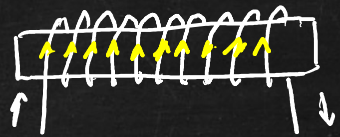
Permanent Magnetic

Electric Magnetic

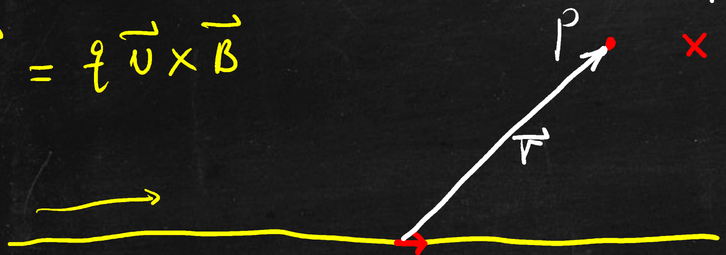
point magnetic charge 磁荷



— soft iron

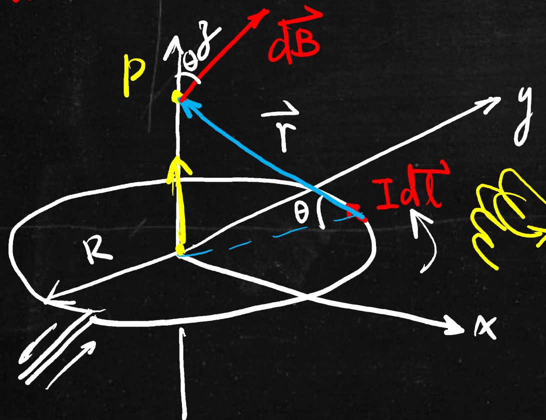
Magnetic Field

$\vec{F} = q\vec{v}\times\vec{B}$



elementary current 电流元 $i d\vec{l}$

Bio-Savart Law



$$dB = \frac{\mu_0}{4\pi}\cdot\frac{i d\vec{l}\times\vec{r}}{r^3} = \frac{\mu_0}{4\pi}\frac{i d\vec{l}\times\hat{r}}{r^2}$$

$$dB_z = dB\cdot\cos\theta = \frac{\mu_0}{4\pi}\frac{I dl}{r^2}\frac{R}{r} = \frac{\mu_0}{4\pi}\frac{IR\,dl}{r^3}$$

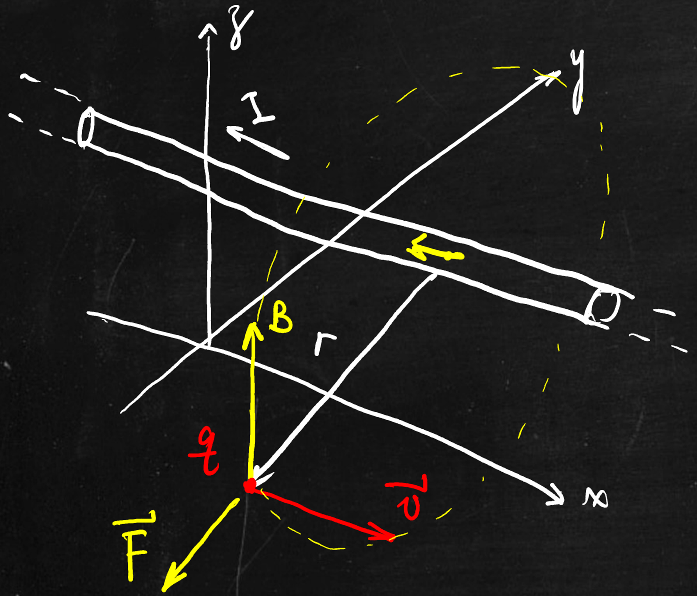
$$B_z = \int \boxed{\frac{\mu_0}{4\pi}\cdot\frac{IR}{r^3}}\,dl = \frac{\mu_0}{2\cancel{4\pi}}\cdot\frac{IR}{r^3}\cdot\cancel{2\pi}R = \frac{\mu_0 IR^2}{2r^3}$$

$$= \frac{\mu_0 IR^2}{2(R^2+z^2)^{\frac{3}{2}}}$$

$z=0$ $B = \frac{\mu_0 I}{2R}$

$\vec{F} = q\vec{E} + q\vec{v}\times\vec{B}$ Lorentz Force

time, space $\vec{F}, \vec{E}, \vec{v}, \vec{B}$



$$\vec{F} = -\hat{y}\cdot\frac{I q\cdot v}{2\pi\varepsilon_0 r c^2}$$

$$\vec{F} = q\vec{v}\times\vec{B} = qvB(\hat{x}\times\hat{z})$$

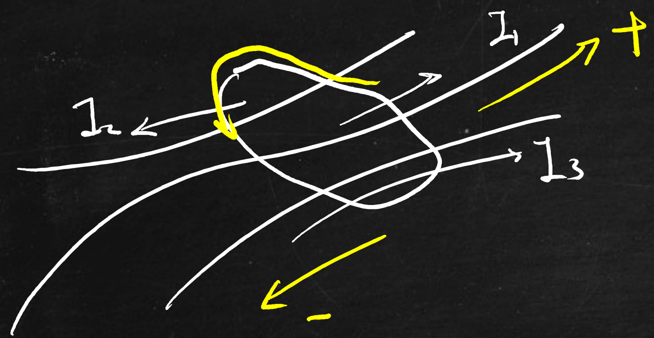
$$\vec{v} = v\cdot\hat{x}$$
$$\vec{B} = B\hat{z}$$

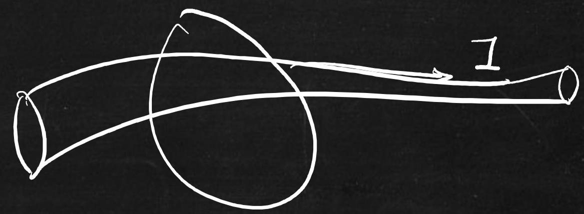
$$= -\hat{y}\cdot qvB$$

$$B = \frac{I}{2\pi\varepsilon_0 r c^2} \quad \text{(Tesla)}$$

$$\vec{B} = \frac{\mu_0 I}{2\pi r}\hat{z} \qquad c^2 = \frac{1}{\mu_0\varepsilon_0} \qquad c = \sqrt{\frac{1}{\mu_0\varepsilon_0}}$$

Ampere's Law: $\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{net}$.





Current Density $\vec{J}$ $\quad \vec{J}(x, y, z)$

$$I = \int_S \vec{J} \cdot d\vec{a}$$

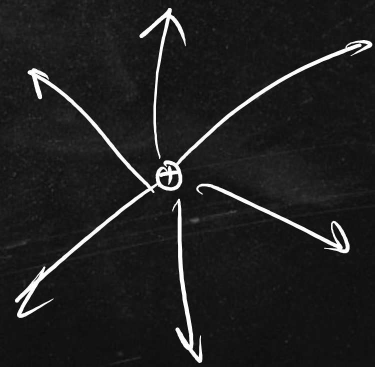
$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \int \vec{J} \cdot d\vec{a}$$

$$\mathrm{div}\,\vec{A} = \vec{\nabla} \cdot \vec{A} \qquad \mathrm{curl}\,\vec{A} = \vec{\nabla} \times \vec{A}$$

Stoke's Theorem

$$\oint \vec{B} \cdot d\vec{l} = \int (\mathrm{curl}\,\vec{B}) \cdot d\vec{a}$$

旋度

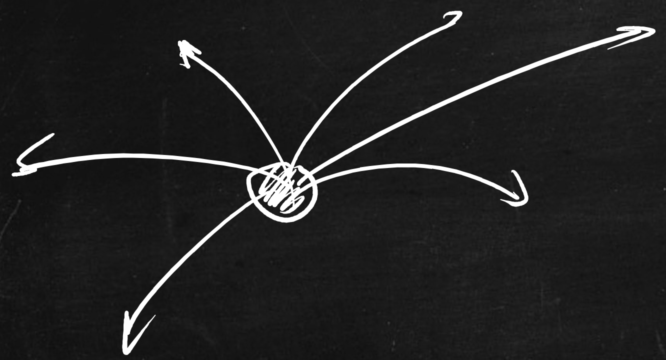


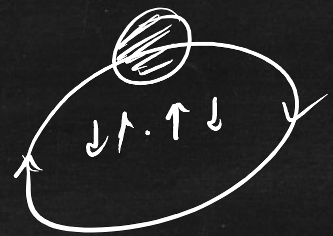
$$\mathrm{curl}\,\vec{B} = \mu_0 \vec{J} \qquad \mathrm{div}\,\vec{B} = 0$$

$$\mathrm{curl}\,\vec{E} = 0 \qquad \mathrm{div}\,\vec{E} = \frac{\rho}{\varepsilon_0} \qquad \oiint \vec{E} \cdot d\vec{A} = \frac{q_{net}}{\varepsilon_0}$$

$$\vec{\nabla}\times\vec{E}=0 \qquad \vec{\nabla}\cdot\vec{E}=\frac{\rho}{\varepsilon_0}$$

$$\vec{\nabla}\times\vec{B}=\mu_0 J \qquad \vec{\nabla}\cdot\vec{B}=0$$





$$\vec{E}=-\vec{\nabla}V \qquad \vec{B}=\vec{\nabla}\times\vec{A}$$ vector potential 磁矢势

$$\operatorname{div}\vec{B}=0 \qquad \operatorname{div}(\vec{\nabla}\times\vec{A})=\operatorname{div}(\operatorname{curl}\vec{A})=0$$

$$\operatorname{curl}(\operatorname{curl}\vec{A})=\mu_0\vec{J} \qquad \vec{\nabla}\times(\vec{\nabla}\times\vec{A})=\mu_0\vec{J}$$

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

$$B_x \hat{x} + B_y \hat{y} + B_z \hat{z} = \left(\frac{\partial}{\partial x} \vec{i} + \frac{\partial}{\partial y} \vec{j} + \frac{\partial}{\partial z} \vec{k} \right) \times \left(A_x \vec{i} + A_y \vec{j} + A_z \vec{k} \right)$$

$$\underline{B_z = \frac{\partial A_y}{\partial x} - \frac{\partial A_x}{\partial y}} , \quad \underline{B_y = \frac{\partial A_x}{\partial z} - \frac{\partial A_z}{\partial x}} \qquad \underline{\vec{\nabla} \times \vec{B}} = \mu_0 \vec{J}$$

$$\left(\frac{\partial B_z}{\partial y} - \frac{\partial B_y}{\partial z} \right) \vec{i} + \left(\quad \right) \vec{j} + \left(\quad \right) \vec{k} = \mu_0 \left(J_x \vec{i} + J_y \vec{j} + J_z \vec{k} \right)$$

$$\frac{\partial B_z}{\partial y} - \frac{\partial B_y}{\partial z} = J_x \mu_0 \qquad \underline{\underline{\frac{\partial}{\partial y}}} \left(\frac{\partial A_y}{\partial x} - \underline{\underline{\frac{\partial A_x}{\partial y}}} \right) - \underline{\frac{\partial}{\partial z}} \left(\underline{\frac{\partial A_x}{\partial z}} - \frac{\partial A_z}{\partial x} \right) = \mu_0 J_x$$

$$\frac{\partial}{\partial y} \left(\frac{\partial A_y}{\partial x} \right) = \frac{\partial}{\partial x} \left(\frac{\partial A_y}{\partial y} \right) \qquad \frac{\partial}{\partial z} \left(\frac{\partial A_z}{\partial x} \right) = \frac{\partial}{\partial x} \left(\frac{\partial A_z}{\partial z} \right)$$

$$-\frac{\partial^2 A_x}{\partial y^2} - \frac{\partial^2 A_x}{\partial z^2} + \underline{\frac{\partial}{\partial x} \left(\frac{\partial A_y}{\partial y} \right) + \frac{\partial}{\partial x} \left(\frac{\partial A_z}{\partial z} \right)} = \mu_0 J_x$$

$$\frac{\partial}{\partial x} \left(\frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z} \right)$$

$$-\frac{\partial^2 A_x}{\partial y^2} - \frac{\partial^2 A_x}{\partial z^2} + \frac{\partial}{\partial x}\left(\frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z}\right) = \mu_0 J_x$$

$$\underline{-\frac{\partial^2 A_x}{\partial x^2} - \frac{\partial^2 A_x}{\partial y^2} - \frac{\partial^2 A_x}{\partial z^2}} + \cancel{\frac{\partial}{\partial x}\left(\frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z}\right)} = \mu_0 J_x$$

$$\operatorname{div}\vec{A} = 0$$

$$\vec{\nabla}\cdot\vec{A} = \left(\frac{\partial}{\partial x}\vec{i} + \frac{\partial}{\partial y}\vec{j} + \frac{\partial}{\partial z}\vec{k}\right)\cdot\left(A_x\vec{i} + A_y\vec{j} + A_z\vec{k}\right)$$

$$= \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z} = 0$$

$$\frac{\partial^2 A_x}{\partial x^2} + \frac{\partial^2 A_x}{\partial y^2} + \frac{\partial^2 A_x}{\partial z^2} = -\mu_0 J_x$$

$$\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2} = -\frac{\rho}{\varepsilon_0}$$

$$\vec{E} = -\vec{\nabla} V$$

$$-\vec{E} = \vec{\nabla} V = \frac{\partial V}{\partial x}\vec{i} + \frac{\partial V}{\partial y}\vec{j} + \frac{\partial V}{\partial z}\vec{k}$$

$$\vec{\nabla}\cdot\vec{E} = \frac{\rho}{\varepsilon_0} \qquad \vec{\nabla} = \frac{\partial}{\partial x}\vec{i} + \frac{\partial}{\partial y}\vec{j} + \frac{\partial}{\partial z}\vec{k}$$