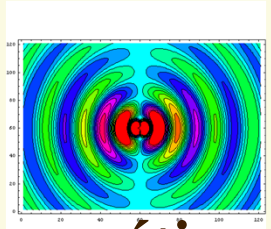
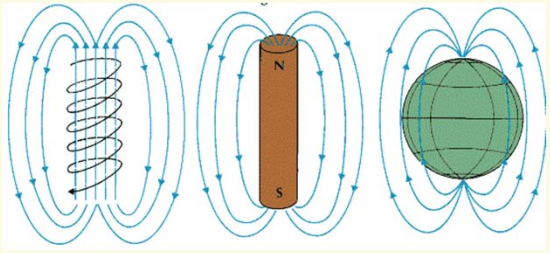


Aula 11: Ordem magnética



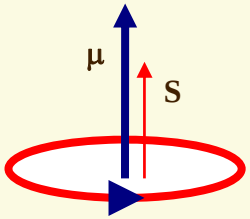
11.1. Vector magnetização

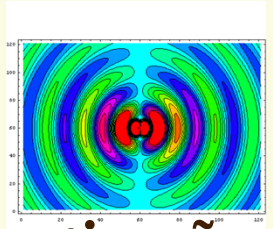
11.2. Permeabilidade magnética

11.3. Paramagnetismo

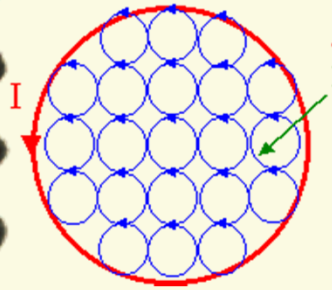
11.4. Ferromagnetismo

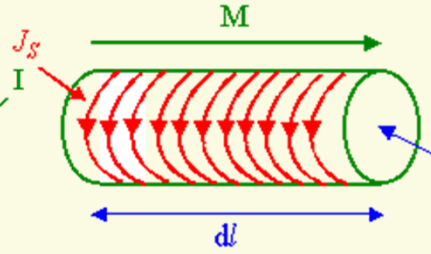
11.5. Ferrimagnetismo e Antiferromagnetismo

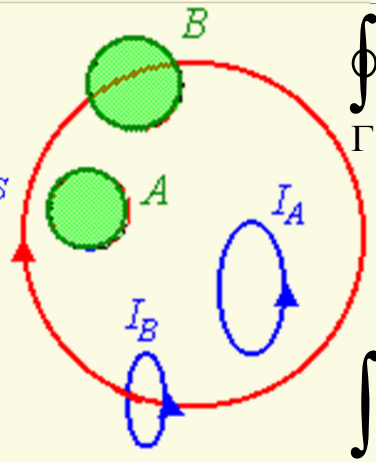




11.1. Vector magnetização







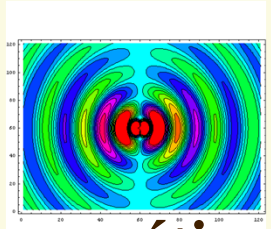
$$\vec{M} = N\vec{\mu} = \frac{d\vec{\mu}}{dV}$$

$$I_m = \oint_\Gamma \vec{M} \cdot d\vec{l}$$

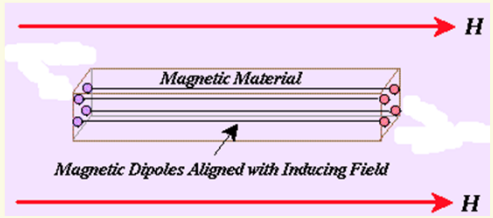
$$\oint_\Gamma \vec{B} \cdot d\vec{l} = \mu_0 \left(I + I_m \right)$$

$$\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{M}$$

$$\int_\Gamma \vec{H} \cdot d\vec{l} = \int_S \vec{j} \cdot d\vec{S}$$



11.2. Permeabilidade magnética



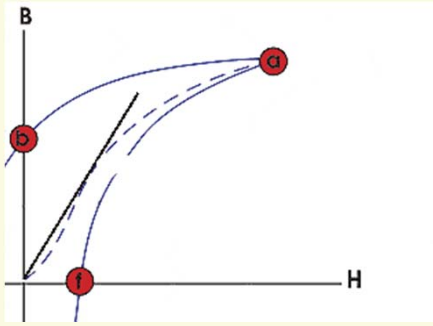
$$\vec{M} = \chi_m \vec{H}$$

$$\vec{B} = \mu_0 \left(1 + \chi_m\right) \vec{H} = \mu_0 \mu_r \vec{H}$$

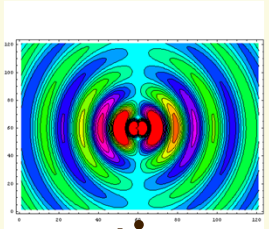
$$\vec{B} = \mu_0 \left(\vec{H} + \vec{M}\right)$$

$$\vec{M} = \chi_m \frac{\vec{B}_0}{\mu_0}$$

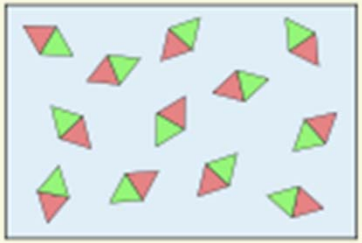
$$\mu_r = 1 + \chi_m$$



Simulação: distribuição de Boltzmann



11.3. Paramagnetismo



$$U = -\vec{\mu}\cdot\vec{B}_0 = -\mu B\cos\vartheta$$

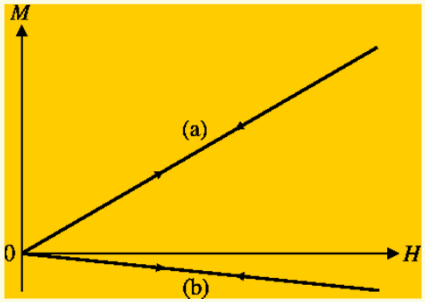
$$\frac{dN}{dU} = -\beta N \quad N = N_0 e^{-U/k_B T}$$

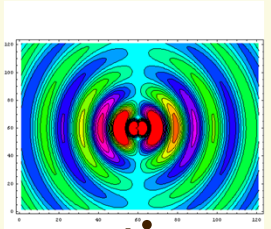
$$\chi_m = \frac{\mu_0 M}{B_0} = \frac{C}{T}$$

Lei de Curie

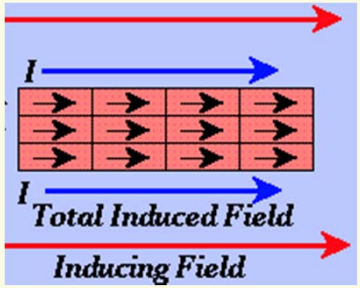
$$M = N\langle\vec{\mu}\rangle = \mu\int\cos\vartheta dN$$

$$C = \frac{N\mu_0\mu^2}{3k_B}$$



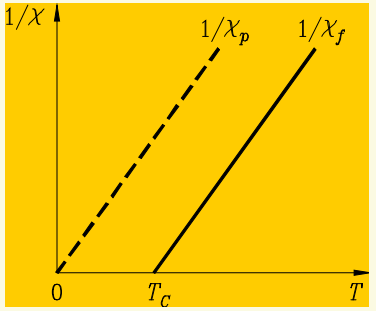


11.4. Ferromagnetismo



$$\vec{B}_{eff} = \vec{B}_0 + \gamma\vec{M}$$

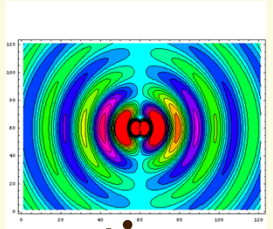
$$M = \frac{C}{\mu_0 T}\left(B_0 + \gamma M\right)$$



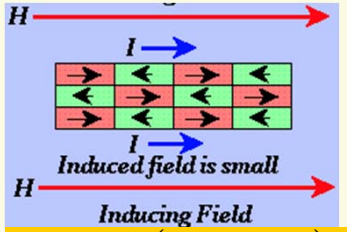
$$\vec{B}_m = \gamma\vec{M}$$

Lei de Curie-Weiss

$$\chi_f = \frac{\mu_0 T_C / \gamma}{\left(T - T_C\right)} = \frac{C}{T - T_C}$$



11.5. Ferrimagnetismo

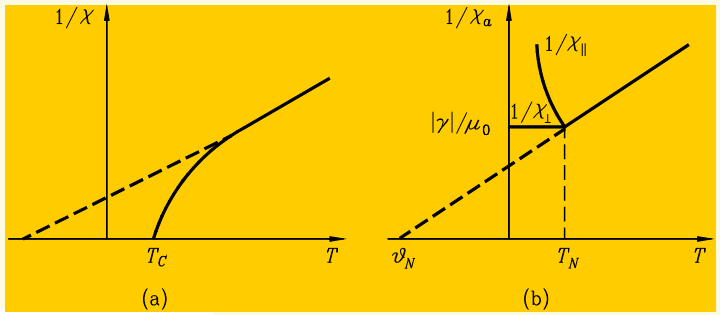


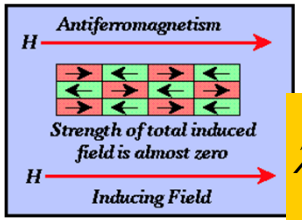
$$M_1 = \frac{C_1}{\mu_0 T}\left(B_0 - \alpha M_2\right)$$

$$M_2 = \frac{C_2}{\mu_0 T}\left(B_0 - \alpha M_1\right)$$

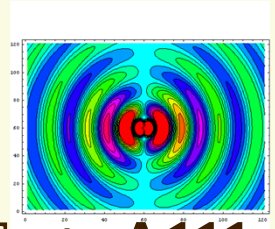
$$\chi_m = \frac{\mu_0\left(M_1 + M_2\right)}{B_0} = \frac{\left(C_1 + C_2\right)T - 2\left(\alpha/\mu_0\right)C_1 C_2}{T^2 - T_c^2}$$

Antiferromagnetismo





$$\chi_m = \frac{2CT - 2CT_N}{T^2 - T_N^2} = \frac{2C}{T + T_N}$$



Teste A111

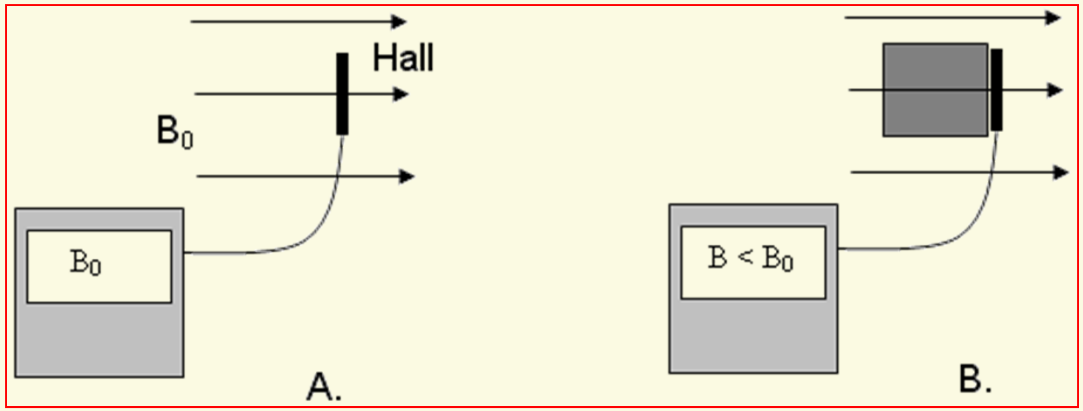
Uma sonda de Hall indica um valor B_0 de um campo uniforme, ver Figura. Colocando um bloco de material perto da sonda, a indicação baixa para um valor ligeiramente inferior $B < B_0$.

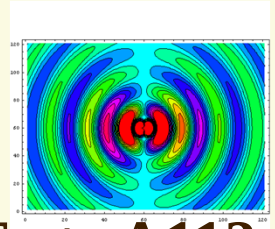
De que tipo de material magnético é constituido o bloco?

A diamagnético

B paramagnético

C antiferromagnético





Teste A112

A magnetização M de um material depende da intensidade do campo magnético aplicado H como está representado na Figura.
Determine o tipo de material:

A paramagnético

B ferromagnético

C antiferromagnético