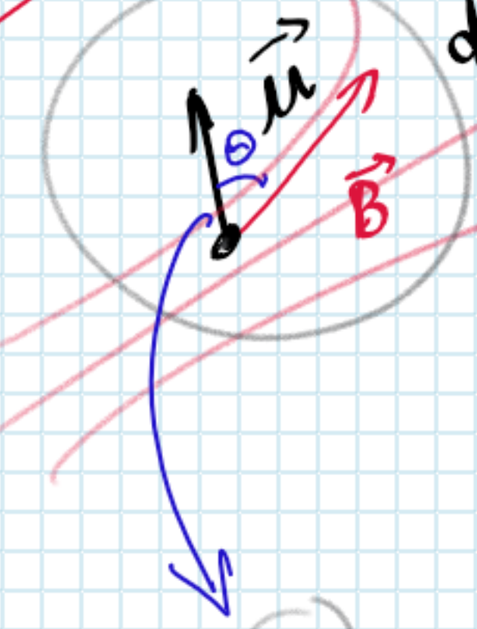
Relembrando



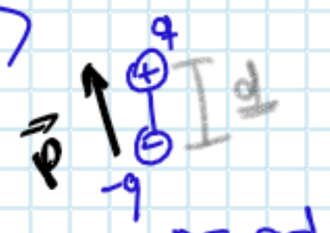
dipolo magnético

Física 3

$U_B \equiv$ energia potencial magnética

$\Rightarrow U_B = -\vec{\mu}\cdot\vec{B}$

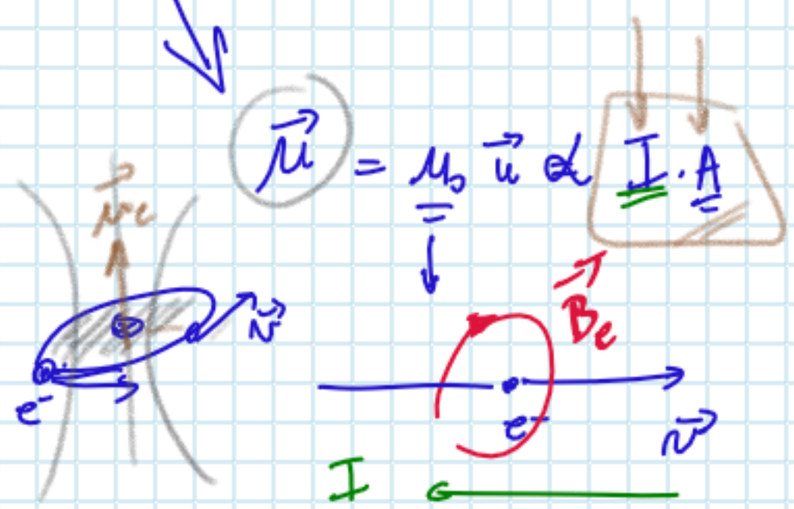
$U_E = -\vec{p}\cdot\vec{E}$



$p = qd$

Força $\Rightarrow \vec{F} = -\vec{\nabla} U(\vec{r})$ $\quad \vec{\nabla} = \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}\right)$

$F_x = -\frac{d}{dx} U(x,y,z) = -\frac{d}{dx} U(r)$



- **Spin**: $\hat{S}_i = \frac{\hbar}{2}\hat{\sigma}_i \longrightarrow S_i = \frac{\hbar}{2}\sigma_i \rightarrow$ (Matriz de Pauli)

$$S_x = \frac{\hbar}{2}\sigma_x = \frac{\hbar}{2}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

$$S_y = \frac{\hbar}{2}\sigma_y = \frac{\hbar}{2}\begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$$

$$S_z = \frac{\hbar}{2}\sigma_z = \frac{\hbar}{2}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

$|+\rangle_x = \alpha|\uparrow\rangle_x + \beta|\downarrow\rangle_x$

$$\begin{cases} \hat{S}_i|+\rangle_i = \hat{S}_i|\uparrow\rangle_i = \frac{\hbar}{2}|+\rangle_i \\ \hat{S}_i|-\rangle_i = \hat{S}_i|\downarrow\rangle_i = -\frac{\hbar}{2}|-\rangle_i \end{cases}$$

($|-\rangle_i$: base $\hat{i} = \{x, y, z\}$)

$$\hat{S}_z|+\rangle_{\hat{z}} = +\hbar/2|+\rangle$$

$$\hat{S}_z|-\rangle_{\hat{z}} = -\frac{\hbar}{2}|-\rangle$$

($|-\rangle_{\hat{z}}$: base $\hat{z}$; $|s, m\rangle \equiv |1/2, 1/2\rangle$)

Toda a álgebra dos op. de spins está expressa nas relações

$$[\hat{S}_i, \hat{S}_j] = i\hbar\,\epsilon_{ijk}\,S_k$$

Levi-Civita: $\epsilon_{ijk} = \begin{cases} \epsilon_{123} = 1 & \text{(cíclico)} \\ \epsilon_{213} = -1 & \text{(não cíclico)} \\ \epsilon_{113} = 0 & \text{(repetição)} \end{cases}$

$\hat{i} \to \hat{j} \to \hat{k} : \{1,2,3\} = \{x, y, z\}$ (permutações cíclicas)

Ex.: p/ $S = 1/2 = \begin{cases} m_S = -1/2 \\ m_S = 1/2 \end{cases}$ $(2S+1)$ elementos

Define-se:

$$\begin{cases} \hat{S}_+ = \frac{1}{2}(\hat{S}_x + \hat{S}_y) \\ \hat{S}_- = \frac{1}{2}(\hat{S}_x - \hat{S}_y) \end{cases}$$

$\Rightarrow$

- $S_\pm |s, m\rangle = \hbar\sqrt{s(s+1) - m(m\pm 1)}\;|s, m\pm 1\rangle$

(spin; $m = \{-s, (-s+1), \ldots (s-1), s\}$; $|s, m\rangle$: estado inicial na base Zeeman; $|s, m\pm 1\rangle$: estado final)

- $S^2|s, m\rangle = \hbar^2 s(s+1)|s, m\rangle$
- $S_z|s, m\rangle = \hbar m|s, m\rangle$

↑ Ações dos operadores

$$\vec{S} = (S_x, S_y, S_z)$$

$$\begin{cases} s = 0, \frac{1}{2}, 1, \frac{3}{2}, \ldots \\ m = -s, (-s+1), \ldots (s-1), s. \end{cases}$$

Energia: $\hat{H} = -\vec{M}\cdot\vec{B}$; $\vec{\mu} = \gamma\vec{S}$ $\Rightarrow$ $\hat{H} = -\gamma\vec{S}\cdot\vec{B}$

(μ_B; Magneton de Bohr $\leftarrow (\mu_B = e\hbar/2mc)$; γ: fator giromagnético $\gamma = -2\mu_B/\hbar$)