LEPTONI

e^-, e^+

μ^-, μ^+

τ^-, τ^+

$\nu_e, \bar{\nu}_e$

$\vdots$

ADRONI

carica frazionaria

- MESONI : $q\bar{q}$
- BARIONI : qqq

$(qqqq)$

$(qqqqq)$

$\frac{1}{3} \quad -\frac{1}{3}$

$\frac{2}{3} \quad -\frac{2}{3}$

ISOSPIN

$p \; n \qquad \underset{p}{\begin{pmatrix}1\\0\end{pmatrix}} \quad \underset{n}{\begin{pmatrix}0\\1\end{pmatrix}}$

$\pi^+ \pi^- \pi^0 \qquad \begin{pmatrix}1\\0\\0\end{pmatrix} \begin{pmatrix}0\\1\\0\end{pmatrix} \begin{pmatrix}0\\0\\1\end{pmatrix}$

$d = $ "pn"

$\nexists \; nn, \; pp$

$$p + p \to d + \pi^+$$
$$p + n \to d + \pi^0$$
$$n + n \to d + \pi^-$$

$$I_d = ?$$

$p = |1/2, 1/2\rangle \qquad I = 1/2 + 1/2$

$n = |1/2, -1/2\rangle \qquad I = |1/2 - 1/2|$

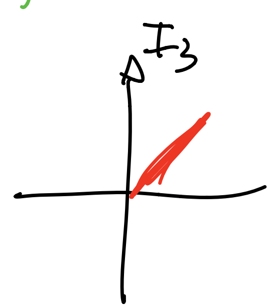
$$I = 1 \qquad \begin{cases} |1\ 1\rangle = |p\ p\rangle \\ |1\ 0\rangle = \frac{1}{\sqrt{2}}\left(|p n\rangle + |n p\rangle\right) \\ |1\ {-1}\rangle = |n\ n\rangle \end{cases}$$

$$I = 0 \qquad \frac{1}{\sqrt{2}}\left(|p n\rangle - |n\ p\rangle\right) = |0 0\rangle$$

I^2_{TOT}

I_3^{TOT}

$$\Rightarrow \quad I_d = 0 \qquad |0, 0\rangle$$
$$I^3_d = 0$$



$\Rightarrow \qquad I_{TOT} = 1 \quad$ è "lungo" $\sqrt{I(I+1)}$

$$V \propto \vec{I}^{(1)} \cdot \vec{I}^{(2)}$$

$$I_{TOT}^2 = \left(I^{(1)} + I^{(2)}\right)^2$$

termine fra

$I^{(1)} \cdot I^{(2)}$

Simmetria continua

$$U(\varepsilon)$$

SIMMETRIA DISCRETA

O operatore

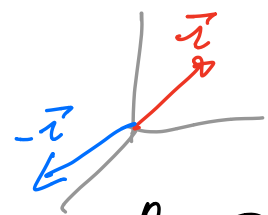
$$O \cdot O = 1$$

esempio : parità

$$P: \quad \vec{r} \xrightarrow{P} -\vec{r}$$

vettori (polari)

$$\vec{r} \to -\vec{r}$$



$$\theta \to \pi - \theta$$

$$\phi \to \pi + \phi$$

$$\vec{v} \to -\vec{v}$$

$$\vec{p} \to -\vec{p}$$

$$\vec{E}(\vec{r}) = \frac{1}{4\pi\varepsilon_0}\int \frac{\rho(\vec{r}\,')\, d^3\vec{r}\,'}{|\vec{r} - \vec{r}\,'|}$$

vettori assiali

$$\vec{L} = \vec{r} \times \vec{p} \qquad \vec{S}$$

$$\vec{B} = \frac{\mu_0}{4\pi}\int \frac{I\, d\vec{l} \times \Delta\vec{r}}{|\Delta\vec{r}|^3}$$

scalari

$$q,\ r^2,\ p^2,\ \frac{p^2}{2m},\ E,\ \vec{L}\cdot\vec{S}$$

pseudoscalari $\frac{\vec{P}\cdot\vec{S}}{|\vec{P}\cdot\vec{S}|}$ (ELICITÀ)

es idrogeno

$$\psi_{nlm} = \frac{u_{nl}}{r} \cdot Y_{lm}(\theta,\phi)$$

$$P\,Y_{lm}(\theta,\phi) = Y_{lm}(\pi-\theta, \pi+\phi)$$

$$= (-1)^l\, Y_{lm}(\theta,\phi)$$

$$P\,\psi_{nlm} = (-1)^l\,\psi_{nlm}$$

$$P^2 = 1$$

autovalori sono ± 1

ogni particella ha una PARITÀ INTRINSECA η

$$\psi(\vec{r}) \xrightarrow{P} \eta \cdot (-1)^{\ell} \psi(-\vec{r})$$

Con 2 particelle:

$$\eta_{12} = \eta_1 \cdot \eta_2 \cdot (-1)^{\ell}$$

- INT. FORTI CONSERVANO P
- INT. EM " "

$$\underset{-1}{\vec{\nabla}} \cdot \underset{-1}{\vec{E}} = \overset{+1}{\rho / \varepsilon_0}$$

$$\partial / \partial x \xrightarrow{P} \frac{\partial}{\partial(-x)} = -\partial / \partial x$$

$$\underset{-1}{\vec{\nabla}} \times \underset{-1}{\vec{E}} + \underset{+1}{\frac{\partial \vec{B}}{\partial t}} = 0$$

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

- $P(\gamma) \equiv -1$
- $P(\text{fermione}) = P(e, \mu, \tau, q, p, n \dots) \equiv 1$

$P(\text{antifermione}) = -1$

ES $P(\pi) = ?$

$$\pi^- + d \longrightarrow n + n$$

TARGET

1) π^- poca energia
2) "ATOMO MESICO"

- conosco $S_\pi = 0$
- $S_d = ?$

d ha $I = |0\ 0\rangle$ singoletto

$\rightarrow \Psi_d = \underbrace{\Psi_{ISOSPIN}}_{} \times \Psi_{SPIN} \times \Psi_{SPAZIO}$

se scambio $\underbrace{p \text{ e } n}_{\text{ANTISIMM}}$:

- Ψ_{SPIN}, Ψ_{SPAZIO} entrambe simm
- oppure entrambe antisimm

$\rightarrow$ gli spin di p e n saranno preferenzialmente allineati

$S_d = 1$ (SIMM)

$\Rightarrow L = 0$

$|i\rangle$: $S = 1$

$L = 0 \quad (= L_\pi \oplus L_d)$

$J = 1$

$|f\rangle: \quad J = 1$

$$P_i = (-1)^{L_i} \, P_\pi \cdot P_d$$

- $P_d = P_n \cdot P_p \cdot (-1)^{L_d}$
$= (+1)(+1)\,(-1)^0 = +1$

- $L_i = 0$ (a causa del fatto che formano un atomo MESICO)

$$P_i = (-1)^0 \cdot P_\pi \cdot (+1)$$
$$\equiv P_f = P_n \cdot P_n \cdot (-1)^{L_f}$$

$|f\rangle = |n\rangle|n\rangle$

$$\psi_f = \psi_{SPAZIO} \times \psi_{SPIN}$$

deve essere antisimm. sotto scambio $n \leftrightarrow n$

$S_f = ?$ $\quad \frac{1}{2} \otimes \frac{1}{2} = 0 \oplus 1$

se $S_f = 0$: SPIN ANTISIMM

$\rightarrow$ SPAZIO sarà SIMM

$l = 0, 2, 4 \dots$

$J_i = J_f = 1$

$\rightarrow$ deve essere $S_f = 1$

$\rightarrow$ SPIN SIMM

$l = 1$

$$P_f = P_n \cdot P_n \cdot (-1)^l$$

$$= -1$$

$$= P_i = P_\pi$$

CONIUGAZIONE DI CARICA

$C^2 = 1$

$$C|\pi^+\rangle = |\pi^-\rangle$$

$$C|e^-\rangle = |e^+\rangle$$

$$C|\gamma\rangle = -|\gamma\rangle$$

è un numero quantico moltiplicativo

$$\pi^0 \to \gamma + \gamma \qquad C(\pi^0) = +1 = (-1)\times(-1)$$

interazione EM!

$$\pi^0 \to \gamma + \gamma + \gamma \qquad +1 \neq (-1)^3$$

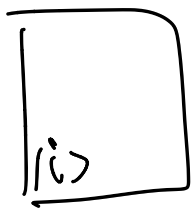
$\to$ è vero per int
- FORTE
- EM

INVERSIONE TEMPORALE

$$|i\rangle \to |f\rangle$$

$$\text{"T"}\downarrow$$

$$|f\rangle \to |i\rangle$$



$$\frac{dN_f}{dt} = N_i \cdot P(i\to f) - N_f \cdot P(f\to i)$$

$= 0$ se

$$\frac{N_i}{N_f} = \frac{P(f\to i)}{P(i\to f)}$$

$$P(i\to f) = 2\pi \left|\langle f|H|i\rangle\right|^2 \rho(E_i)$$

$$P(f\to i) = 2\pi \left|\langle i|H|f\rangle\right|^2 \rho(E_f)$$

se H commuta con T

$$\left|\langle i|H|f\rangle\right|^2 = \left|\langle f|H|i\rangle\right|^2$$

PRINCIPIO DEL BILANCIO DETTAGLIATO

$$\frac{P(i\to f)}{P(f\to i)} = \frac{\rho_i}{\rho_f}$$

Come scrivo T?

$$|\psi(t)\rangle \longrightarrow |\psi(-t)\rangle\ ?$$

$$|\psi(t)\rangle = e^{-i\frac{H}{\hbar}t}|\psi(0)\rangle$$

$$T|\psi(t)\rangle \equiv |\psi(-t)\rangle$$
$$= e^{i\frac{H}{\hbar}t}|\psi(0)\rangle$$

$$T|\psi(0)\rangle = |\psi(0)\rangle$$

$$T|\psi(-t)\rangle = T\, e^{i\frac{H}{\hbar}t}|\psi(0)\rangle$$
$$= e^{-\frac{i}{\hbar}Ht}|\psi(0)\rangle$$
$$= e^{-i/\hbar\, Ht}\cdot T|\psi(0)\rangle$$

$$T e^{i\frac{H}{\hbar}t} = e^{-\frac{i}{\hbar}Ht}\, T$$

se prendo t piccolo

$$T\, iH = -iHT$$

$$[T,H] \neq 0 ! \qquad \{T,H\} = TH + HT = 0$$

NON VA BENE!

SERVE

$$T: \quad \psi(t) \xrightarrow{T} \psi^*(-t)$$

fermione!

$$i\hbar \frac{\partial \psi(\vec{x},t)}{\partial t} = H \psi(\vec{x},t)$$

c.c. $$-i\hbar \frac{\partial \psi^*(\vec{x},t)}{\partial t} = H \psi^*(\vec{x},t)$$

$t \to -t$

$$-i\hbar \frac{\partial \psi^*(\vec{x},-t)}{\partial(-t)} = H \psi^*(\vec{x},-t)$$

$$= i\hbar \frac{\partial \psi^*(\vec{x},-t)}{\partial t}$$

è uguale ad applicare T all' eq. di Schroedinger

$$T \cdot (\text{SCHR.}) = T i\hbar \frac{\partial \psi(\vec{x},t)}{\partial t} =$$

$$= i\hbar \frac{\partial \psi^*(x,-t)}{\partial t} = TH\psi(\vec{x},t)$$

e se $[H, T] = 0$ (come nel caso di EM e STRONG)

$= H T \psi(\vec{x}, t)$

$= H \psi^*(\vec{x}, -t)$

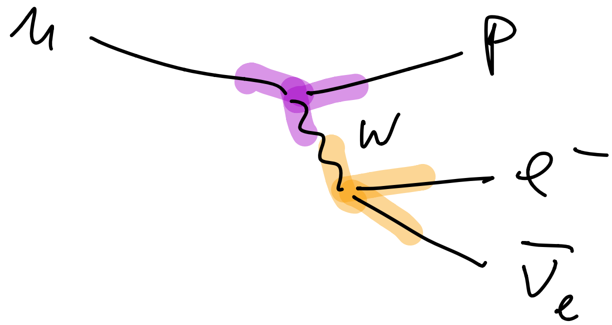
$$T : \quad \psi(\vec{x}, t) \rightarrow \psi^*(\vec{x}, -t)$$

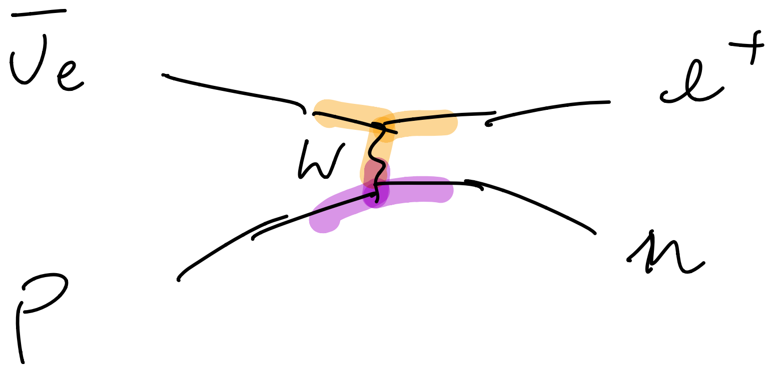
è un operatore ANTILINEARE

$$f(a\vec{x} + b\vec{y}) \neq a f(\vec{x}) + b f(y)$$

$$f(a\vec{x} + b\vec{y}) = a^* f(\vec{x}) + b^* f(\vec{y})$$

ES





SIMMETRIA DI CROSSING

se esiste $A + B \to C + D$

esisterà $A + \bar{C} \to \bar{B} + D$

se esiste $A + B \to C + D$

esisterà $C + D \to A + B$