② statistics

[sociology of particles, not psychology]

all particles obey either
1) Fermi-Dirac statistics (fermions)
2) Bose-Einstein statistics (bosons)

[GS.9, p 175]

• Let $P(\vec{r}_1, \vec{r}_2)$ = probability (density) of finding particle 1 at position $\vec{r}_1$ and " 2 " " $\vec{r}_2$

• If the particles are identical, then $P(\vec{r}_1, \vec{r}_2) = P(\vec{r}_2, \vec{r}_1)$

• In QM, $P(\vec{r}_1, \vec{r}_2) = |\psi(\vec{r}_1, \vec{r}_2)|^2$ where

$\psi(\vec{r}_1, \vec{r}_2)$ is the probability amplitude.

• For identical particles, $\exists$ two possibilities:

$$\begin{cases} \psi(\vec{r}_1, \vec{r}_2) = \psi(\vec{r}_2, \vec{r}_1) & \text{symmetric under exchange} \\ \psi(\vec{r}_1, \vec{r}_2) = -\psi(\vec{r}_2, \vec{r}_1) & \text{antisymmetric " "} \end{cases}$$

• Each type of particle obeys one or the other of them.

If symmetric, $\Rightarrow$ boson (eg γ, & force carriers in general)

If antisymmetric $\Rightarrow$ fermion (eg quarks & leptons; matter particles)

For fermions, $\psi(\vec{r}, \vec{r}) = 0 \Rightarrow P(\vec{r}, \vec{r}) = 0$; no prob. of finding two identical fermions at the same place (Pauli exclusion)
$\rightarrow$ stability of matter

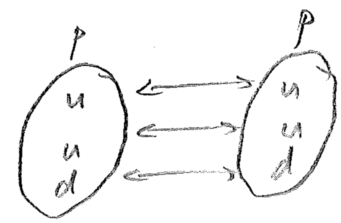
Bosons, on the other hand, like to be together
$\rightarrow$ lasers

statistics of composite particles

Any # of bosons is a boson

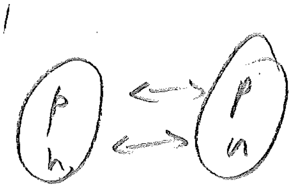
An even/odd # of fermions is a boson/fermion

e.g. $p = uud$



3 exchanges $\Rightarrow (-1)^3 = -1 \Rightarrow$ fermion

deuteron $^2_1H = pn$ $\quad ^2_1H$



$\Rightarrow$ boson

$(-1)^2 = 1$

$^4_2He = ppnn$ boson (superfluid; Bose Einstein condensate)