



ESCOLA POLITÉCNICA DA UNIVERSIDADE DE SÃO PAULO

Campo

Magnetostático

Solenoide

Toroide

Potencial Magnetostático

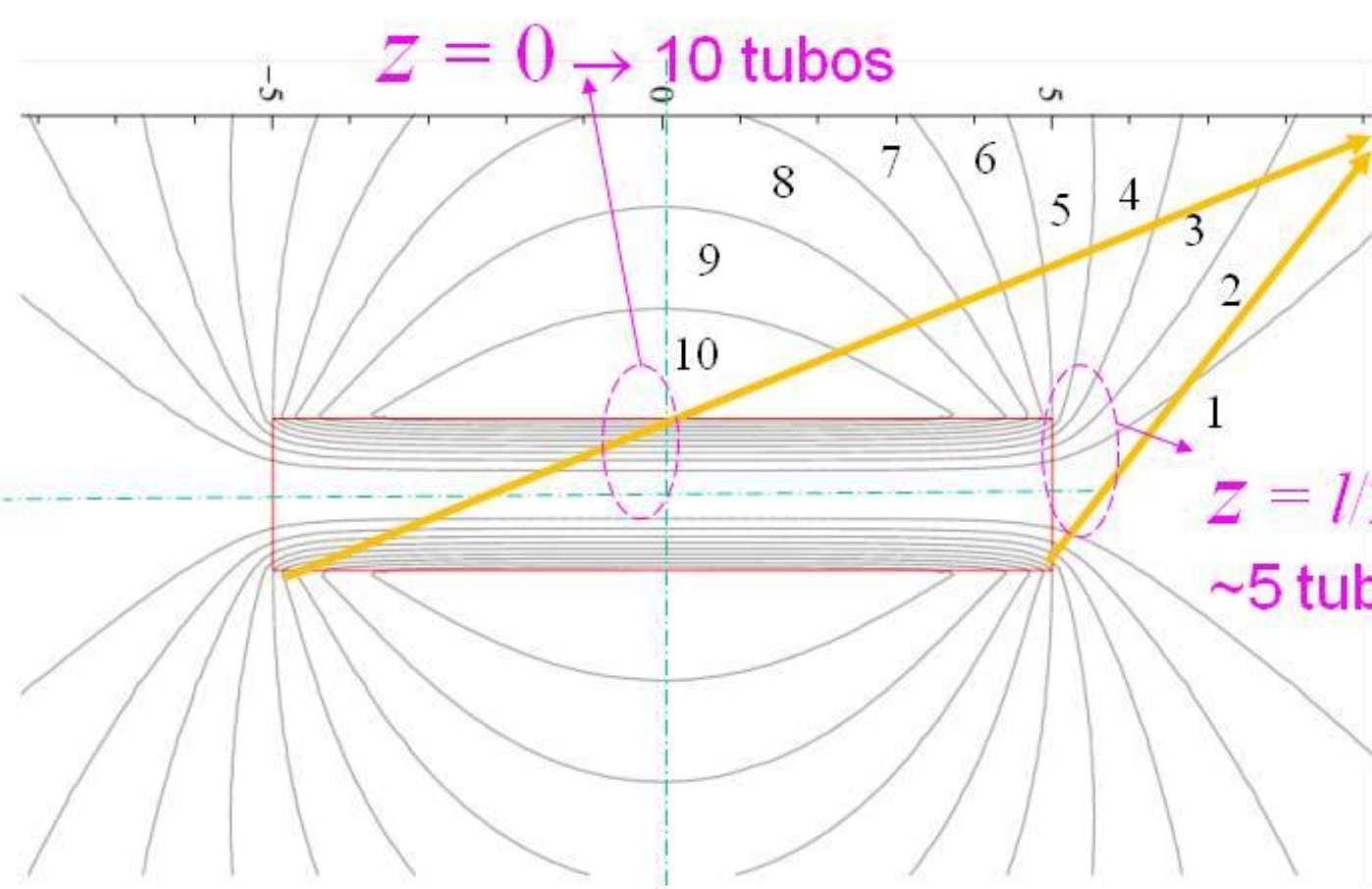
Circuitos Magnéticos



Campo de Solenoide

$$\vec{H}(0,0) \approx \frac{NI}{l} \hat{u}_z \quad \rightarrow \quad |\vec{H}(0,0)| = \frac{NI}{l} = H_0$$

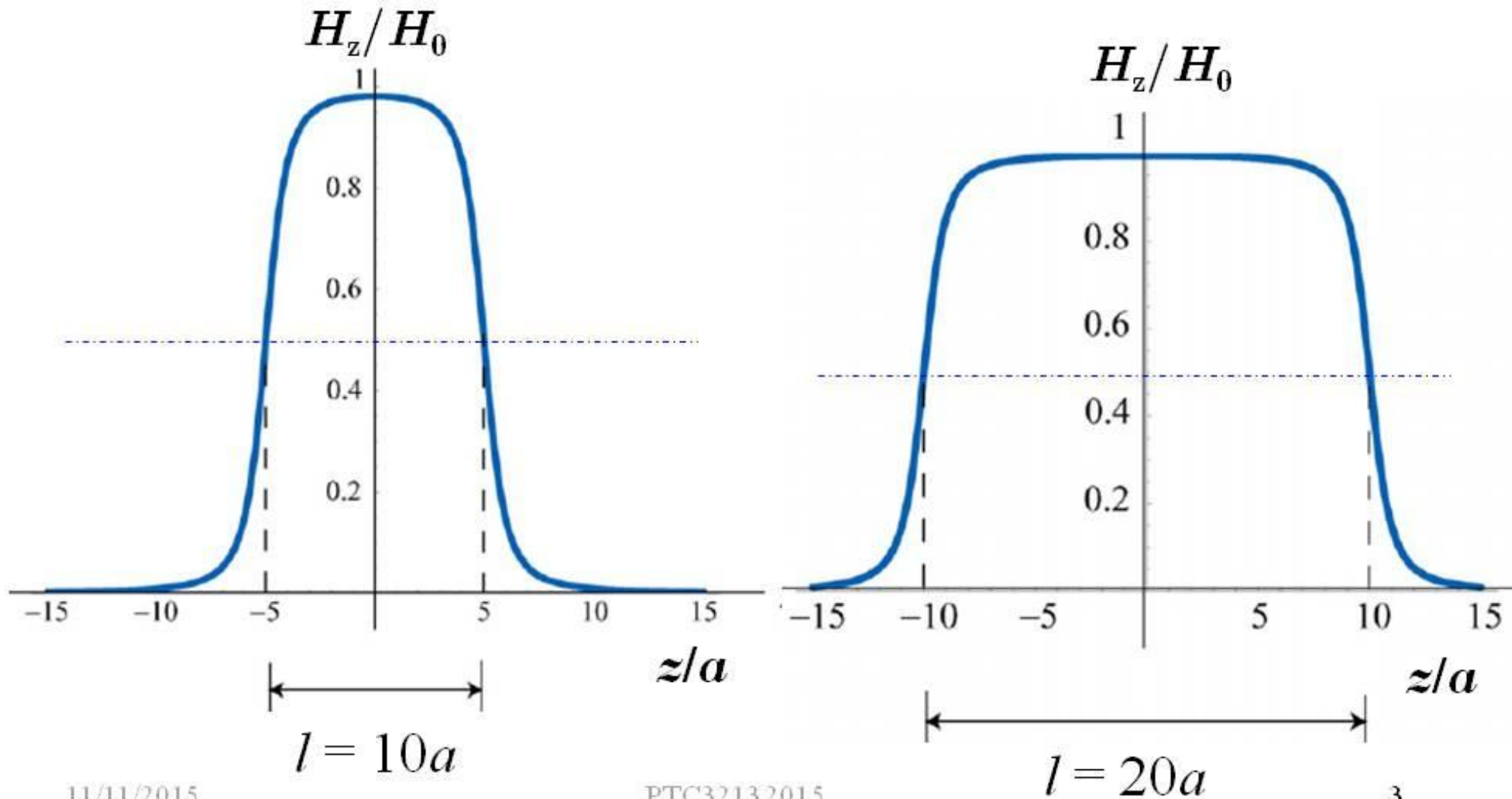
$$z = \pm l/2$$



$$|H_z(0, z = \pm \frac{l}{2})| = \frac{H_0}{2}$$



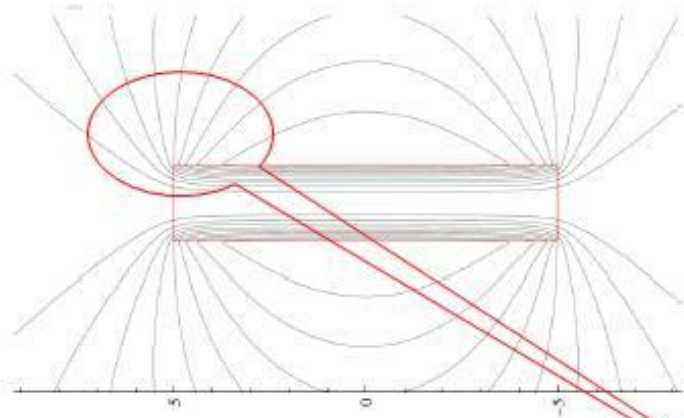
Campo de Solenoide





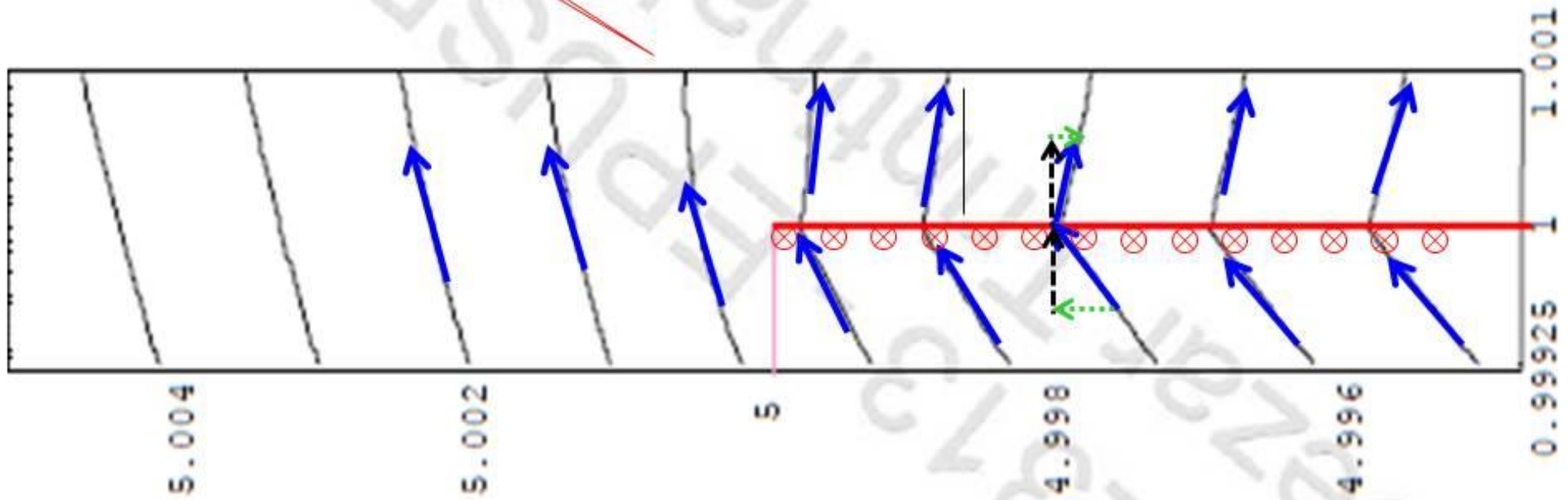
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Campo de Solenoide



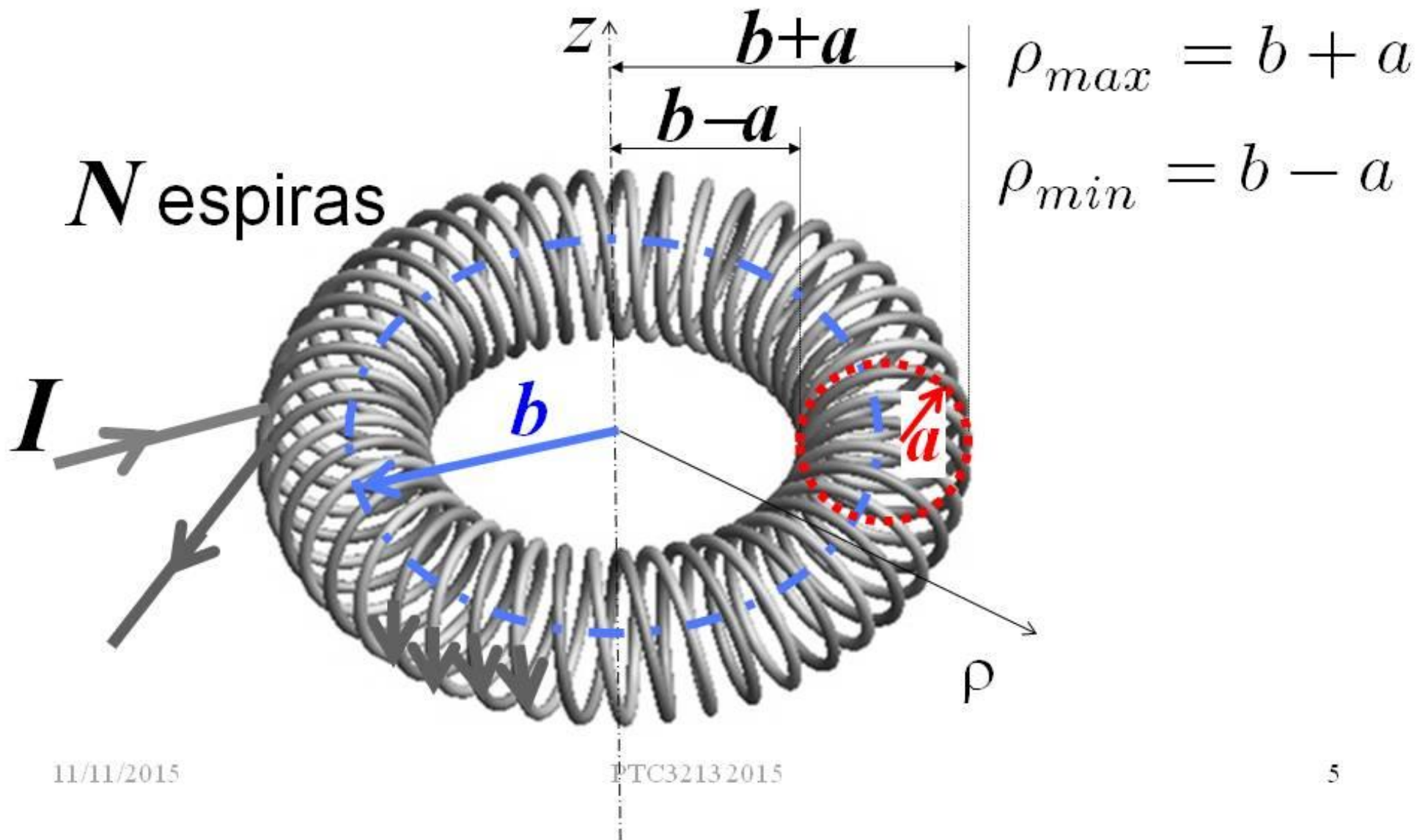
$$B_{n1} = B_{n2} \quad \mu_0 \quad H_{n1} = H_{n2}$$

$$H_{t1} - H_{t2} = J_S$$





Campo de Toroide





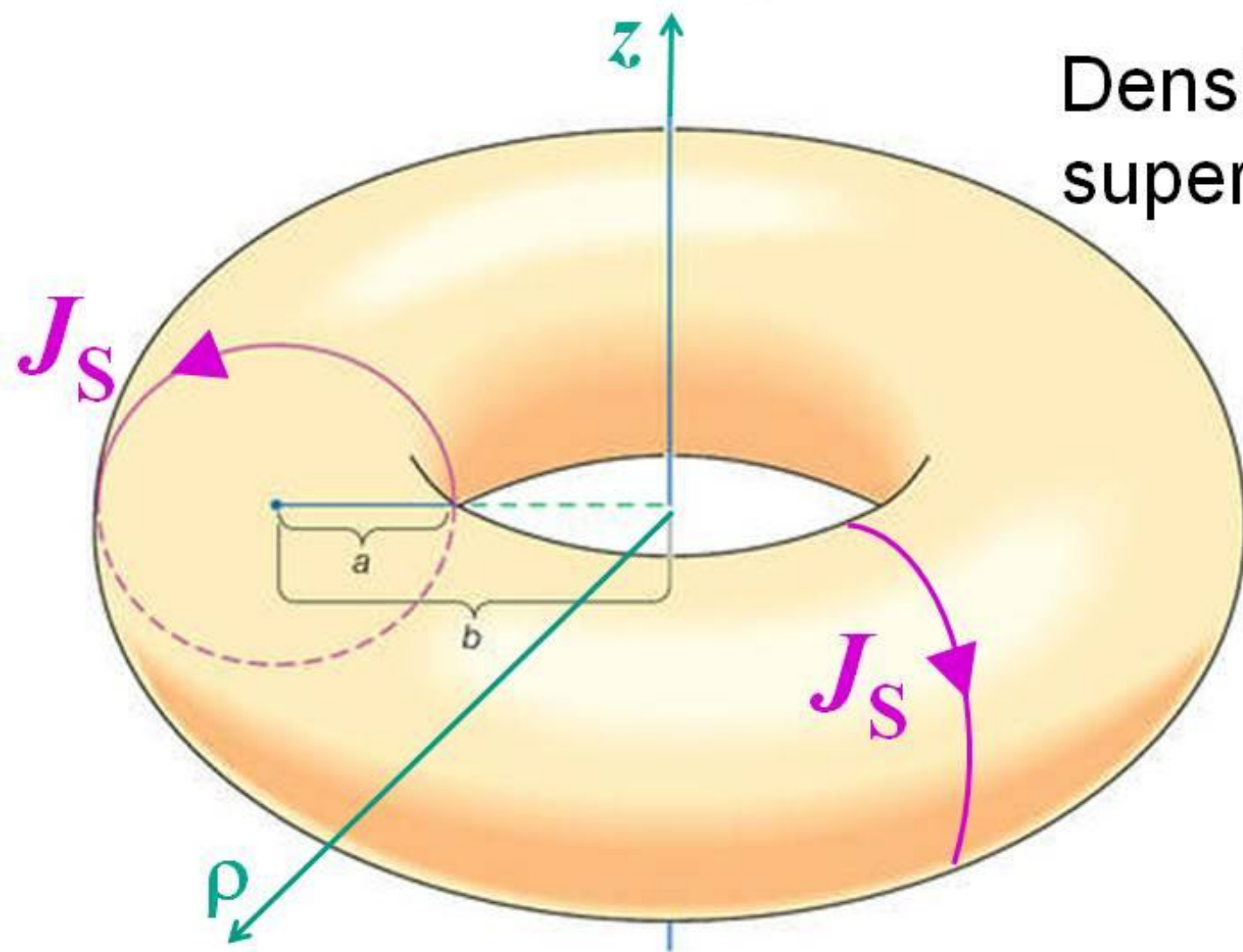
Campo de Toroide

Densidade de corrente superficial equivalente:

$$J_S = \frac{NI}{2\pi\rho}$$

$$\rho_{max} = b + a$$

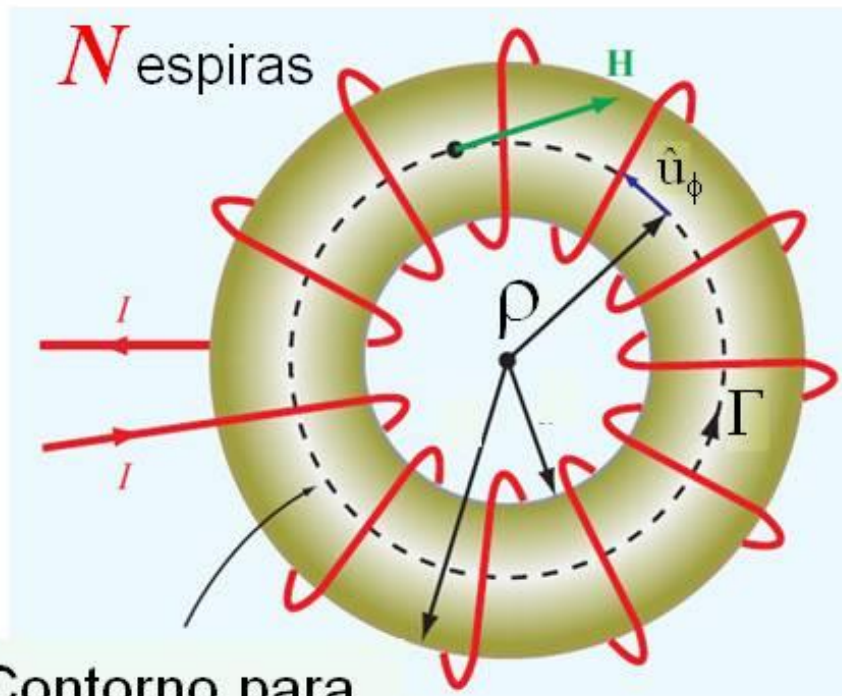
$$\rho_{min} = b - a$$





Toroide – Aplicação da Lei de Ampère

$$\rho_{min} = b - a \quad \rho_{max} = b + a$$



Contorno para aplicação da Lei de Ampère

2015

Toroide delgado:

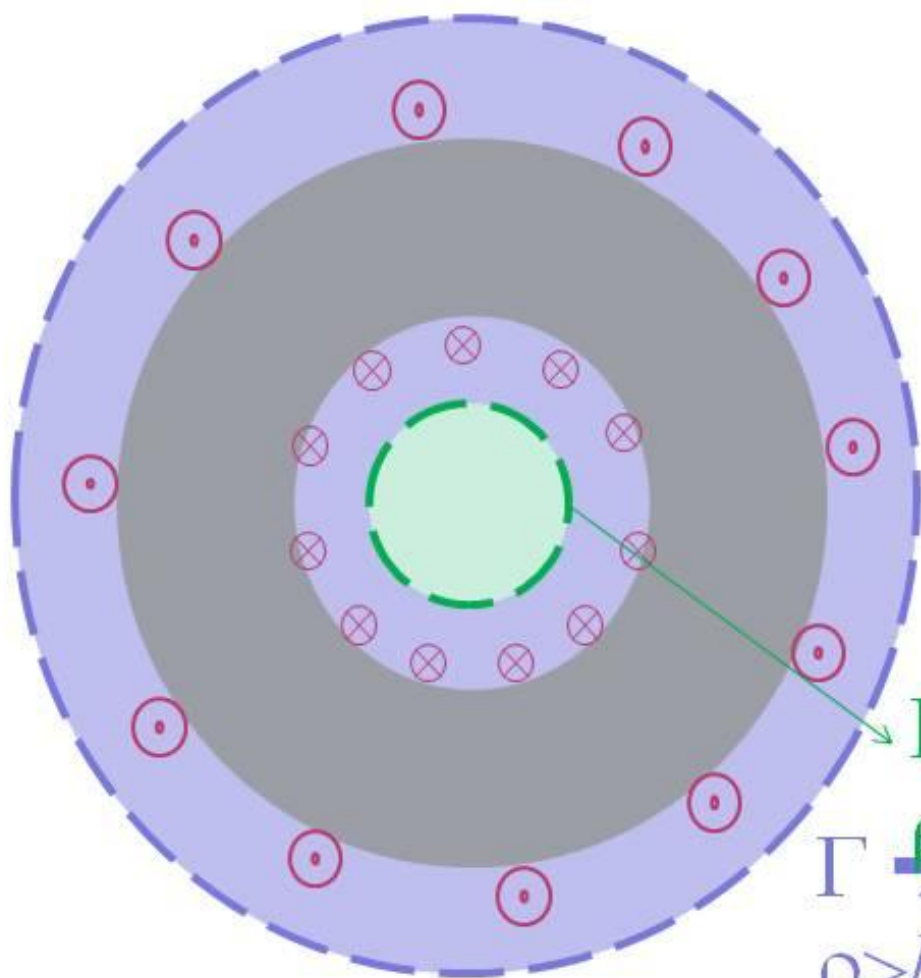
$$b \gg a \rightarrow \rho \approx b$$

$$\oint_{\Gamma} \vec{H} \cdot d\vec{l} = 2\pi\rho H_\phi$$

$$\iint_{S_\Gamma} \vec{J} \cdot d\vec{S} = NI$$



Toroide – Aplicação da Lei de Ampère



$$\oint_{\Gamma} \vec{H} \cdot d\vec{l} = 2\pi\rho H_{\phi}$$

$$\oint_{\Gamma} \vec{H} \cdot d\vec{l} = \iint_{S_{\Gamma}} \vec{J} \cdot d\vec{S} = NI$$

$\Gamma \rightarrow$

$\rho < b$

$\rho > b$



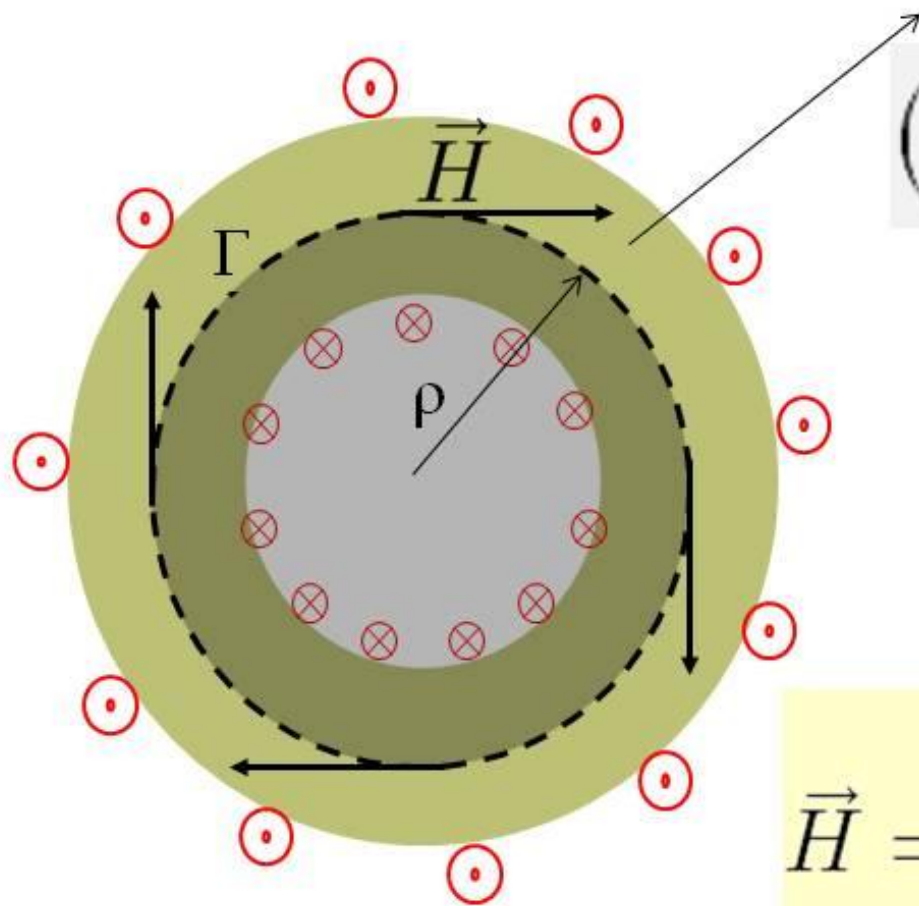
=0

$$2\pi\rho H_{\phi} = NI$$

$$H_{\phi} = 0$$



Toroide – Aplicação da Lei de Ampère



Dentro do núcleo:

$$(\rho - b)^2 + z^2 < a^2$$

$$\oint_{\Gamma} \vec{H} \cdot d\vec{l} = 2\pi\rho H_{\phi} = NI$$
$$\vec{H} = \frac{NI}{2\pi\rho} \hat{u}_{\phi}$$

$$b \gg a \rightarrow \rho \approx b$$

$$\vec{H} = \begin{cases} \frac{NI}{2\pi b} \hat{u}_{\phi}, & \text{dentro do núcleo} \\ 0, & \text{fora do núcleo} \end{cases}$$



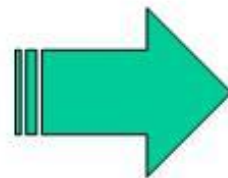
Potencial Magnetostático (Potencial Escalar Magnético) Força Magnetomotriz (f.m.m.)

$$\oint_{\Gamma} \vec{H} \cdot d\vec{l} = NI$$

$$\oint_{\Gamma} \vec{H} \cdot d\vec{l} = \mathcal{F} \quad (\text{A ou Ae})$$

$$I = 0 \quad \rightarrow \quad \oint_{\Gamma} \vec{H} \cdot d\vec{l} = 0$$

15



$$\vec{H} = -\nabla U$$

10

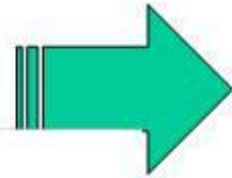


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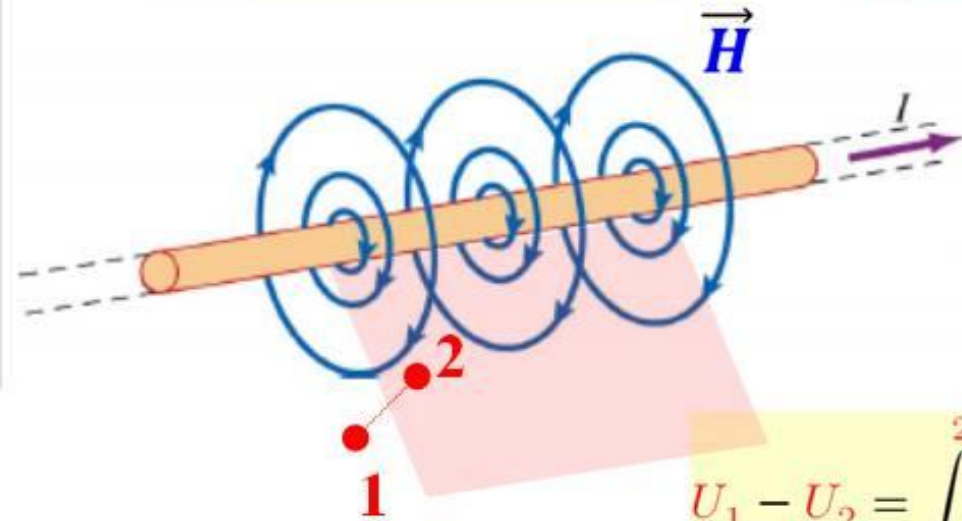
Potencial Magnetostático

Superfícies Barreira (Corte)

$$\vec{H} = -\nabla U$$

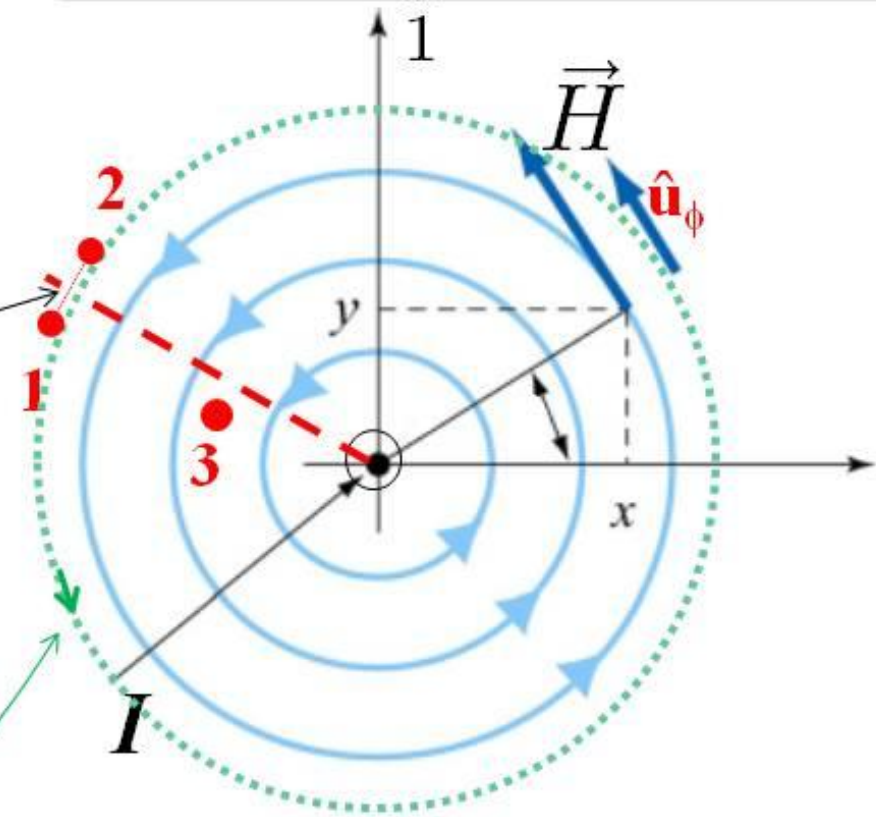


$$U_1 - U_2 = \int_1^2 \vec{H} \cdot d\vec{l}$$



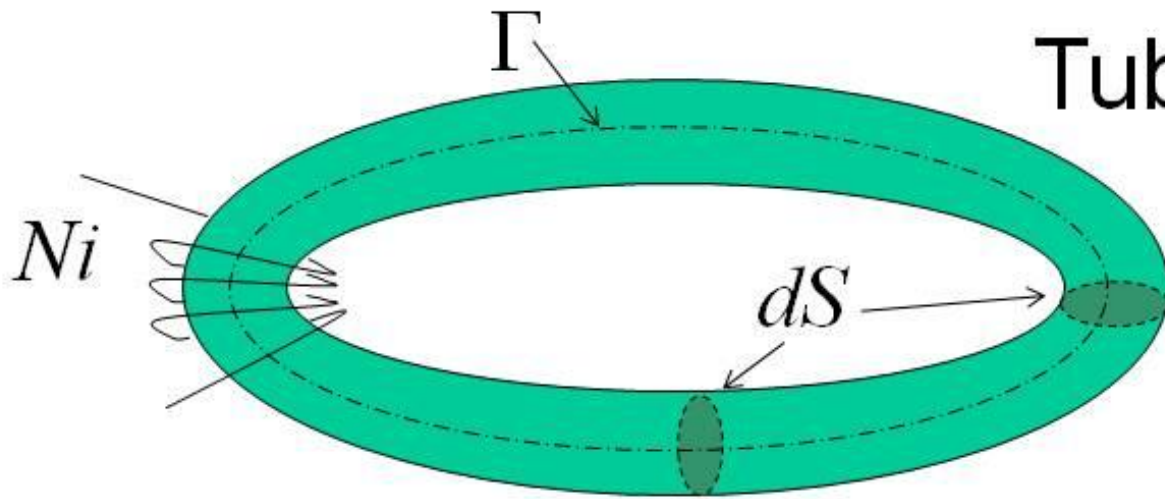
$$U_1 - U_2 = \int_1^2 \vec{H} \cdot d\vec{l} = 0$$

$$U_1 - U_2 = \int_1^2 \vec{H} \cdot d\vec{l} = I$$





Circuitos Magnéticos - Relutância



Tubo de fluxo dS

$$\oint_{\Gamma} \frac{\vec{B}}{\mu} \cdot d\vec{l} = NI$$

$$B = \frac{d\psi}{dS}$$

$$d\psi \oint_{\Gamma} \frac{dl}{\mu dS} = Ni$$

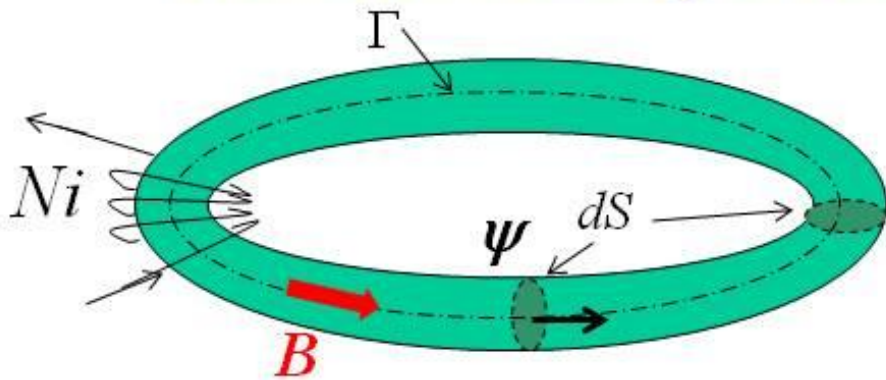
$B \sim$
constante
sobre S

$$\psi \oint_{\Gamma} \frac{dl}{\mu S} = Ni$$

$$\mathcal{R} = \oint_{\Gamma} \frac{dl}{\mu S} \quad (\text{H}^{-1})$$



Circuitos Magnéticos × Circuitos Elétricos

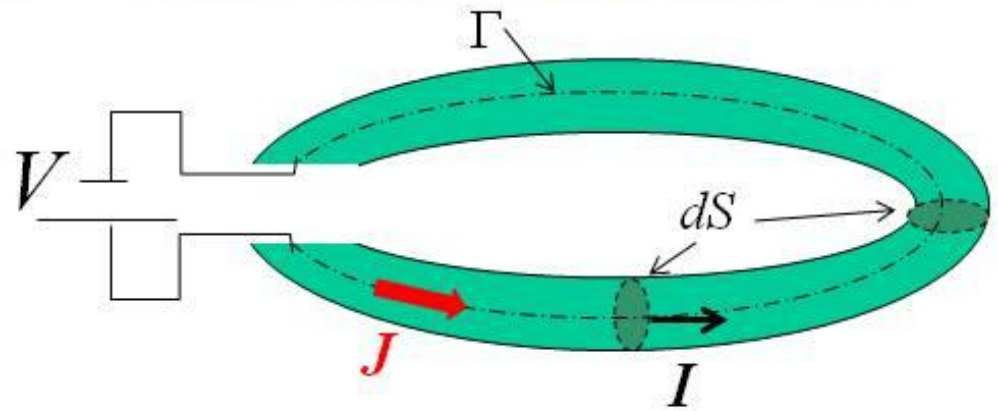


$$\psi \mathcal{R} = Ni$$

$$\psi = \mathcal{P} Ni$$

$$\mathcal{P} = \frac{1}{\mathcal{R}}$$

$$\mathcal{R} = \oint_{\Gamma} \frac{dl}{\mu S}$$



$$I R = V$$

$$I = G V$$

$$G = \frac{1}{R}$$

$$R = \oint_{\Gamma} \frac{dl}{\sigma S}$$



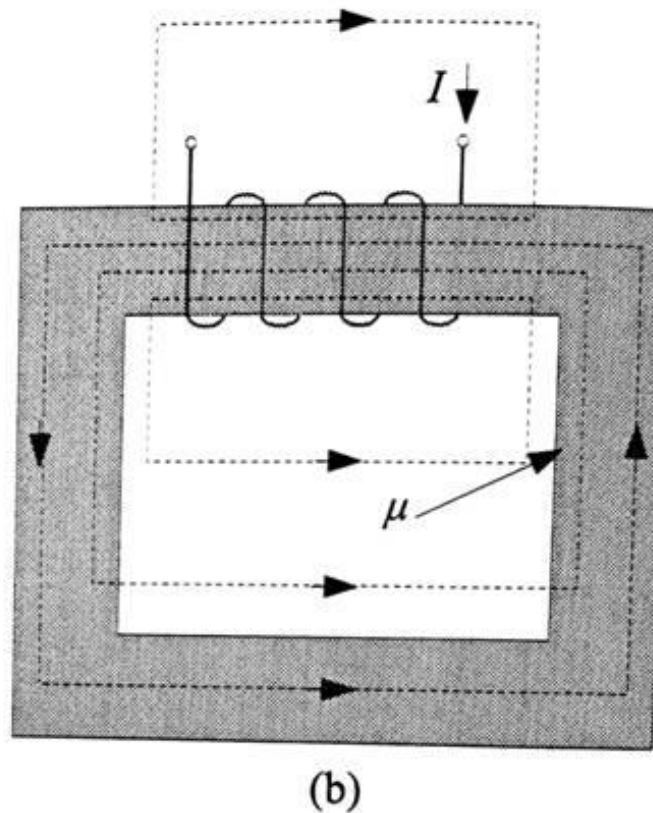
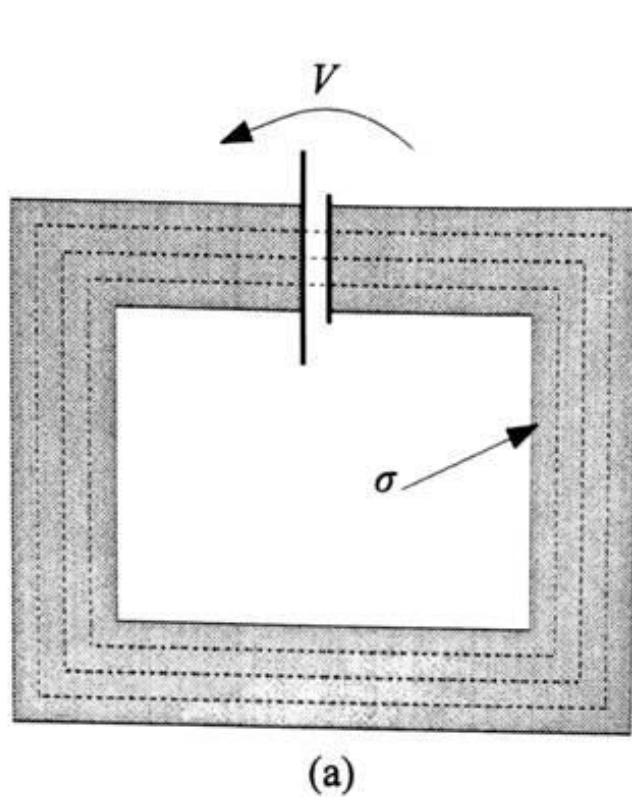
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Circuitos Magnéticos × Circuitos Elétricos

Circuito Elétrico	Circuito Magnético
Força Eletromotriz V	Força Magnetomotriz $\mathcal{F}=Ni$
Diferença de Potencial V_{AB}	Diferença de Potencial U_{AB}
Intensidade de Corrente I	Fluxo Magnético ψ
Condutividade σ	Permeabilidade μ
Resistência R	Relutância \mathcal{R}
Condutividade G	Permeância \mathcal{P}
Lei de Ohm $V=RI$	Lei de Ohm “Magnética” $U=\mathcal{R}\psi$



Circuitos Magnéticos × Circuitos Elétricos



$$Ni = \sum \mathcal{R}_i \psi_i$$

Ao longo
de uma
malha

$$\sum \psi_i = 0$$

Num nó