Experimental Test of Parity Conservation in Beta Decay

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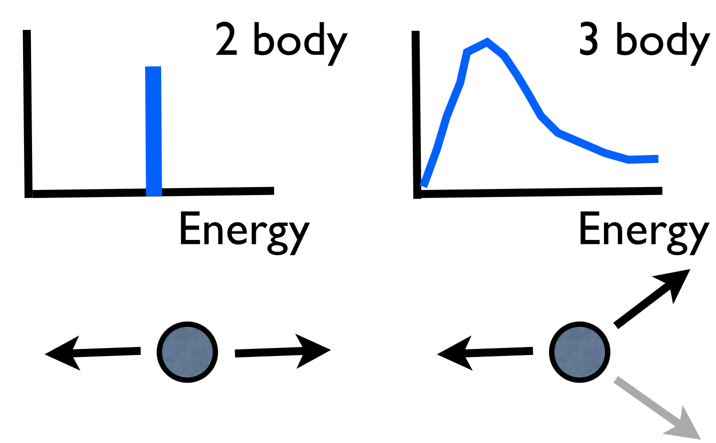
Introduction

- What was known at the time
- Concept of Parity
- The idea to test parity conservation in beta decay
- Important experimental issues
- The experiment, results and consequences

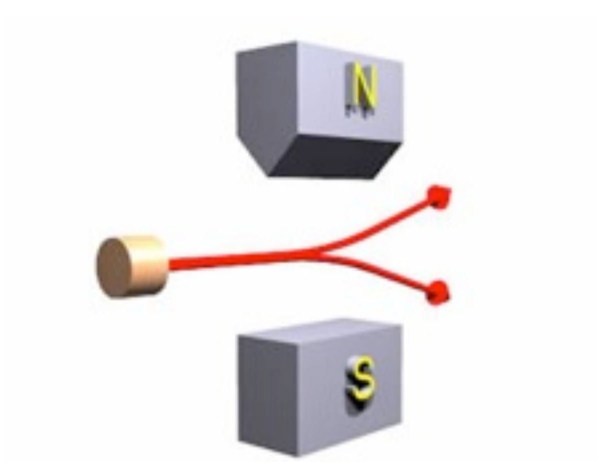
What was known at the time

$$(i\gamma\cdot\partial - m)\psi = 0$$

Continuous β spectrum:
Chadwick 1914, Ellis 1927
Neutrino proposed by Pauli 1930

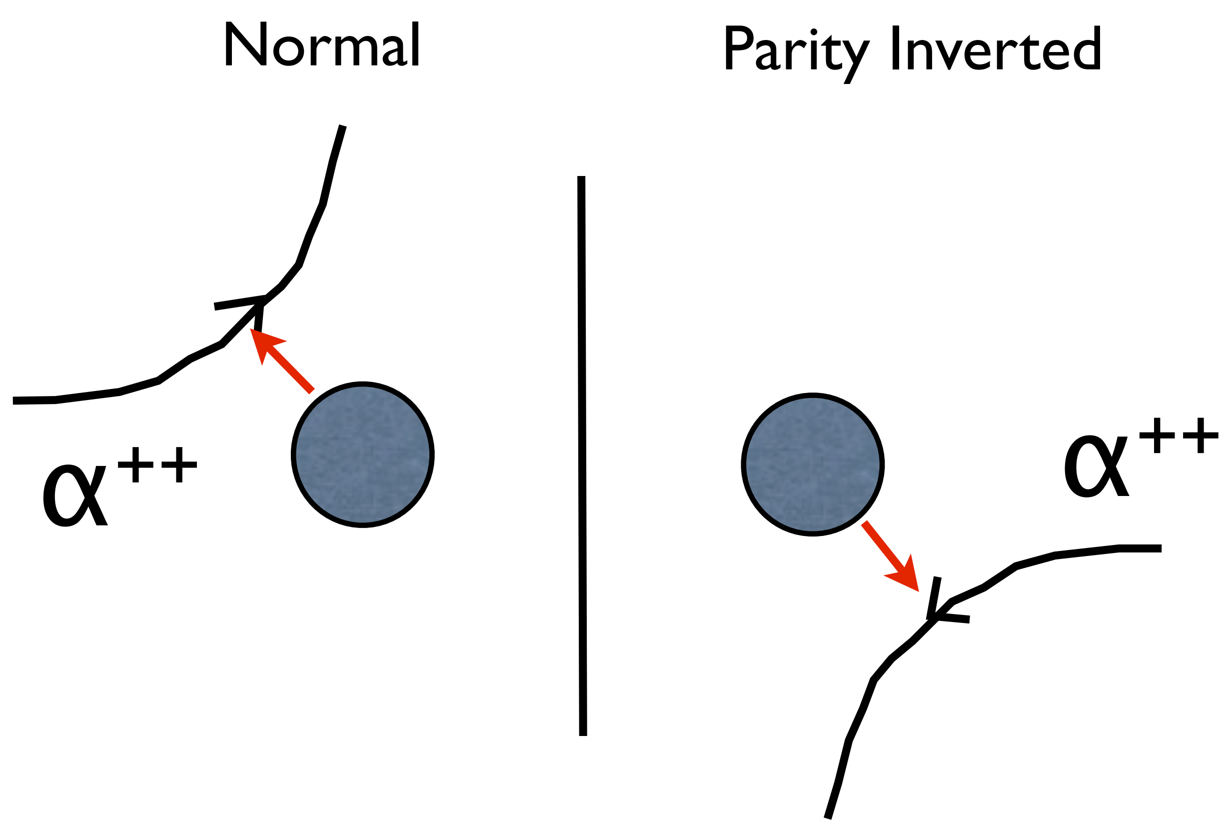


- Beta decay: $n \rightarrow p^{+} + e^{-} + ?$
- Spin (Stern-Gerlac 1922)
- Dirac equation 1928
- Fermi theory of beta decay (1934; 3 body; no W)
- Symmetry was important: C, P, T
- $\bar{\nu}$ observation July 1956 (not yet) Cowan et. al.

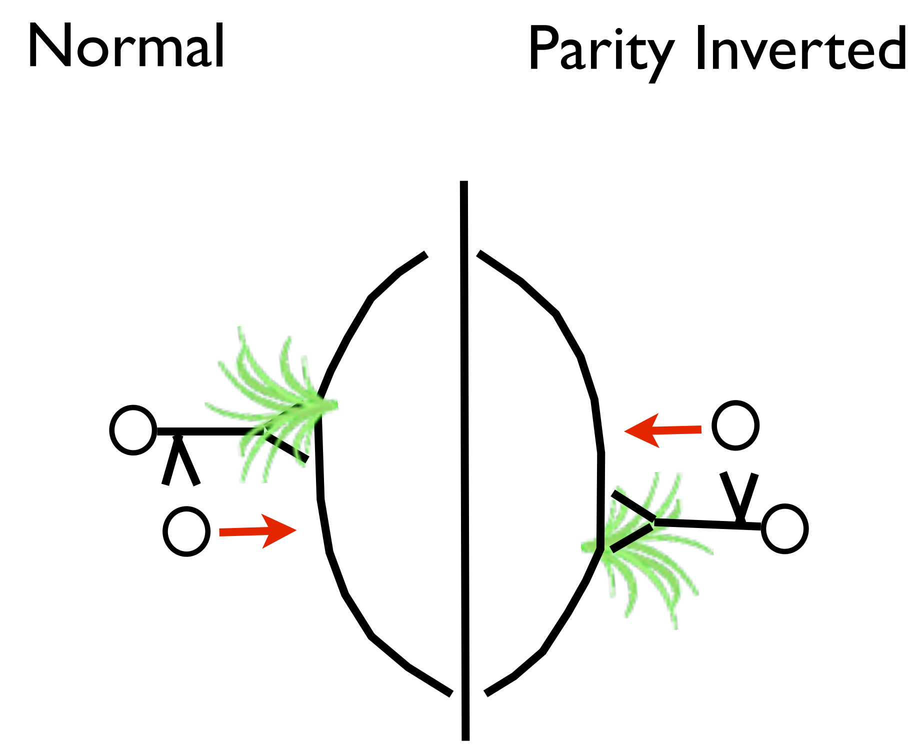


Parity

- $\underline{r} \rightarrow -\underline{r}$ (vector); **not** the same as rotation.



Electrostatics

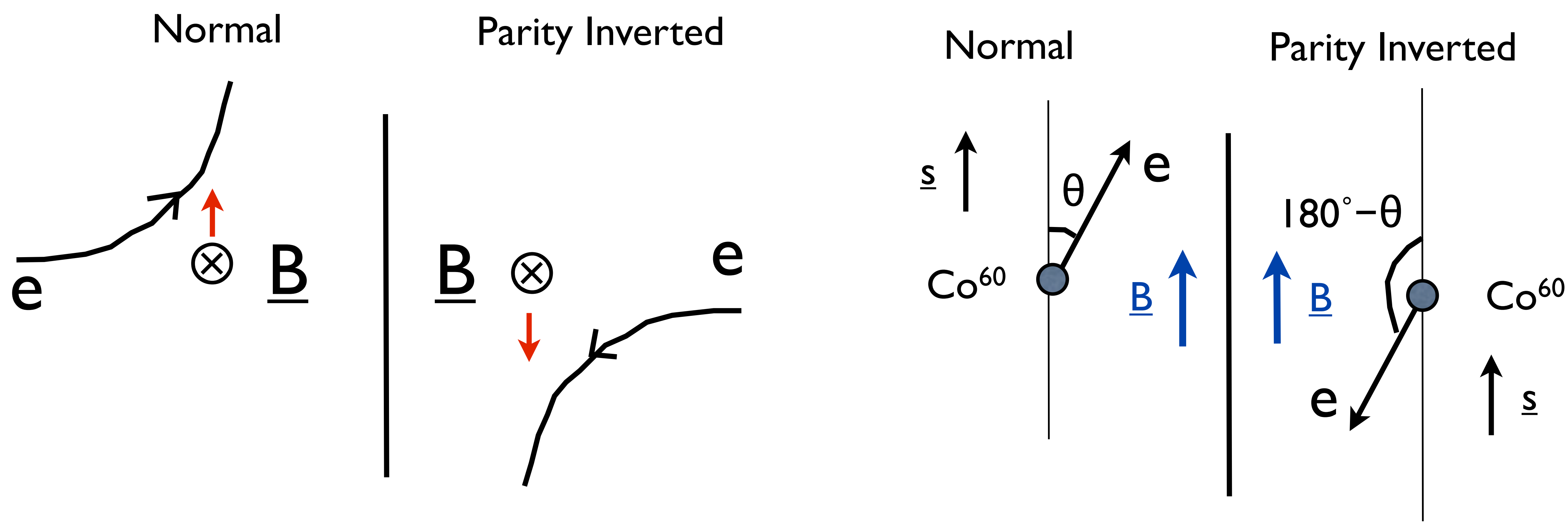


Gravity

Same behaviour in normal and parity inverted situations ⇒ parity is conserved in electrostatic and gravitational interactions.

Is parity conserved in β decay?

- $\underline{B} \rightarrow \underline{B}$ (axial vector) unchanged.



EM

β Decay

Parity is conserved in EM. Can compare the asymmetry of the θ and 180°−θ distributions to test if parity is conserved in β decay.

Lee Yang Paper

Examine the possibility of parity violation in the weak interaction and suggest possible experimental tests.

This is identical to the method employed in this paper.

be formed out of the measured quantities.

POSSIBLE EXPERIMENTAL TESTS OF PARITY CONSERVATION IN β DECAYS

The above discussion also suggests the kind of experiments that could detect the possible interference between C and C' and consequently could establish whether parity conservation is violated in β decay. A relatively simple possibility is to measure the angular distribution of the electrons coming from β decays of oriented nuclei. If θ is the angle between the orientation of the parent nucleus and the momentum of the electron, an asymmetry of distribution between θ and $180°-\theta$ constitutes an unequivocal proof that parity is not conserved in β decay.

To be more specific, let us consider the allowed β transition of any oriented nucleus, say Co^{60}. The angular distribution of the β radiation is of the form (see Appendix):

$$I(\theta)d\theta = (\text{constant})(1+\alpha\cos\theta)\sin\theta d\theta, \qquad (2)$$

where α is proportional to the interference term CC'. If $\alpha \neq 0$, one would then have a positive proof of parity nonconservation in β decay. The quantity α can be obtained by measuring the fractional asymmetry between $\theta < 90°$ and $\theta > 90°$; i.e.,

$$\alpha = 2\left[\int_0^{\pi/2} I(\theta)d\theta - \int_{\pi/2}^{\pi} I(\theta)d\theta\right] \Big/ \int_0^{\pi} I(\theta)d\theta.$$

It is noteworthy that in this case the presence of the magnetic field used for orienting the nuclei would automatically cause a spatial separation between the electrons emitted with $\theta < 90°$ and those with $\theta > 90°$. Thus, this experiment may prove to be quite feasible.

It appears at first sight that in the study of γ-radia-

APPENDIX

If parity is not conserved in β decay, the most general form of Hamiltonian can be written as

$$\begin{aligned}
H_{\text{int}} = {} & (\psi_p^\dagger\gamma_4\psi_n)(C_S\psi_e^\dagger\gamma_4\psi_\nu + C_S'\psi_e^\dagger\gamma_4\gamma_5\psi_\nu) \\
& + (\psi_p^\dagger\gamma_4\gamma_\mu\psi_n)(C_V\psi_e^\dagger\gamma_4\gamma_\mu\psi_\nu + C_V'\psi_e^\dagger\gamma_4\gamma_\mu\gamma_5\psi_\nu) \\
& + \tfrac{1}{2}(\psi_p^\dagger\gamma_4\sigma_{\lambda\mu}\psi_n)(C_T\psi_e^\dagger\gamma_4\sigma_{\lambda\mu}\psi_\nu \\
& + C_T'\psi_e^\dagger\gamma_4\sigma_{\lambda\mu}\gamma_5\psi_\nu) + (\psi_p^\dagger\gamma_4\gamma_\mu\gamma_5\psi_n) \\
& \times(-C_A\psi_e^\dagger\gamma_4\gamma_\mu\gamma_5\psi_\nu - C_A'\psi_e^\dagger\gamma_4\gamma_\mu\psi_\nu) \\
& + (\psi_p^\dagger\gamma_4\gamma_5\psi_n)(C_P\psi_e^\dagger\gamma_4\gamma_5\psi_\nu + C_P'\psi_e^\dagger\gamma_4\psi_\nu), \qquad (A.1)
\end{aligned}$$

where $\sigma_{\lambda\mu} = -\frac{1}{2}i(\gamma_\lambda\gamma_\mu - \gamma_\mu\gamma_\lambda)$ and $\gamma_5 = \gamma_1\gamma_2\gamma_3\gamma_4$. The ten constants C and C' are all real if time-reversal

Important Problems

- Radioactive nuclei must be in a thin surface layer and must be polarized.
- It must be kept cold.
- β counter must be placed inside magnetic field.

The Experiment

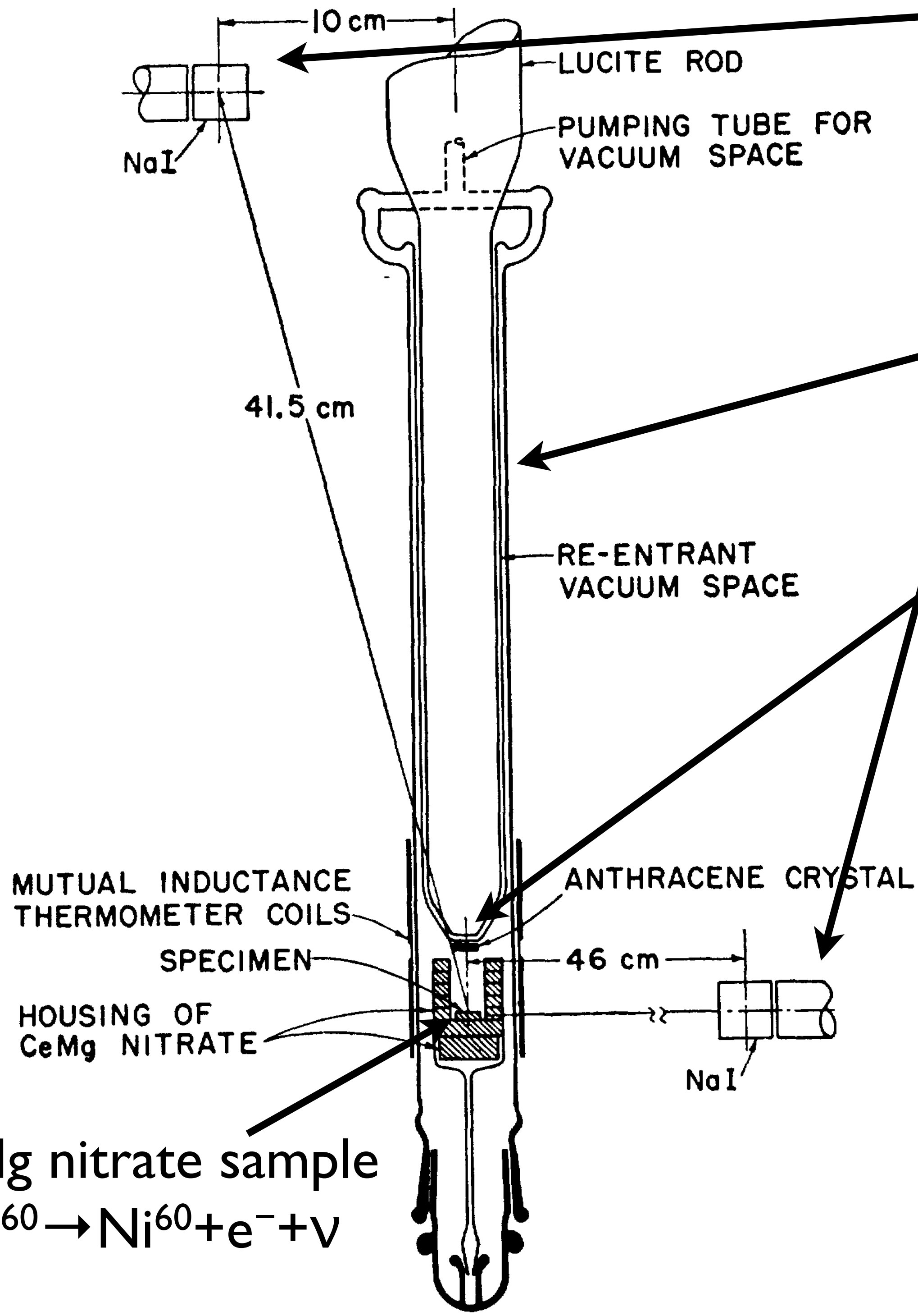


FIG. 1. Schematic drawing of the lower part of the cryostat.

γ counters (NaI) polar and equatorial to check the polarization of the Co^{60}

Cryostat to keep cold to maintain the polarization and vacuum to prevent interactions with air

Anthracene crystal to detect β particles emits light detected by photomultiplier at end of lucite rod.

CoMg nitrate sample
$Co^{60} \rightarrow Ni^{60} + e^{-} + \nu$

Reverse direction of B-field and measure asymmetry in β rate to test parity conservation in β decay. Measure γ anisotropy to confirm the polarization.

Solenoid raised over lower part of cryostat to create B-field to polarize Co^{60}

The Results

Why?

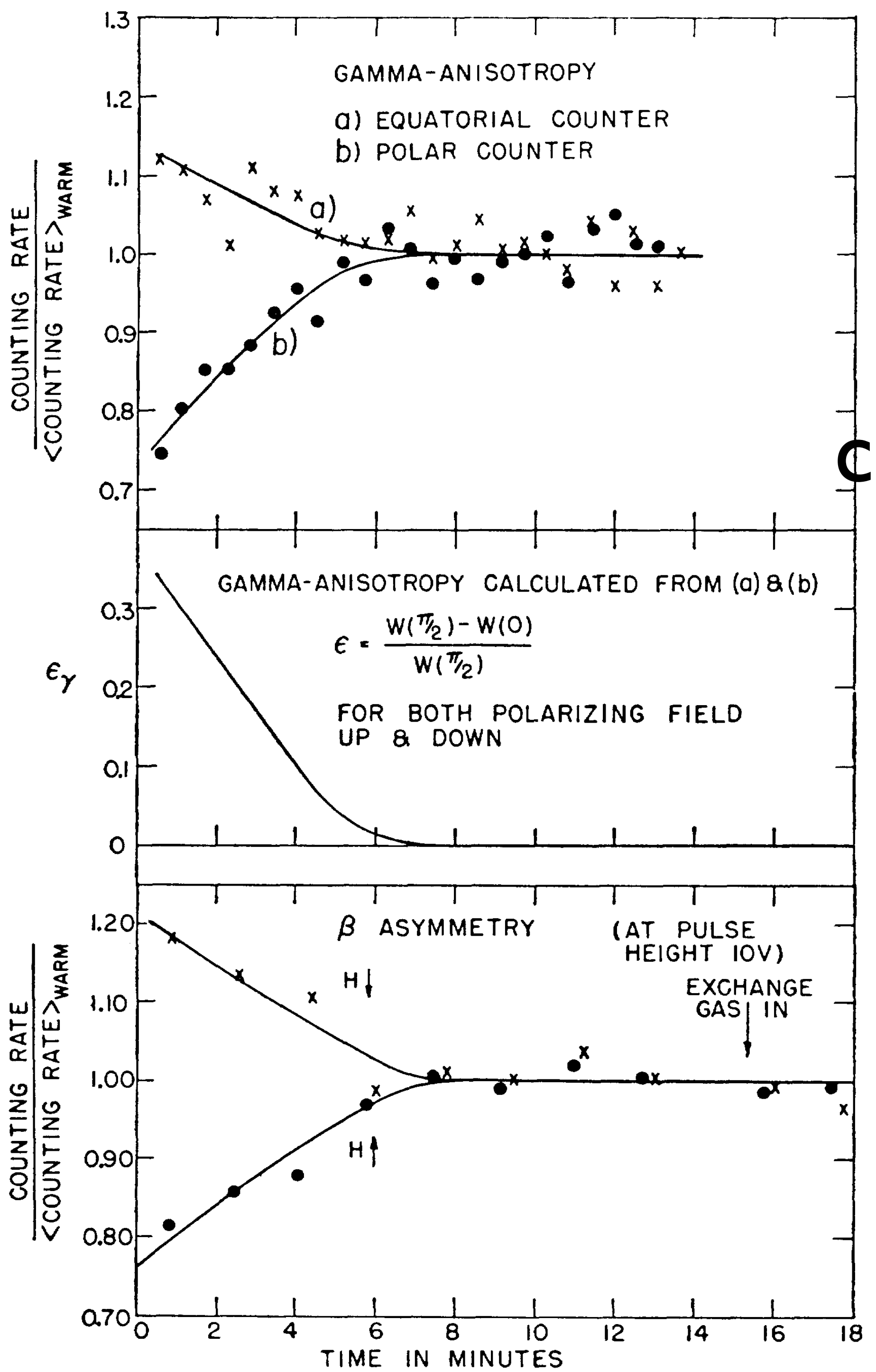


FIG. 2. Gamma anisotropy and beta asymmetry for polarizing field pointing up and pointing down.

After 6 minutes the system warms up and the sample is no longer polarized.

The disappearance of β asymmetry corresponds well with that of γ anisotropy.

$$\beta_{asym} = \frac{R(\uparrow) - R(\downarrow)}{R(\uparrow) + R(\downarrow)}$$

0.4

Sign of asymmetry is negative i.e. β emission in opposite direction to nuclear spin is favoured.

Sign of C and C′ (parity conserving and non-parity conserving components) must be opposite. If maximal, V−A.

The Asymmetry

- Although they do not measure the asymmetry they do show that it is large.
- Incomplete polarization (measured by γ isotropy) dilutes the asymmetry by factor ~ 0.6.
- Asymmetry ~ 0.4/0.6 ~ 0.7 (lower limit - other effects tend to dilute asymmetry)

Physics Consequences

- β decay of Co^{60} involves $\Delta P = 0, \Delta S = 1 \Rightarrow$ only Gamov-Teller interaction.
- Hamiltonian terms
- Parity violated $\Rightarrow$ Charge conjugation also violated.

Conclusion

- This is a beautiful experiment because of its simplicity, yet profound consequences.