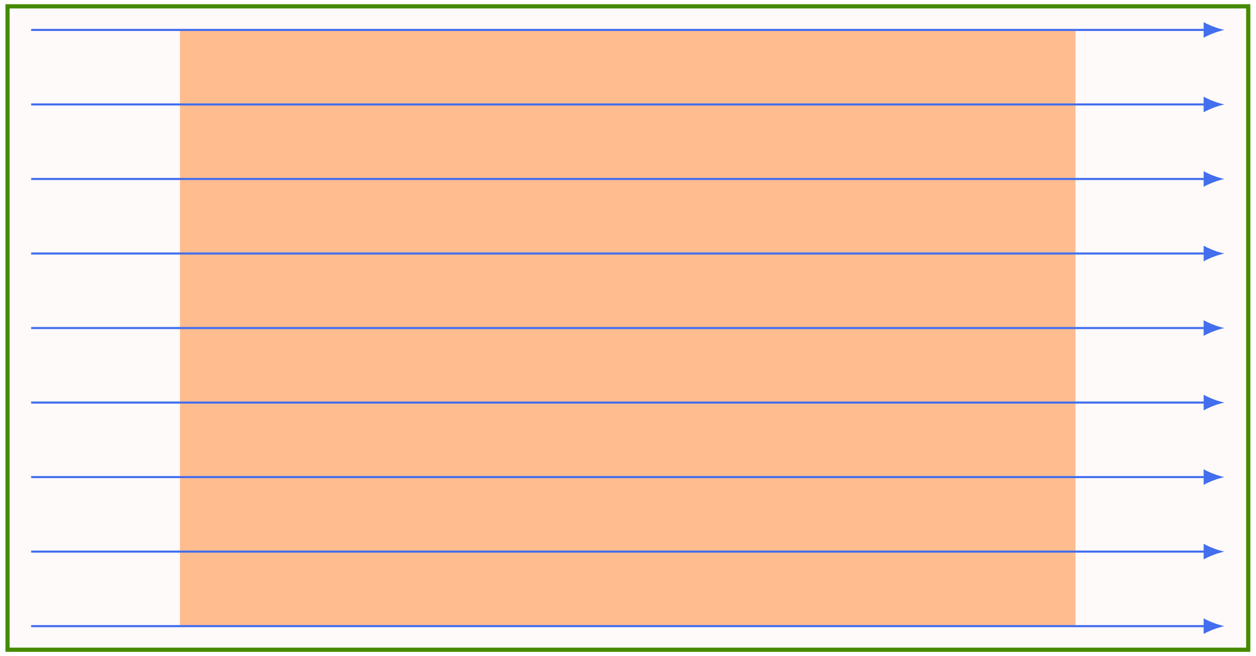
Magnetismo em materiais

- Diamagnéticos



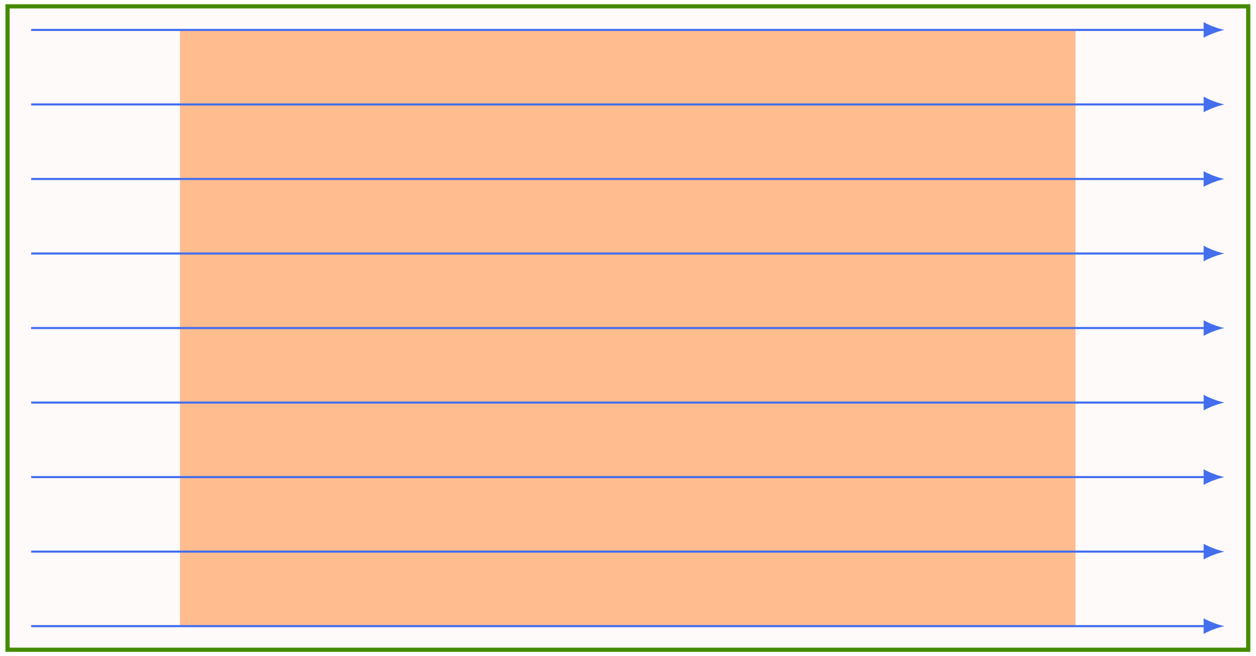
Magnetismo em materiais

- Ferromagnéticos



Magnetismo em materiais

- Antiferromagnéticos



Magnetização

$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi}\frac{\vec{m} \times \hat{r}}{r^2}$$