

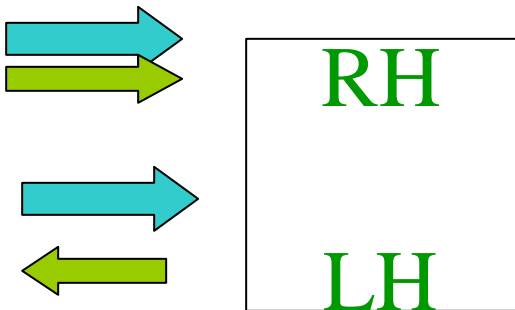
# Parity Violation in Beta Decays

- The Parity operator is the mirror image and is NOT conserved in Weak decays (is conserved in EM and strong)

$$P(x, y, z) \rightarrow (-x, -y, -z)$$

$$P(r, \mathbf{q}, \mathbf{f}) \rightarrow (r, \mathbf{p} - \mathbf{q}, \mathbf{f} + \mathbf{p})$$

- non-conservation is on the lepton side, not the nuclear wave function side
- spin 1/2 electrons and neutrinos are (nominally) either right-handed (spin and momentum in same direction) or left-handed (opposite)
- Parity changes LH to RH



$$P(\vec{p}) = -\vec{p}$$

$$P(\vec{L} = \vec{r} \times \vec{p}) = \vec{L}$$

# “Handedness” of Neutrinos

- “handedness” is call chirality. If the mass of a neutrino = 0 then:
- all neutrinos are left-handed  
all antineutrinos are right-handed
- Parity is maximally violated
- As the mass of an electron is  $> 0$  can have both LH and RH. But RH is suppressed for large energy (as electron speed approaches  $c$ )
- fraction RH vs LH can be determined by solving the Dirac equation which naturally incorporates spin

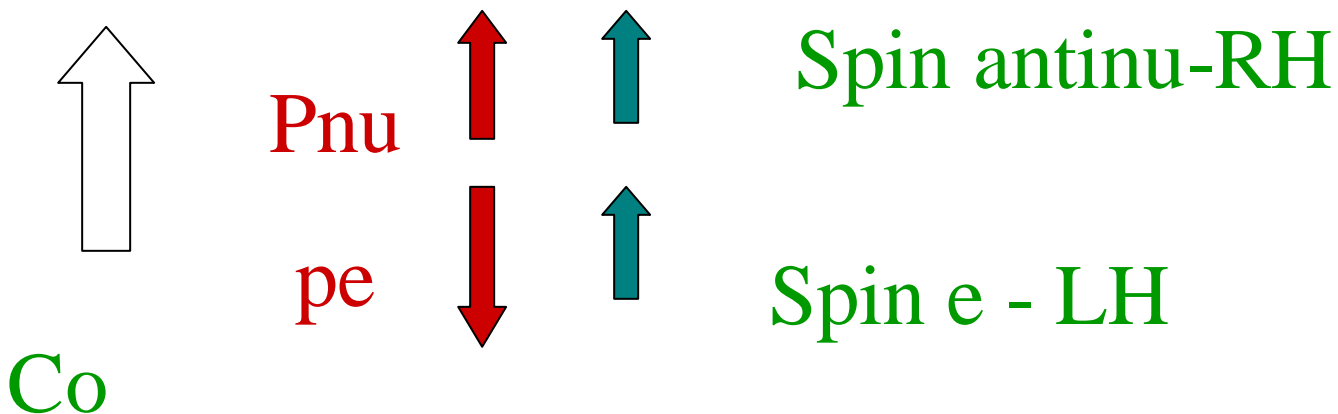
# Polarized Beta Decays

- Some nuclei have non-zero spin and can be polarized by placing in a magnetic field
- magnetic moments of nuclei are small (1/M factor) and so need low temperature to have a high polarization (see Eq 14-4 and 14-5)



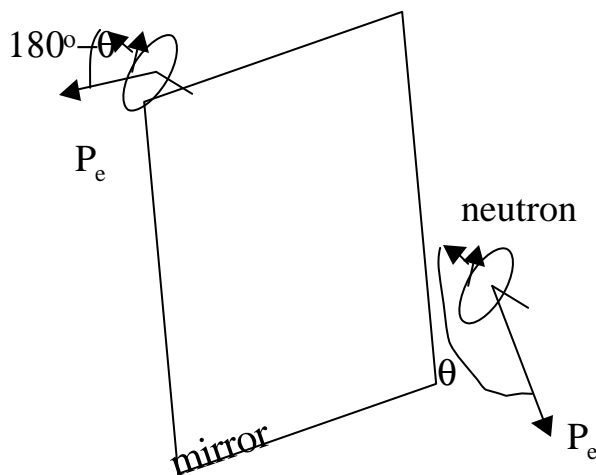
$$i = 5 \quad i = 4 \quad s = \frac{1}{2}, \frac{1}{2}$$

- Gamow-Teller transition with  $S(e-\nu) = 1$
- if Co polarized, look at angular distribution of electrons. Find preferential hemisphere (down)



# Discovery of Parity Violation in Beta Decay by C.S. Wu et al.

- Test parity conservation by observing a dependence of a decay rate (or cross section) on a term that changes sign under the parity operation. If decay rate or cross section changes under parity operation, then the parity is not conserved.
- Parity reverses momenta and positions but not angular momenta (or spins). Spin is an axial vector and does not change sign under parity operation.



Beta decay of a neutron in a real and mirror worlds:

If parity is conserved, then the probability of electron emission at  $\theta$  is equal to that at  $180^\circ - \theta$ .

Selected orientation of neutron spins - polarisation.

# Wu's experiment

- Beta-decay of  $^{60}\text{Co}$  to  $^{60}\text{Ni}^*$ . The excited  $^{60}\text{Ni}^*$  decays to the ground state through two successive  $\gamma$  emissions.
- Nuclei polarised through spin alignment in a large magnetic field at  $0.01^\circ\text{K}$ . At low temperature thermal motion does not destroy the alignment. Polarisation was transferred from  $^{60}\text{Co}$  to  $^{60}\text{Ni}$  nuclei. Degree of polarisation was measured through the anisotropy of gamma-rays.
- Beta particles from  $^{60}\text{Co}$  decay were detected by a thin anthracene crystal (scintillator) placed above the  $^{60}\text{Co}$  source. Scintillations were transmitted to the photomultiplier tube (PMT) on top of the cryostat.

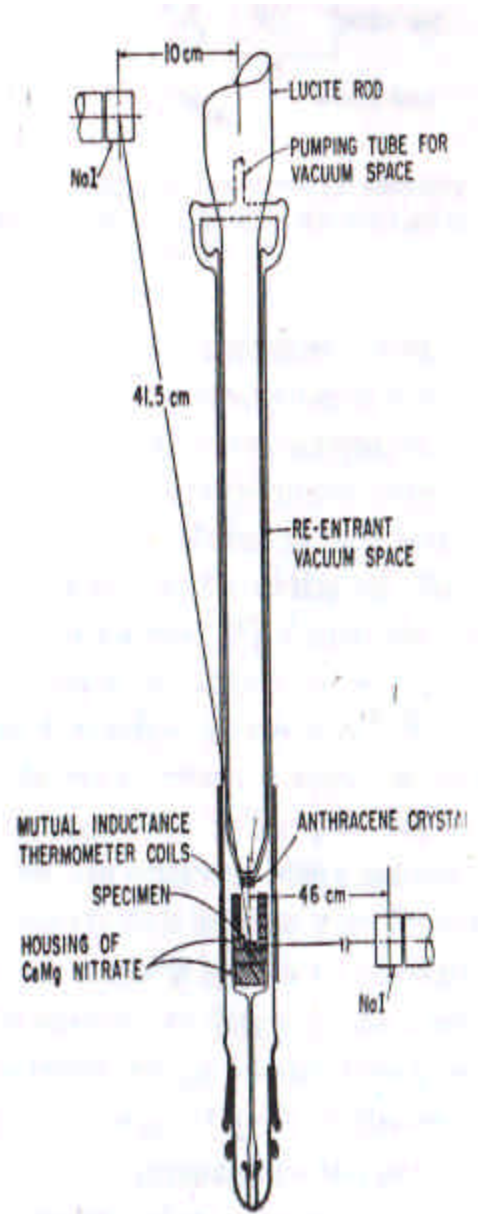


FIG. 1. Schematic drawing of the lower part of the cryostat.

# Wu's results

- Graphs: top and middle - gamma anisotropy (difference in counting rate between two NaI crystals) - control of polarisation; bottom -  $\beta$  asymmetry - counting rate in the anthracene crystal relative to the rate without polarisation (after the set up was warmed up) for two orientations of magnetic field.
- Similar behaviour of gamma anisotropy and beta asymmetry.
- Rate was different for the two magnetic field orientations.
- Asymmetry disappeared when the crystal was warmed up (the magnetic field was still present): connection of beta asymmetry with spin orientation (not with magnetic field).
- Beta asymmetry - Parity not conserved

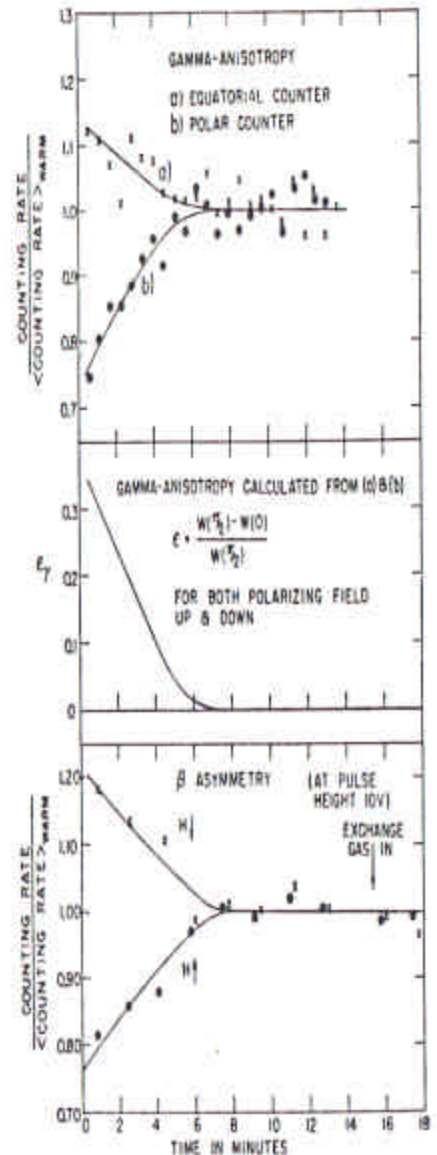


FIG. 2. Gamma anisotropy and beta asymmetry for polarizing field pointing up and pointing down.