El campo magnetostático

F II

El experimento de Oersted. Ley de Ampere

Fuerza de Lorentz. Campo magnético

Dinámica de partículas en campos magnéticos

El efecto Hall

Par sobre una espira. El dipolo magnético.

Materiales magnéticos. Imanación

Fuerzas magnéticas

F II **Experiencias con imanes**

W. Gilbert (1600)

Experiencias con corrientes

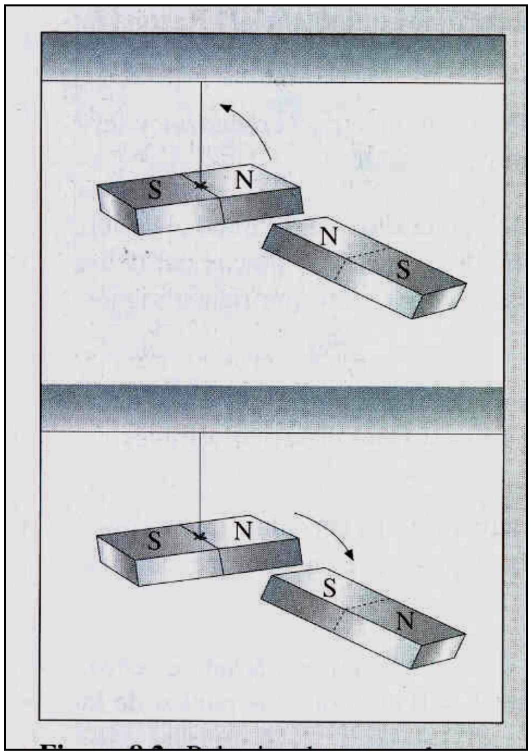
H. Oersted y A. Ampere (1820)

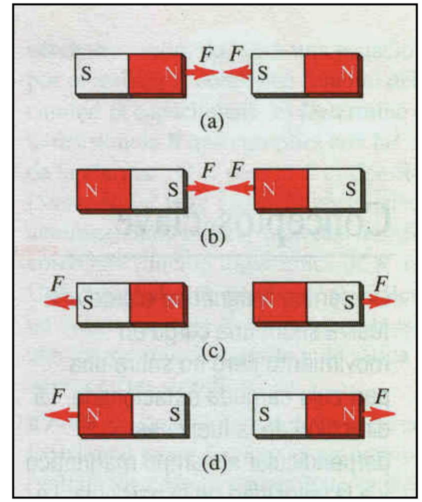
Acción de un campo sobre partícula cargada en movimiento

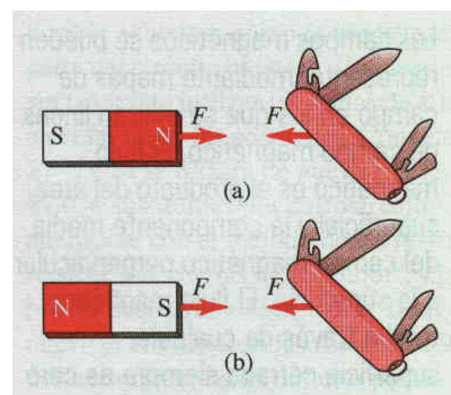
H. Lorentz (1892-1904)

Experiencias con imanes

F II

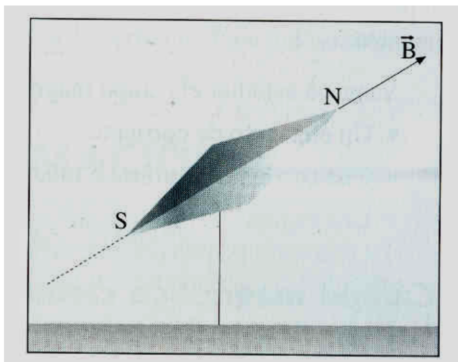


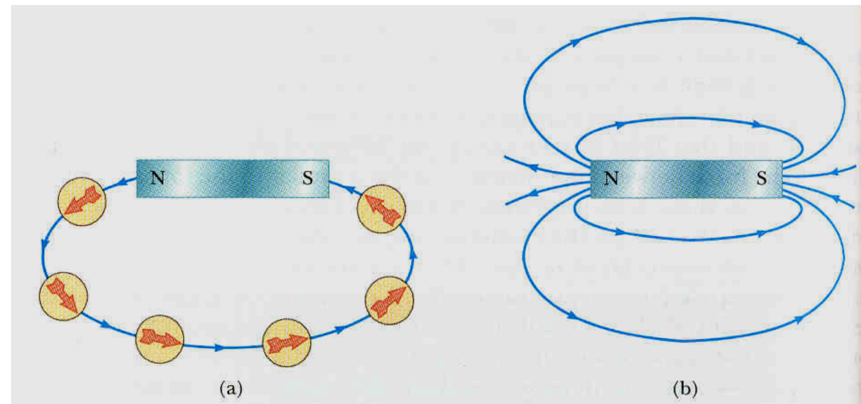


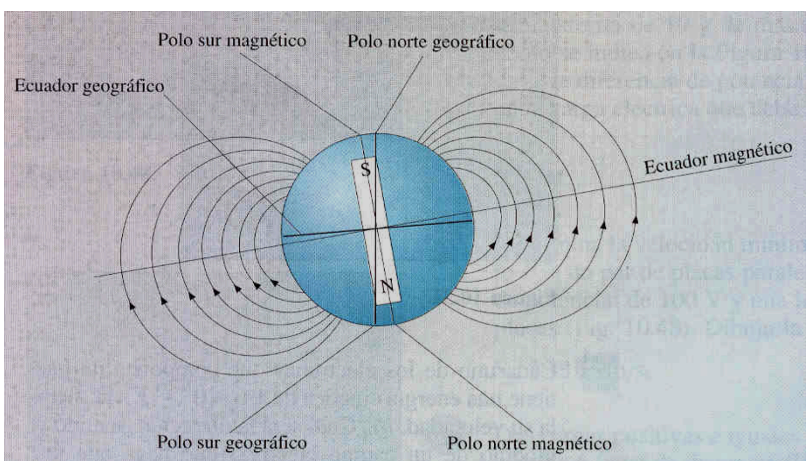


Campo magnético terrestre

F II

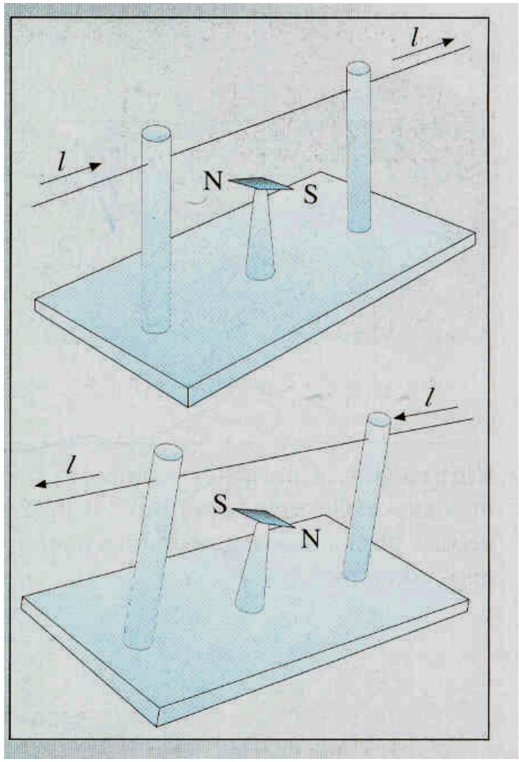


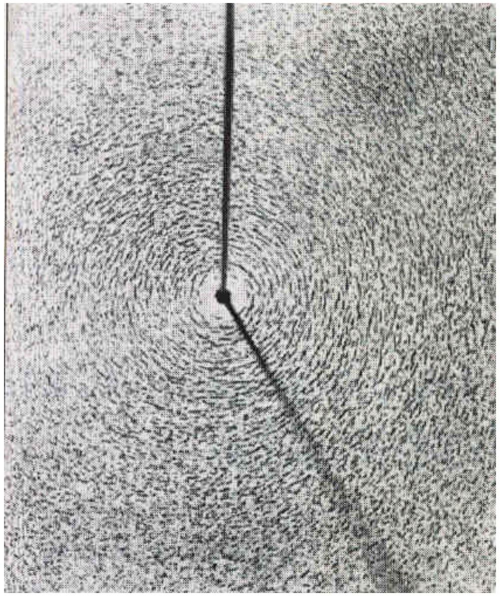




Experiencias con corrientes

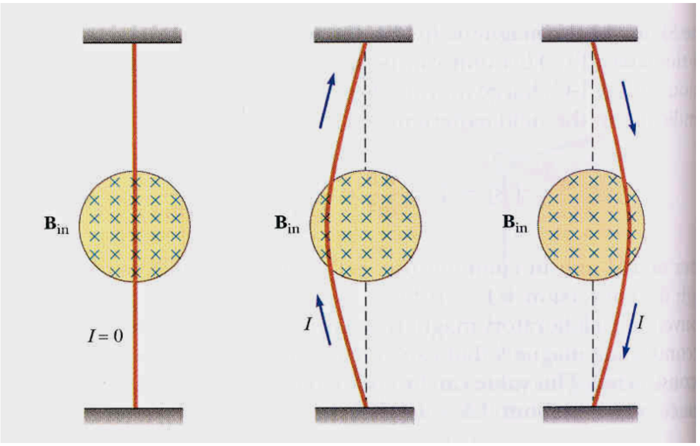
F II

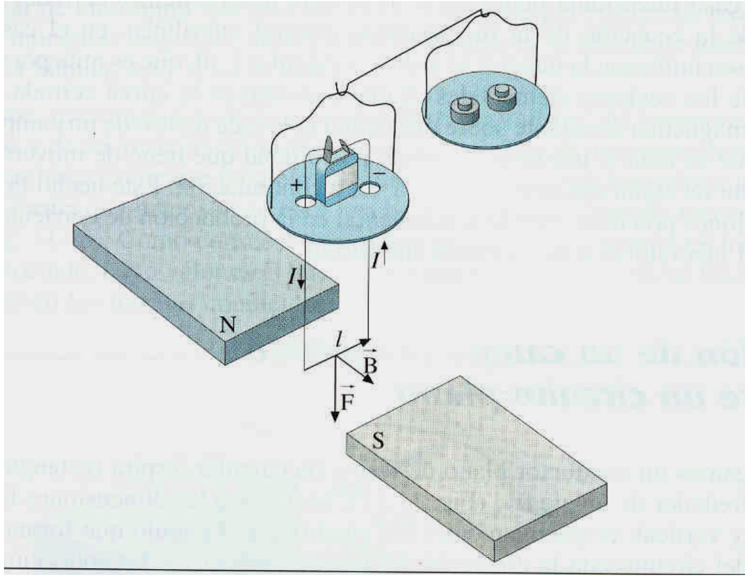




Acción campo-corriente

F II

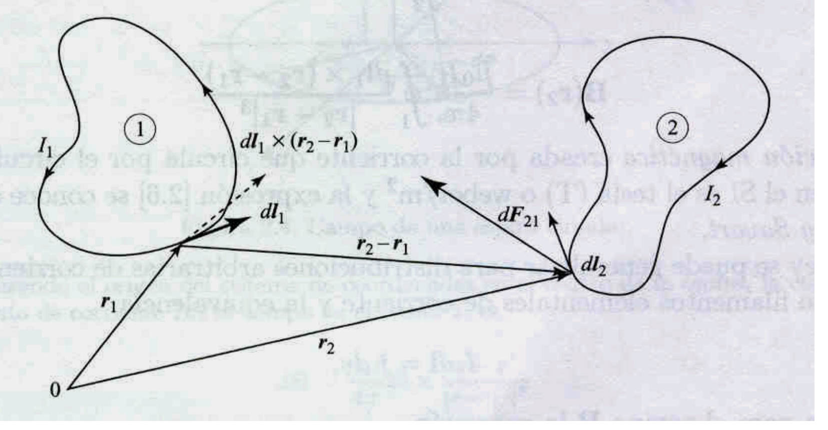




Ley de Ampère

Paralelismo con la ley de Coulomb

F II



$$\mathbf{F}_{2,1} = \frac{\mu_0 I_2 I_1}{4\pi} \oint_{C_2}\oint_{C_1} \frac{d\mathbf{l}_2 \times \left[d\mathbf{l}_1 \times \left(\mathbf{r}_2 - \mathbf{r}_1\right)\right]}{\left|\mathbf{r}_2 - \mathbf{r}_1\right|^3}$$

Campo magnético. Ley de Biot-Savart

F II

Campo magnético

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0 I}{4\pi} \oint_C \frac{\left[d\mathbf{l} \times (\mathbf{r} - \mathbf{r}')\right]}{\left|\mathbf{r} - \mathbf{r}\right|^3}$$

Fuerza de Lorentz y campo magnético

F II

Fuerza sobre carga q con velocidad v

$$\mathbf{F} = q\left(\mathbf{v} \times \mathbf{B}\right)$$

Dificultad para determinar el campo

Imposibilidad transferir energía

Relación Ampère-Lorentz

F II

$$d\mathbf{F} = Id\mathbf{l} \times \mathbf{B},$$

$$Id\mathbf{l} = (\mathbf{j} \cdot d\mathbf{a})d\mathbf{l} = nq\mathbf{v}d\tau = dq\mathbf{v}$$

$$d\mathbf{F} = dq\mathbf{v} \times \mathbf{B}$$

$$Id\mathbf{l}$$

$$d\mathbf{B} = \frac{\mu_0 I}{4\pi} \frac{d\mathbf{l} \times (\mathbf{r} - \mathbf{r}')}{|\mathbf{r} - \mathbf{r}'|^3}$$

$$q, \mathbf{v}$$

$$\mathbf{B} = \frac{\mu_0 q}{4\pi} \frac{\mathbf{v} \times (\mathbf{r} - \mathbf{r}')}{|\mathbf{r} - \mathbf{r}'|^3}$$

Determinación de campos

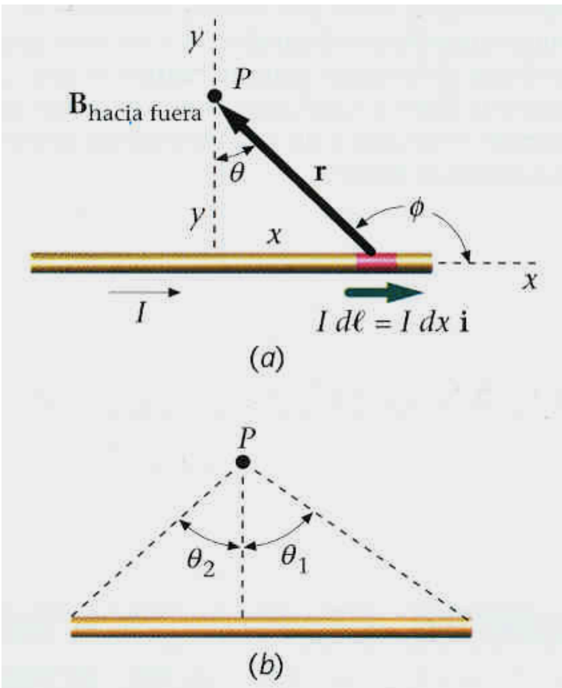
F II

Línea indefinida

P. Superposición/T. Ampère

F II

Línea indefinida I



$$dB = \frac{\mu_0}{4\pi}\frac{Idx}{r^2} sen\,\phi = \frac{\mu_0}{4\pi}\frac{Idx}{r^2}\cos\theta$$

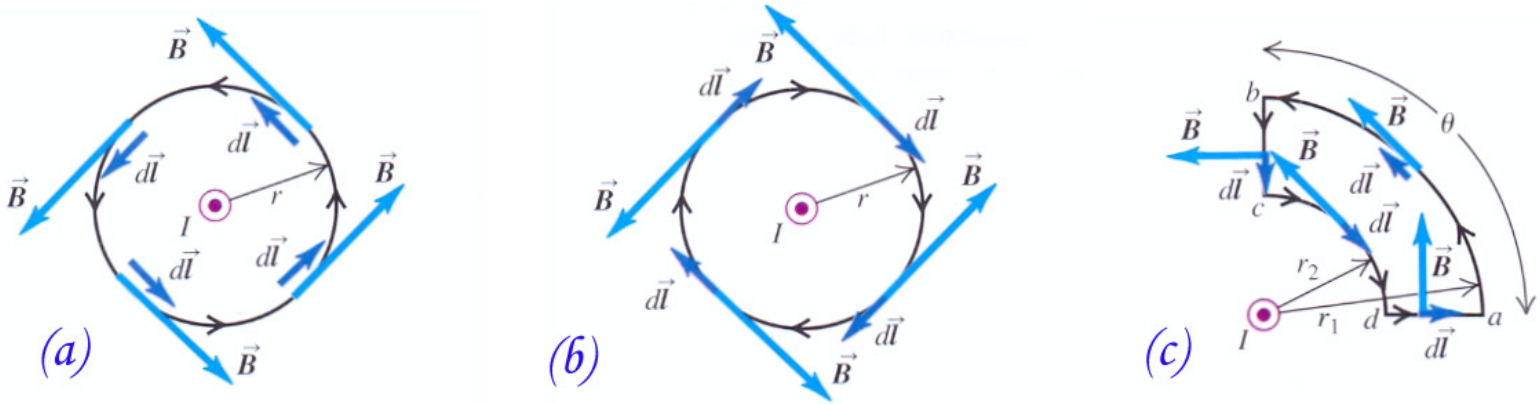
$$B = \frac{\mu_0}{4\pi}\frac{I}{R}\left(sen\,\theta_1 + \text{sen}\,\theta_2\right)$$

$$\mathbf{B} = \frac{\mu_0 I}{2\pi r}\mathbf{u}_\varphi$$

Teorema de Ampère

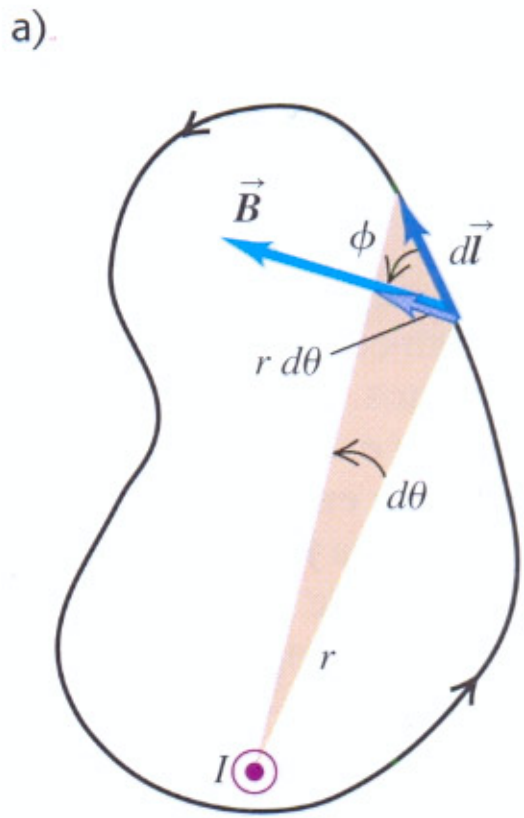
F II

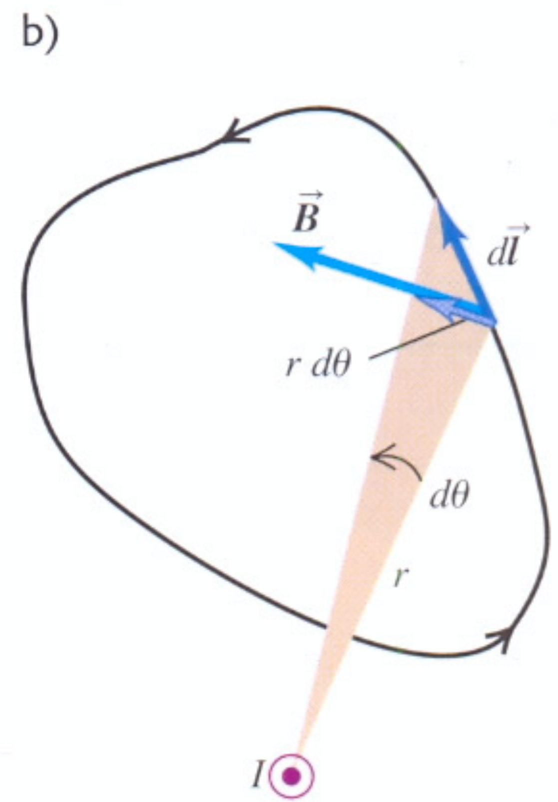
$$\oint_C \mathbf{B} \cdot d\mathbf{l} = \mu_0 I$$



Teorema de Ampère

F II



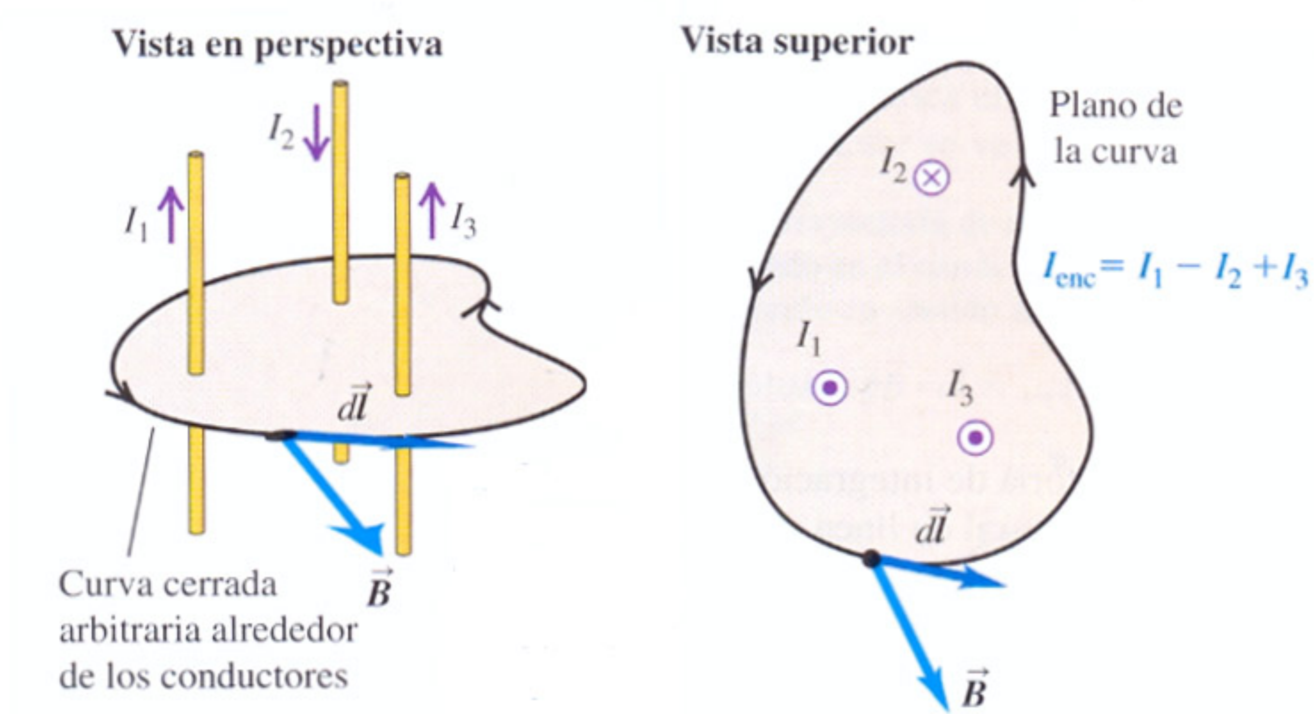


$$\oint_C \mathbf{B} \cdot d\mathbf{l} = \mu_0 I$$

$$\oint_C \mathbf{B} \cdot d\mathbf{l} = 0$$

Teorema de Ampère

F II



$$\oint_C \mathbf{B} \cdot d\mathbf{l} = \mu_0 I$$

Teorema de Ampère

F II

Ley circuital (integral curvilínea)

Equivalencia con teorema Gauss

$$\oint_C \mathbf{B} \cdot d\mathbf{l} = \mu_0 I$$

Ecuaciones del campo magnético

F II

1ª Ecuación

Campo solenoidal

Inseparabilidad polos

$$\oint_S \mathbf{B} \cdot \mathbf{n}\, da = 0$$

2ª Ecuación

Ley circuital Ampère

$$\oint_C \mathbf{B} \cdot d\mathbf{l} = \mu_0 I$$

Determinación de campos

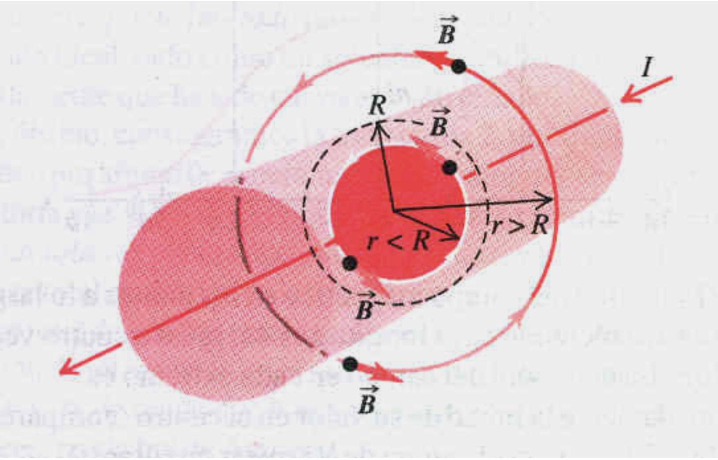
F II

Línea indefinida	**Teorema de Ampère**
Espira en eje	**P. Superposición**
Solenoide	**P. Superposición/T. Ampère**
Toroide	**T.Ampère**
Plano indefinido	**P. Superposición/T. Ampère**

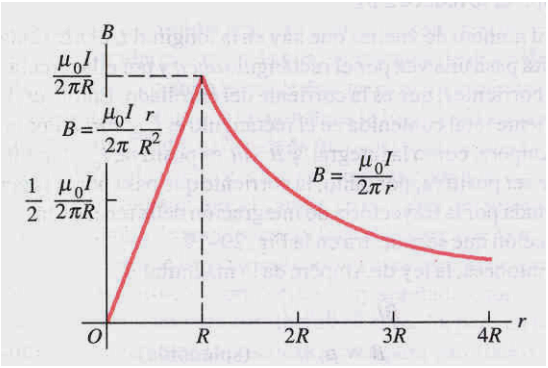
Línea indefinida II

F II

Corriente I, radio *R*



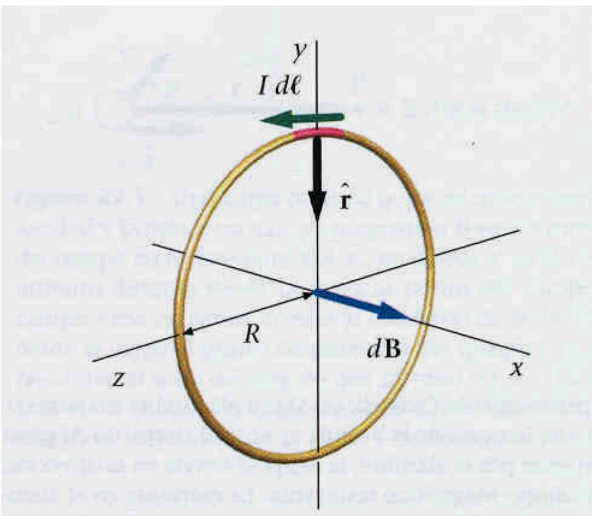
r<*R* $2\pi r B = \mu_0 \frac{I}{\pi R^2}\pi r^2,\ \mathbf{B} = \frac{I}{2\pi R^2} r\mathbf{u}_\varphi$

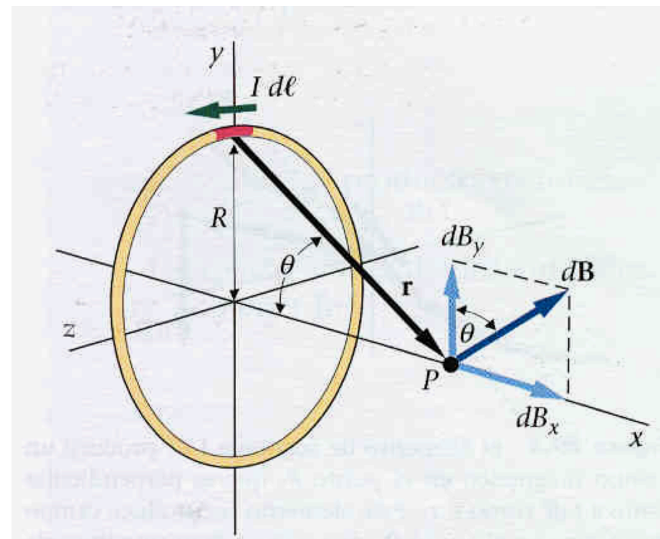


r>*R* $$\mathbf{B} = \frac{\mu_0 I}{2\pi r}\mathbf{u}_\varphi$$

Espira de radio R

F II

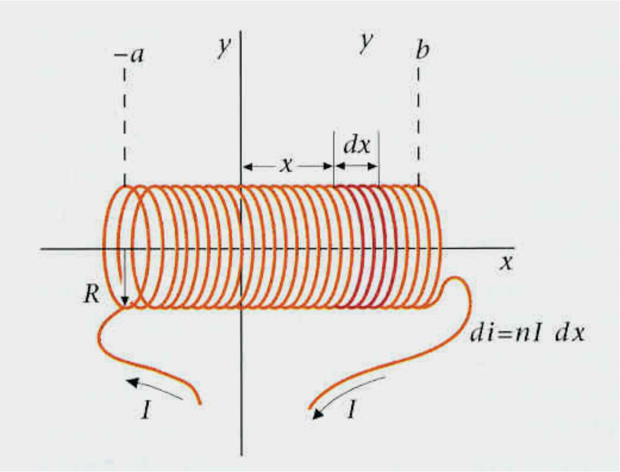


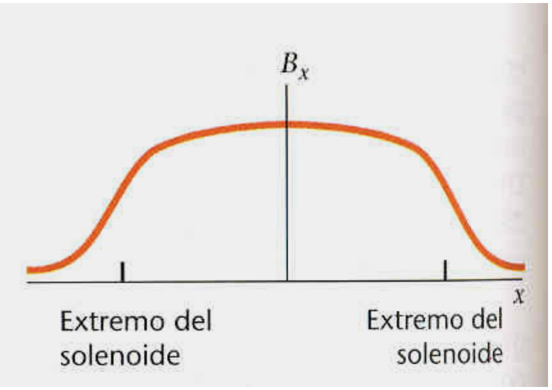


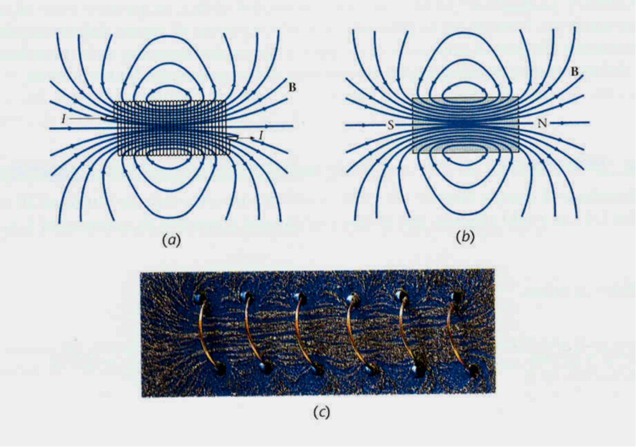
$$\mathbf{B} = \frac{\mu_0 I R^2}{2\left(x^2 + R^2\right)^{3/2}}\,\mathbf{u}_z$$

Solenoides

F II





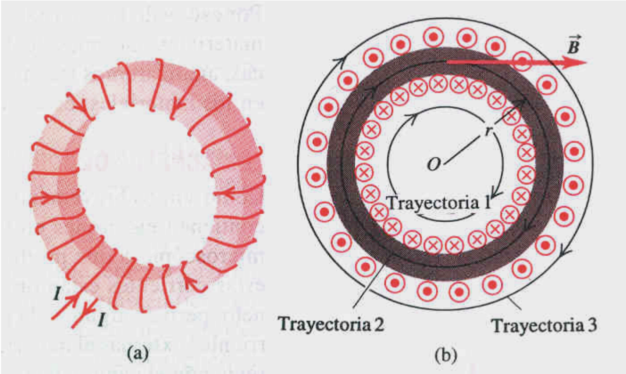


$$\mathbf{B} = \mu_0 n I \mathbf{u}_z$$

Otras geometrías

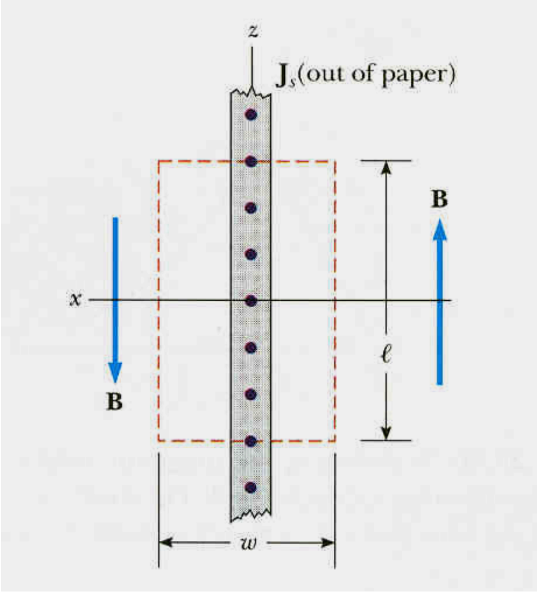
F II

Toroide



$$B = \frac{\mu_0 N I}{2\pi R}$$

Plano indefinido



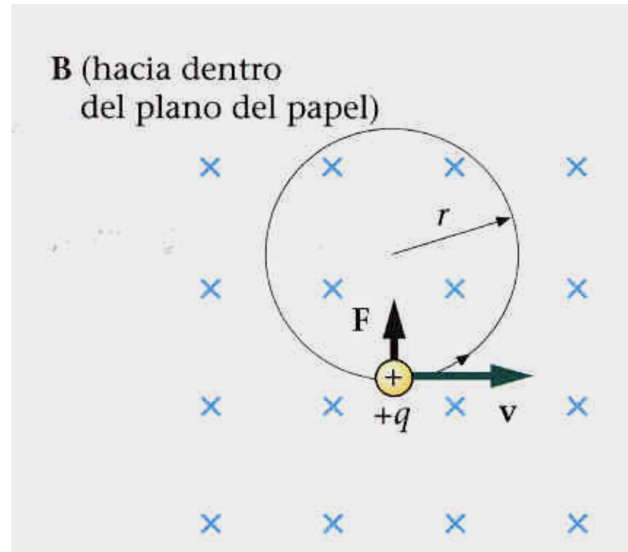
$$B = \frac{\mu_0 K}{2}$$

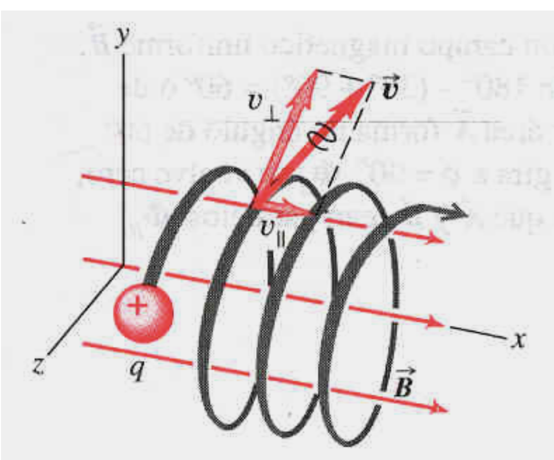
Dinámica de partículas en campos electromagnéticos

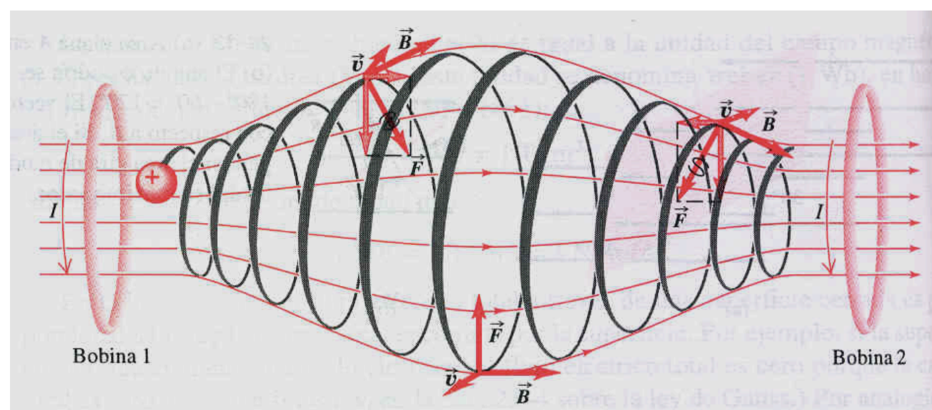
F II

$$\mathbf{F} = q\left(\mathbf{E} + \mathbf{v} \times \mathbf{B}\right)$$

$$F = qvB = m\frac{v^2}{R} \Rightarrow R = \frac{mv}{qB}$$

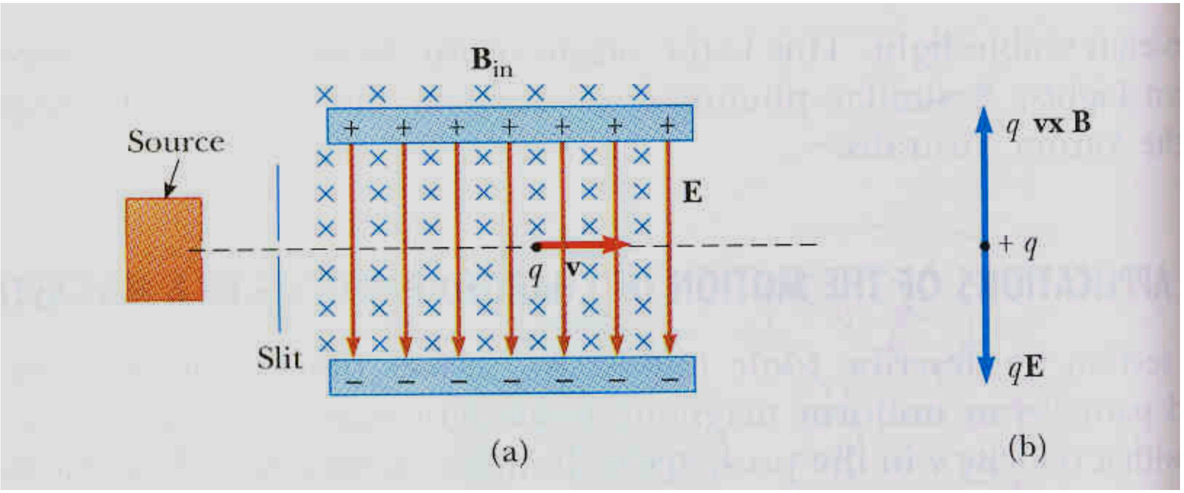






F II

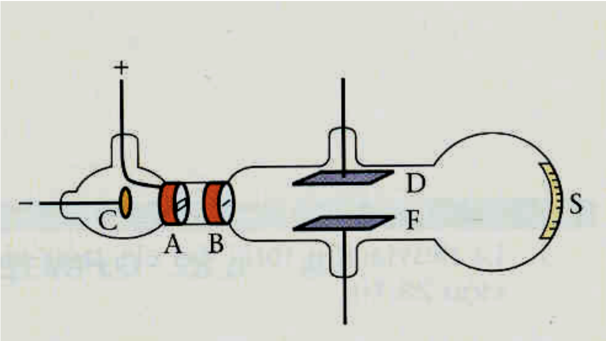
Selector de velocidades

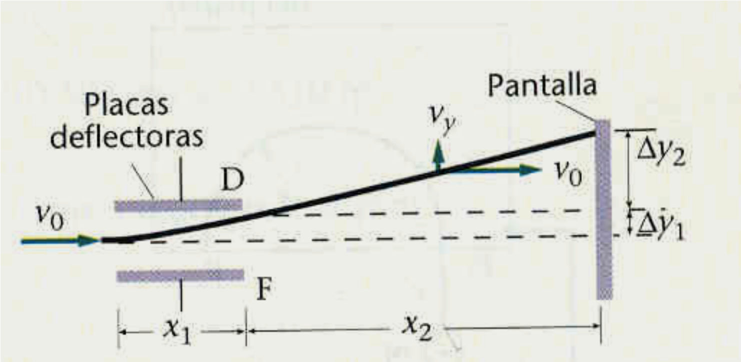


$$v = \frac{E}{B}$$

Relación q_e/m

F II



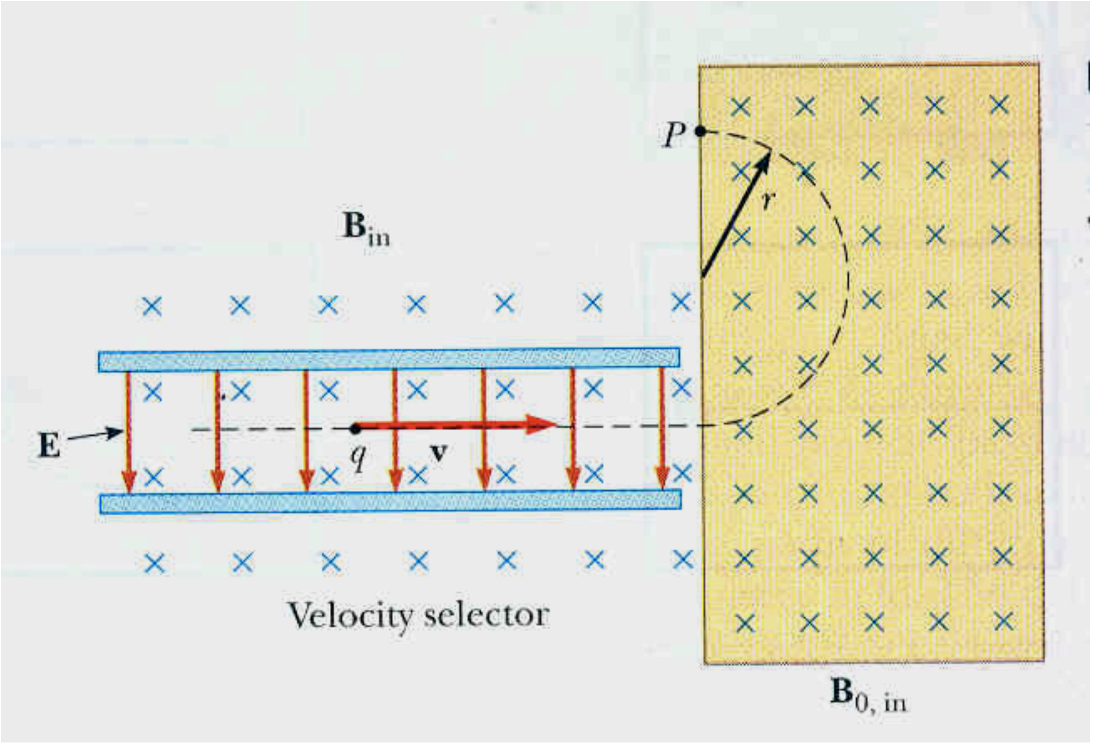


$$v_0, t_1 = \frac{x_1}{v_0}, v_y = at_1 = \frac{qE}{m} t_1 = \frac{\mathrm{qE}}{\mathrm{m}} \frac{\mathrm{x_1}}{\mathrm{v_0}}, \Delta y_1 = \frac{1}{2} at^2 = \frac{1}{2} \frac{qE}{m} \left(\frac{x_1}{v_0} \right)^2$$

$$t_2 = \frac{x_2}{v_0}, \Delta y_2 = v_y t_2 = \frac{qE}{m} \frac{x_1}{v_0} \frac{x_2}{v_0} \qquad \Delta y = \Delta y_1 + \Delta y_2 = \frac{1}{2} \frac{qE}{m} + \frac{qE}{m} \frac{x_1 x_2}{{v_0}^2}$$

Espectrómetro de masas

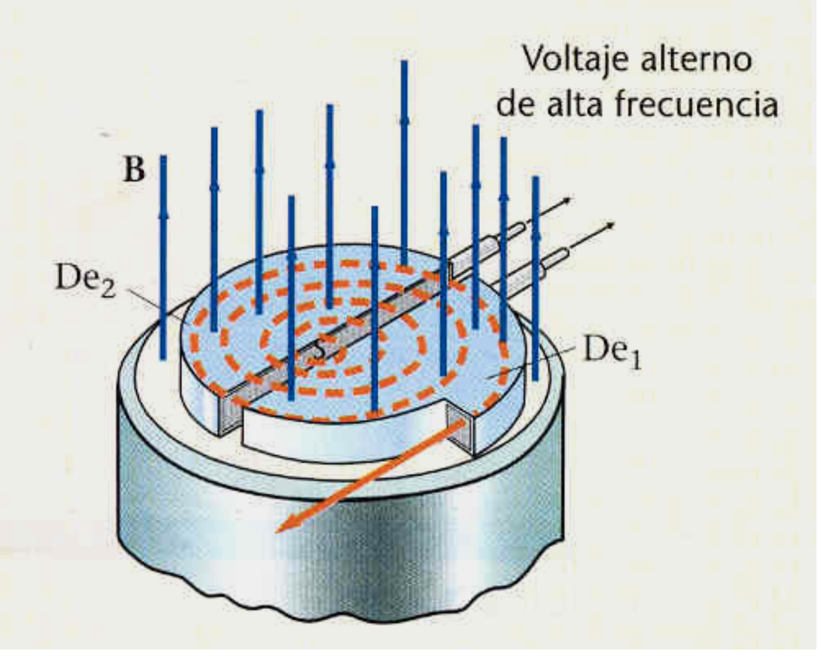
F II



$$\frac{m}{q} = \frac{rB_0}{v} = \frac{rB_0B}{E}$$

El ciclotrón

F II



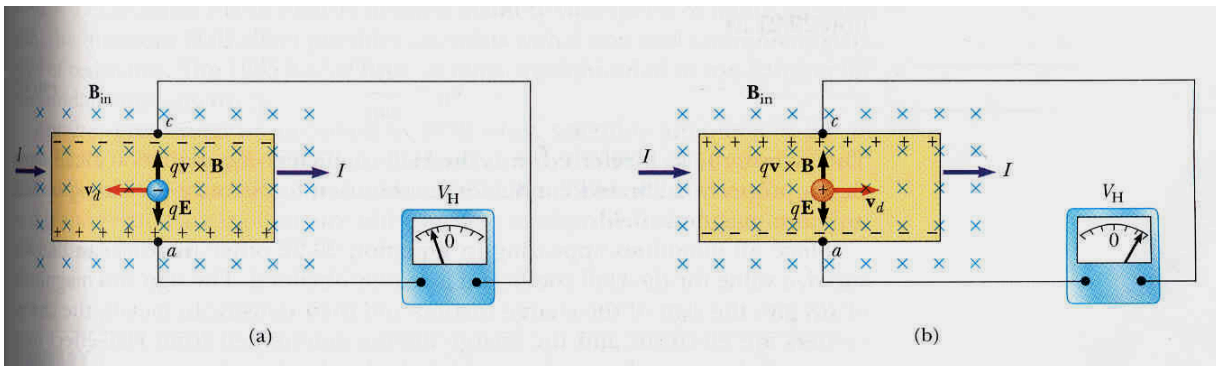
$$T = \frac{2\pi m}{qB}$$

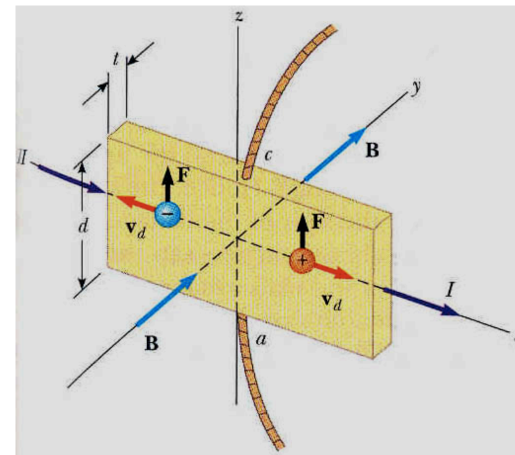
$$r = \frac{mv}{qB}, \ v = \frac{qBr}{m}$$

$$E_c = \frac{1}{2}mv^2 = \frac{1}{2}\left(\frac{q^2B^2}{m}\right)r^2$$

El efecto Hall

F II





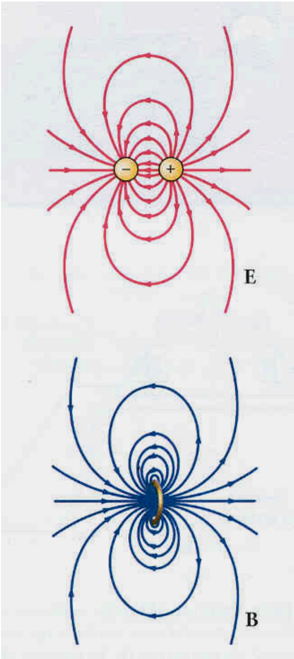
$$qv_dB = qE_H, E_H = v_dB, V_H = E_Hd = v_dBd$$

$$v_d = \frac{I}{nqA}, V_H = \frac{IBd}{nqA} = \frac{IB}{nqt}$$

F II

Dipolo magnético

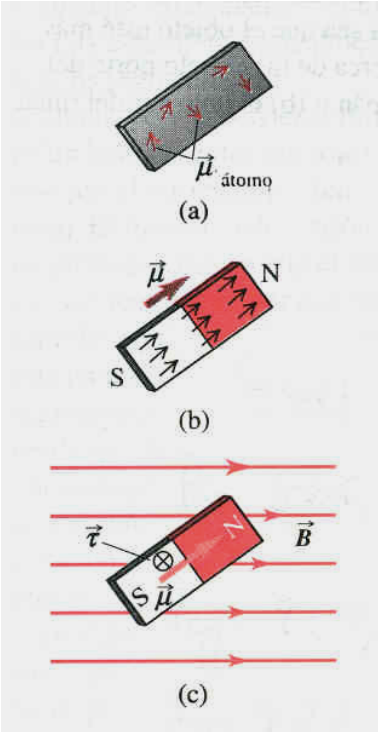
Momento dipolar magnético m

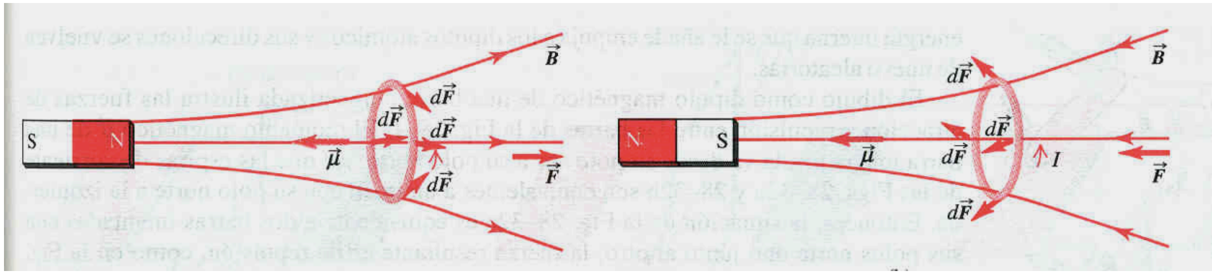


Si en espira $R << x$

$$B \cong \frac{\mu_0}{4\pi}\frac{2I\pi R^2}{\left|x^3\right|} = \frac{\mu_0}{4\pi}\frac{2m}{\left|x^3\right|}, \quad m = \pi R^2 I$$

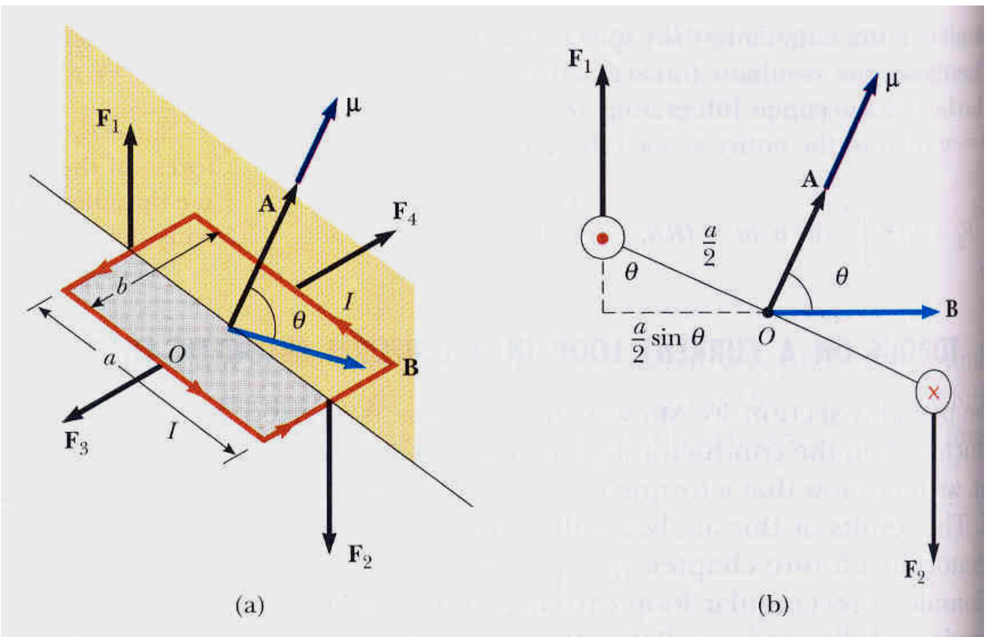
$$\boldsymbol{\Gamma} = \mathbf{m} \times \mathbf{B}, \quad U = -\mathbf{m} \cdot \mathbf{B}$$





Par sobre una espira

F II



$$\tau = F_1 \frac{a}{2} sen\,\theta + \mathrm{F}_2 \frac{a}{2} sen\,\theta =$$

$$IbB\left(\frac{a}{2} sen\,\theta\right) + IbB\left(\frac{a}{2} sen\,\theta\right) =$$

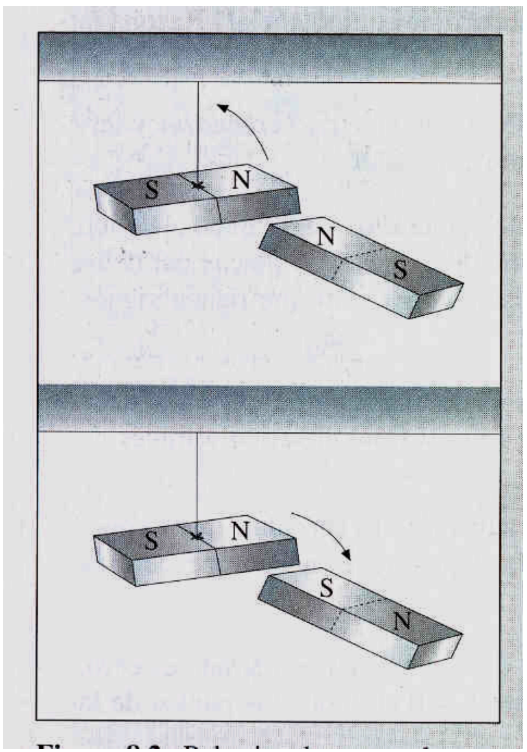
$$IabB\; sen\,\theta = IAB\; sen\,\theta$$

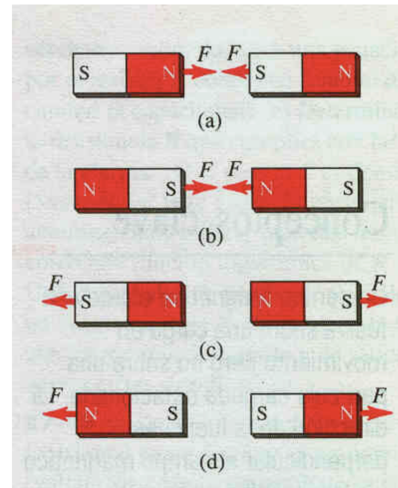
Momento dipolar magnético

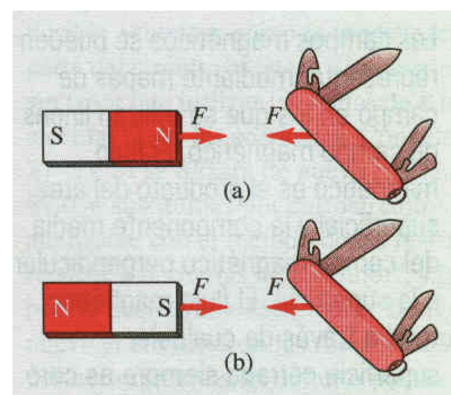
$$\boldsymbol{\tau} = I\mathbf{A} \times \mathbf{B},\ \mathbf{m} = I\mathbf{A},\ \boldsymbol{\tau} = \mathbf{m} \times \mathbf{B}$$

Experiencias con imanes

F II







Medios magnéticos I

F II

Modelo atómico

Orbital

$$I = \frac{e}{T} = \frac{ev}{2\pi r}, m = \frac{ev}{2\pi r}\left(\pi r^2\right) = \frac{e}{2m_e} L,\ L = m_e v r$$

$$m = \frac{e}{2m_e} L,\ L = 0, \hbar, 2\hbar, \ldots$$

Espín

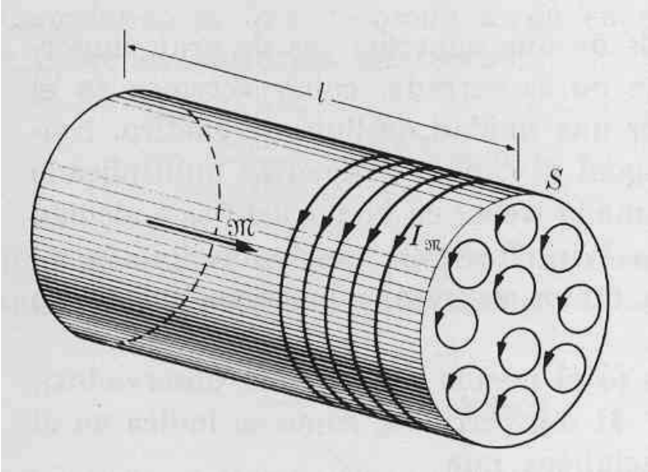
$$S = \frac{\hbar}{2},\ m = \mu_B = \frac{e}{2m_e}\hbar = \text{magnetón de Bohr}$$

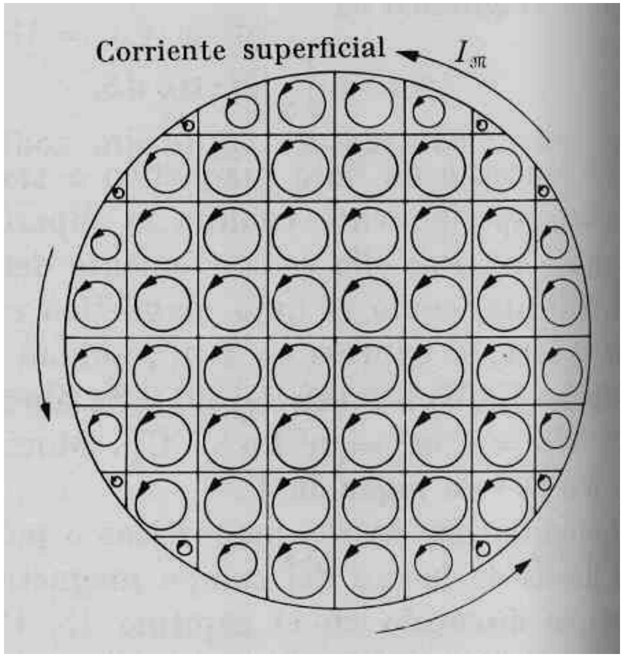
Medios magnéticos II

F II

Tratamiento macroscópico.Vector imanación

$$\mathbf{M} = \frac{d\mathbf{m}}{dv} \qquad M\pi a^2 = K\pi a^2, K = M, \mathbf{K} = \mathbf{M}\times\mathbf{n}$$





Medios magnéticos III

F II **Relacción constitutiva. Susceptibilidad y permeabilidad magnética**

$$B = \mu_0\left(nI + K\right) = \mu_0\left(nI + M\right), \frac{B}{\mu_0} - M = nI = H$$

$$\mathbf{M} = \chi_m \mathbf{H}, \mathbf{B} = \mu_0\left(\mathbf{H} + \mathbf{M}\right) = \mu_0\left(1 + \chi_m\right)\mathbf{H} = \mu\mathbf{H}$$

$$\mu = \mu_0\left(1 + \chi_m\right), \mu_r = 1 + \chi_m$$

Medios magnéticos IV

F II

Diamagnetismo $\chi_m < 0, \mu_r < 1$

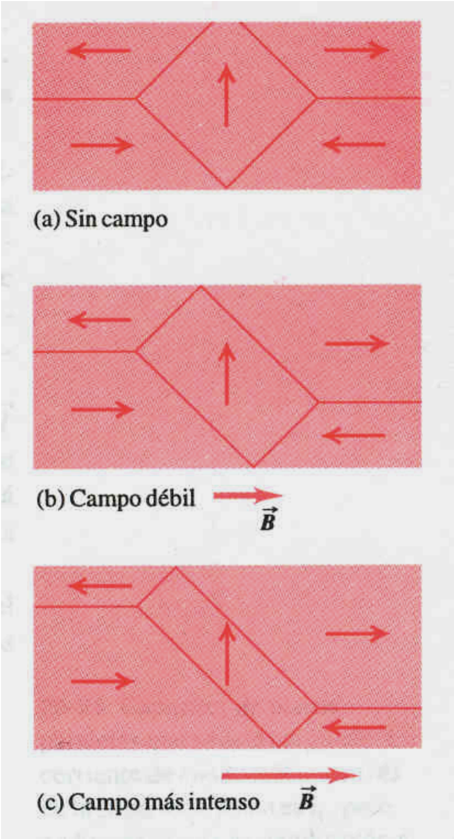
Paramagnetismo $\chi_m > 0, \mu_r > 1$

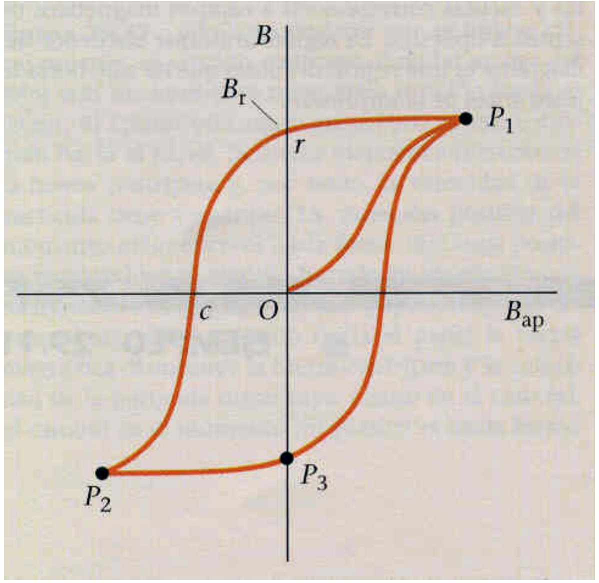
Ferromagnetismo **Ciclo de histéresis**

Medios magnéticos V

F II

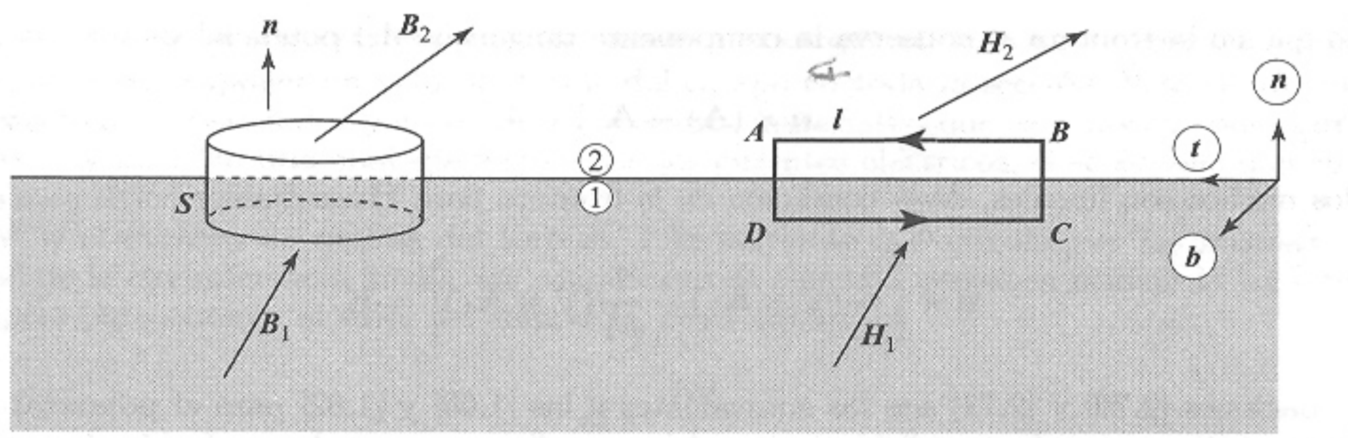
Ferromagnetismo $\mu = f(B)$





Condiciones Frontera

F II



$$\mathbf{n}\cdot\left(\mathbf{B}_2-\mathbf{B}_1\right)=0,$$
$$\mathbf{t}\cdot\left(\mathbf{H}_2-\mathbf{H}_1\right)=0$$