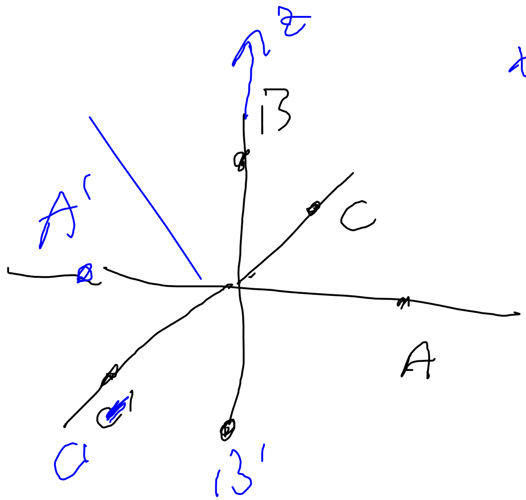
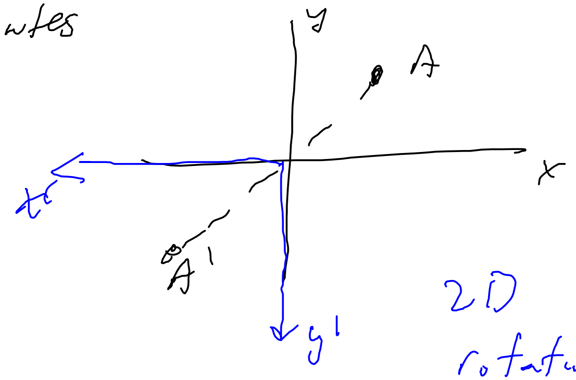
Symmetry

translations - space-time → momentum
rotations → Energy

inversion of coordinates

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





2D rotation = P

living creatures L ↔ R

select one type

T reversal $\left(\frac{d^2}{dt^2}\right)$

p, E

$S(\vec{r} \pm \vec{v}t)$

C particle - antiparticle
all q.n.'s reversal

(CPT) conserved for relativistic local theory

$l, B, S, c, b,$

(PTC)

$$\boxed{ds^2 = d\vec{r}^{\,2} - c^2 dt^2}$$

CPT → $m = \bar{m}$ $\tau = \bar{\tau}$ ⊄ CP

P	T
$\vec{r} \to -\vec{r}$	$\vec{r} \to \vec{r}$
$\vec{p} \to -\vec{p}$	$\vec{p} \to -\vec{p}$
$\vec{r}\times\vec{p} \to \vec{L}$	$\vec{L} \to -\vec{L}$
$\vec{v} \to -\vec{v}$	$\vec{v} \to \vec{v}$
$\vec{E} \to -\vec{E}$	$E \to \vec{E}$
$B \to B$	$B \to -\vec{B}$

Pseudovector

$\nabla \cdot E = 4\pi\rho$

$\nabla \times E + \frac{1}{c}\frac{\partial B}{\partial t} = 0$

QM

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

T $$-i\hbar \frac{\partial \psi(-t)}{\partial t} = H\psi(-t)$$

$\psi^*(-t)$ satisfies T reversed equ.

NOT $\psi(-t)$

S.E.

$$\psi(r, t+\tau) = \left[1 + \frac{\tau}{i\hbar}H\right]\psi(r,t) \quad \tau \to 0$$

$S\psi$ satisfies S.E.

$$S\psi = S\left[1 + \frac{\tau H}{i\hbar}\right]\psi$$

$$S\psi = \left(1 + \frac{\tau H}{i\hbar}\right)S\psi$$

$SH = HS$

$[H, S] = 0$

$H|\psi_i\rangle = E_i|\psi_i\rangle$

$\langle\psi_i|HS - SH|\psi_j\rangle = 0$

$(E_i - E_j)\langle\psi_i|S|\psi_j\rangle = 0$

either $(E_i = E_j)$ or $\langle\psi_i|S|\psi_j\rangle = 0$

$S|\psi_j\rangle = c_j|\psi_j\rangle$

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C, P, T $\quad C_s^2 = 1 \quad C_s = \pm 1$

1949 - Dirac

$\nabla \cdot E = \rho_e \qquad \nabla \cdot B = \cancel{0}\ \rho_m$

$(\vec{E} \times \vec{B})$

$\nabla \times B - \frac{1}{c}\frac{\partial E}{\partial t} = \vec{J}_e \qquad \nabla \times E + \frac{1}{c}\frac{\partial B}{\partial t} = \cancel{0} \to \vec{J}_m$

$\vec{r} \times (\vec{E} \times \vec{B})$

P, T

$\rho_m \to -\rho_m \qquad \vec{J}_m \to \vec{J}_m$

$\begin{pmatrix} PM \\ TM \end{pmatrix}$

Search for Symmetry violation

$\hat{O}$

$$S\hat{O} = -\hat{O}S \Rightarrow \hat{O} = -S^{-1}\hat{O}S$$

$(\vec{\sigma}\cdot\vec{v})$

$(\vec{\sigma}\cdot\vec{\jmath}\times\vec{v})$

$$\langle\psi_i|\hat{O}|\psi_i\rangle \qquad S|\psi_i\rangle = c_s|\psi_i\rangle$$

$$\langle\psi_i|S^+\hat{O}S|\psi_i\rangle$$

$$S^+ = S^{-1}$$

$$= -\langle\psi_i|\hat{O}|\psi_i\rangle = 0$$

$$\langle|\hat{\vec{\jmath}}\cdot\vec{v}|\rangle \neq 0$$

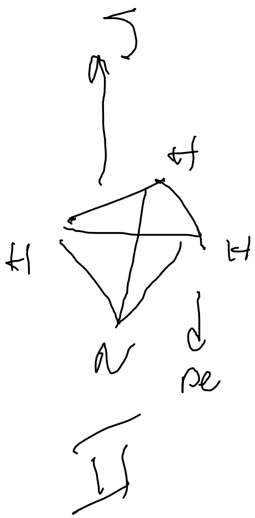
$$H_e = -\vec{p}_e\cdot\vec{E} \qquad p_e \xrightarrow{P} -p_e$$

$\langle|p\cdot\vec{E}|\rangle = 0$ parity eigenstate

$$|\psi\rangle = a|\psi_+\rangle + b|\psi_-\rangle \qquad P|\psi_\pm\rangle = \pm|\psi_\pm\rangle$$

$$\langle\psi_+|p\cdot\vec{E}|\psi_-\rangle \neq 0$$

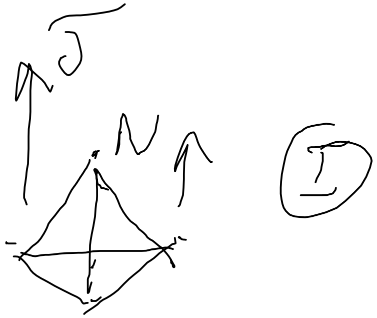
molecule NH_3

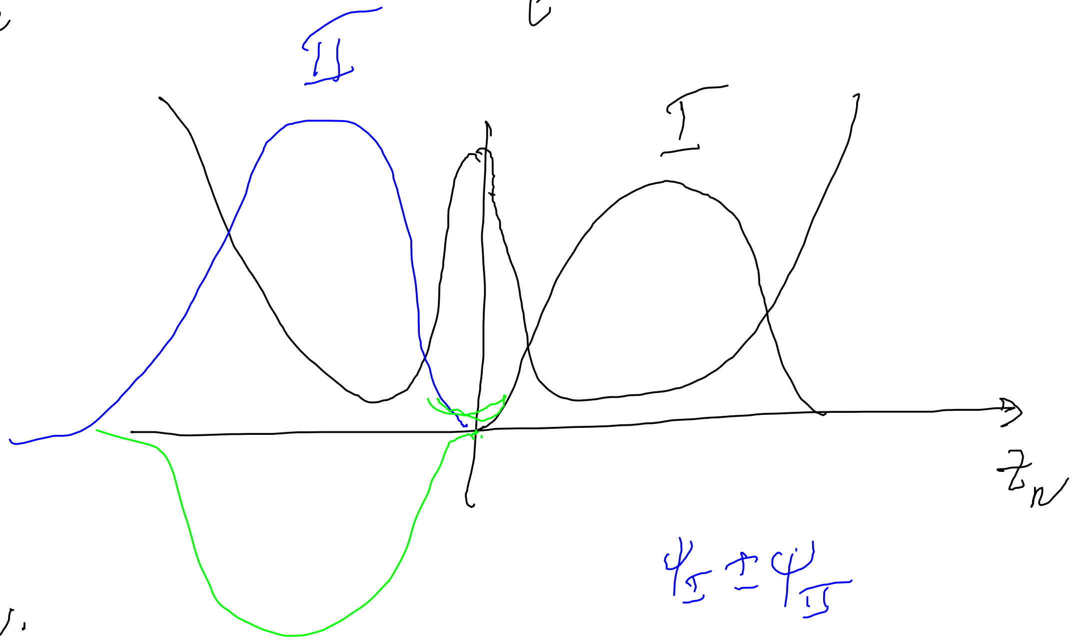


$\vec{E}$

$\vec{p} \to$

$\downarrow \vec{E}$





$\psi_{I} \pm \psi_{II}$

$\Delta = \hbar\omega$.
freq.

$$E = \sqrt{\Delta^2 + \underline{\underline{(pE)^2}}} \to (pE)$$

neutron – we see no degeneracy

1950 Ramsey + Purcell $\Rightarrow$ experiment

Lee + Yang

$\tau^+ \to 2\pi^+ + \pi^-$

$\theta^+ \to \pi^+ + \pi^0$

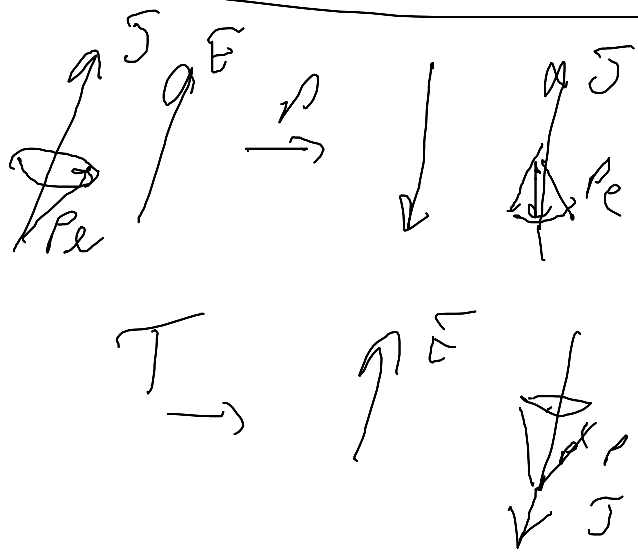
m, τ

$(\vec{I} \cdot \vec{p})$

Landau (CP)

$H = -\vec{p}_e \cdot \vec{E}$

$= -\mu_e(\vec{\sigma} \cdot \vec{E})$



CP conserved. CPT

T conserved

edm $= 0$

τ, θ

$K^\pm$

$CP \, |K^0\rangle = -|\bar{K}^0\rangle$

↓ Weak interaction conserve CP

$\frac{1}{\sqrt{2}}\left(|K_0\rangle - |\bar{K}_0\rangle\right) = K_S$

$+ \qquad = K_L$

$CP|K_S\rangle = +|K_S\rangle$

$CP|K_L\rangle = -|K_L\rangle$