Helicity of Neutrinos

ニュートリノのヘリシティ

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Contents

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1. Introduction

History of neutrino

1903 Rutherford : Discovery of α-ray , β-ray , γ-ray

1904 Chadwick : Discovery of continuous spectrum of β-ray

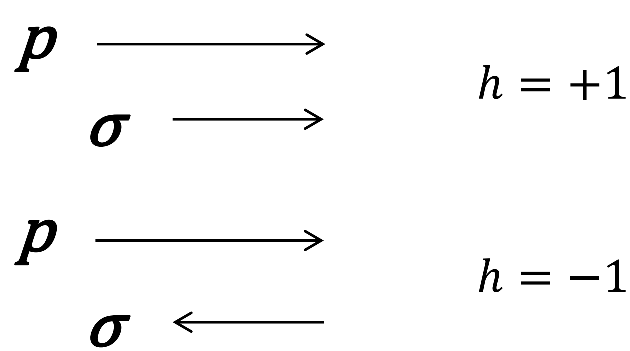
1931 Pauli : Neutrino hypothesis

1954 Reines : Detection of neutrino

1956 Yang, Lee : Parity violation in weak interaction

Helicity is defined as

$$h = \frac{\boldsymbol{\sigma} \cdot \boldsymbol{p}}{|\boldsymbol{\sigma}| \cdot |\boldsymbol{p}|}$$

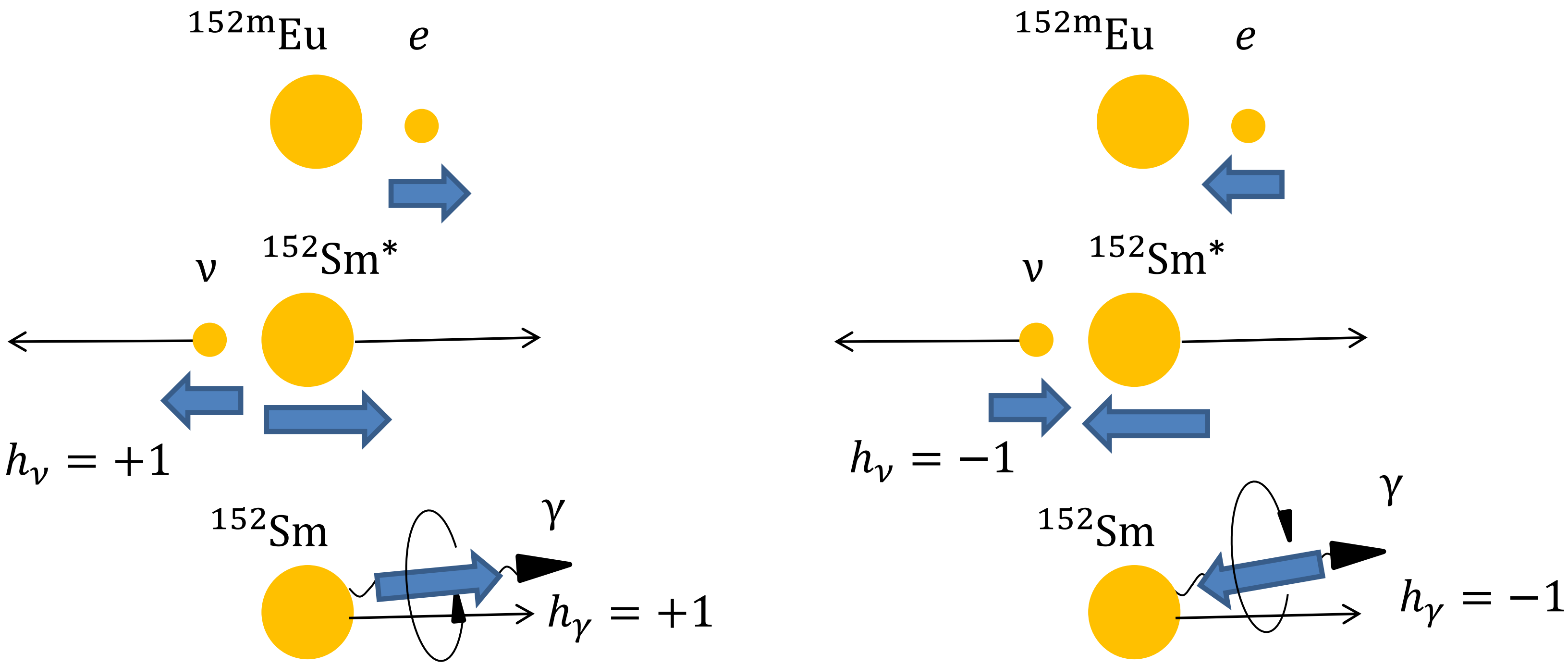


In this experiment, the helicity of neutrino was measured.

2. Principle of experiment

$$^{152m}\mathrm{Eu} + \mathrm{e}^- \rightarrow {}^{152}\mathrm{Sm}^* + \nu$$

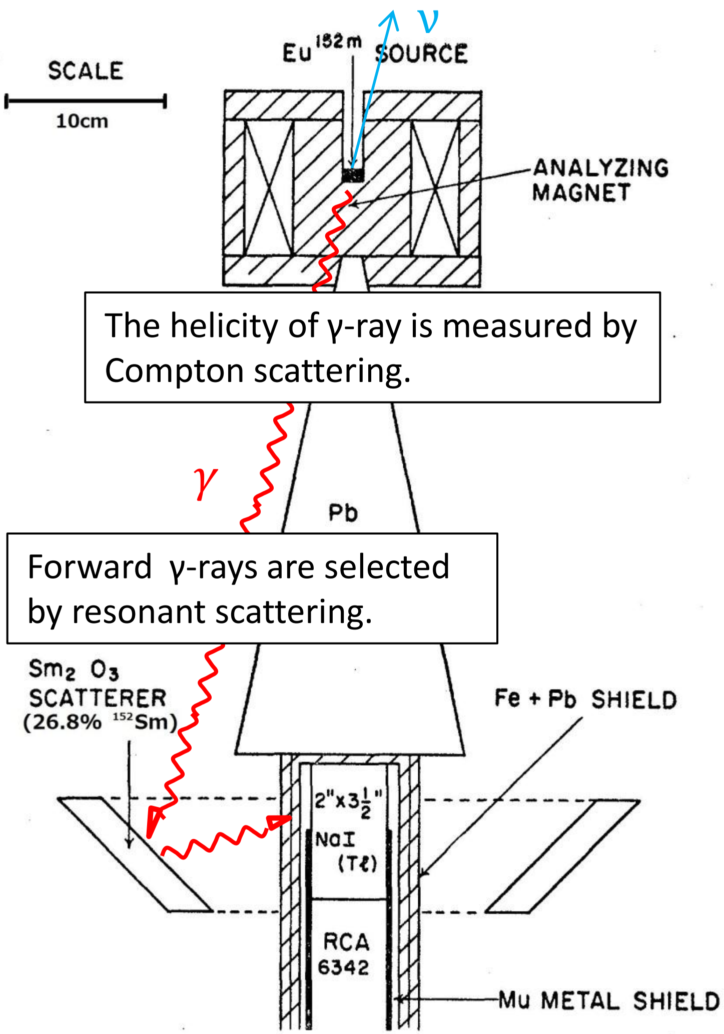
$$\hookrightarrow {}^{152}\mathrm{Sm} + \gamma$$



If $h_\gamma = +1, h_\nu = +1$

If $h_\gamma = -1, h_\nu = -1$

3. Experimental method



- ^{152m}Eu, the source, was produced in the Brookhaven reactor.

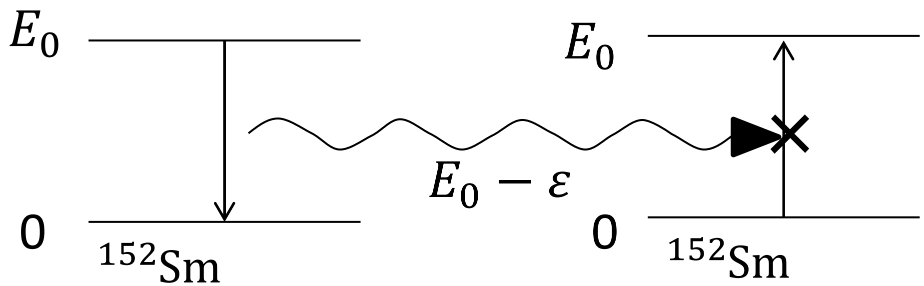
- Electromagnet was alternately magnetized in the up or down direction every 3 minutes.

- 9 runs with length from 3 to 9 hours were carried out.

I will explain about resonant scattering and measurement of γ-ray helicity with Compton polarimeter.

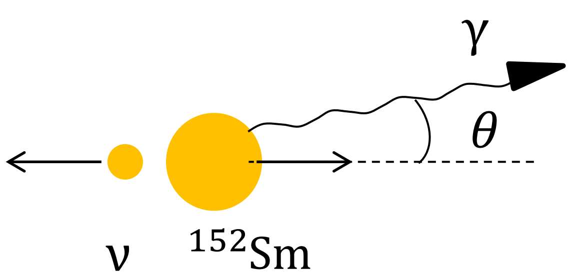
Resonant scattering of γ-rays

In order to select forward γ-ray, resonant scattering was used.
(共鳴散乱)



ε : recoil energy

$$\varepsilon = \frac{{E_0}^2}{2Mc^2}$$



Energy of γ-ray

$$E_\gamma = E_0 - \underbrace{\frac{{E_0}^2}{2Mc^2}}_{\varepsilon} + \underbrace{\frac{E_0 E_\nu}{Mc^2}\cos\theta}_{\text{Doppler shift}}$$

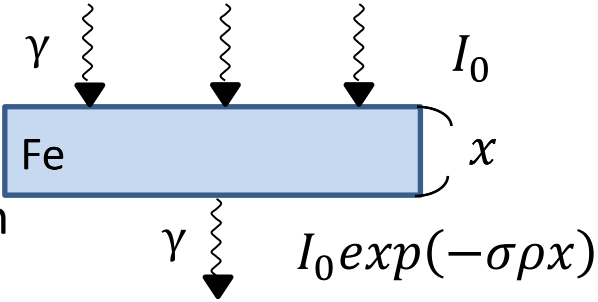
For resonant scattering

$$E_0 = E_\gamma - \varepsilon$$

$$\frac{{E_0}^2}{Mc^2} = \frac{E_0 E_\nu}{Mc^2}\cos\theta$$

$E_\nu \cos\theta = E_0$ ⟹ Condition of resonant scattering

Measurement of γ-ray helicity with Compton polarimeter



・The γ-ray enters into the magnetized iron.

・Cross-section of Compton scattering is larger if electron and γ-ray spins are antiparallel.

$$\sigma_{anti} > \sigma_{para}$$

・The counting rate varies depending on the direction of the magnetization by Compton scattering.

$$\delta \equiv \frac{N_- - N_+}{\frac{1}{2}(N_- + N_+)}$$

N_+ : counting rate with the magnetic field pointing up (The spin of electron pointing down)

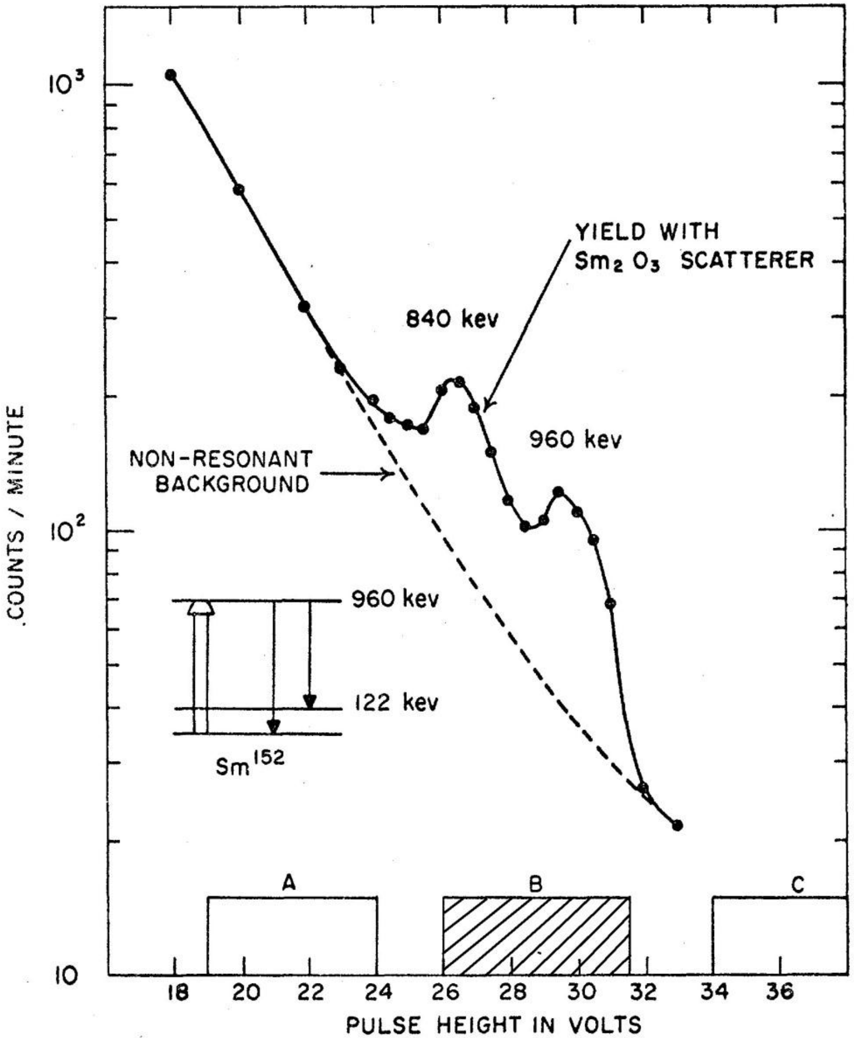
N_- : counting rate with the magnetic field pointing down (The spin of electron pointing up)

・If the γ-ray are 100% circularly polarized, we expect an effect of $\delta = \pm 0.025$ with an accuracy of 10%.

→ $\delta +$ ⟶ $N_-(\sigma_e \text{ up}) > N_+(\sigma_e \text{ down})$ ⟶ $\boldsymbol{\sigma}_\gamma$ up ⟶ $\boldsymbol{h}_\gamma$ −

→ $\delta -$ ⟶ $N_-(\sigma_e \text{ up}) < N_+(\sigma_e \text{ down})$ ⟶ $\boldsymbol{\sigma}_\gamma$ down ⟶ $\boldsymbol{h}_\gamma$ +

4. Result



・An effect $\delta = +0.017 \pm 0.003$ was observed in channel B.

・The helicity of γ-ray is negative.

$$h_{\nu} = -1$$

5. Summary

- The helicity of the neutrino was determined by the measurement of γ-ray from the electron capture of $^{152m}\mathrm{Eu}$.

- To select forward γ-ray, the resonant scattering was used.

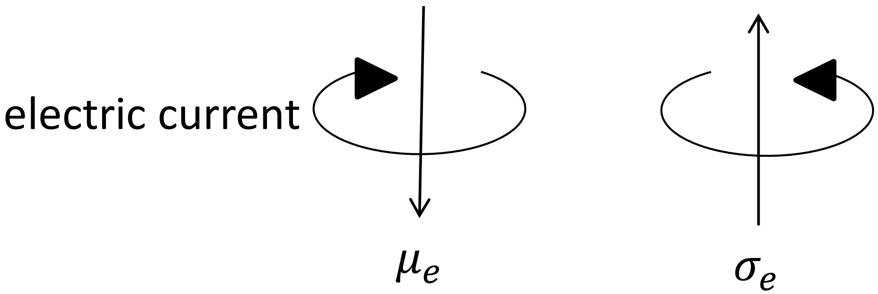
- The helicity of γ-ray was measured by Compton scattering.

- The helicity of forward γ-ray was negative.

- It indicates that the helicity of neutrino is negative; $h_\nu = -1$

以下、補足スライド

δ and h_γ



μ_e: magnetic moment

$$\mu_e = 2\left(-\frac{e}{m}\right)\sigma_e$$

$\boldsymbol{\sigma_\gamma}$ + , $\boldsymbol{p_\gamma}$ −

$$\begin{cases} N_+ \rightarrow \sigma_e - \rightarrow \text{anti} \\ N_- \rightarrow \sigma_e + \rightarrow \text{para} \end{cases} \quad \begin{cases} N_+ = Aexp(\sigma_{anti}\rho x) \\ N_- = Aexp(\sigma_{para}\rho x) \end{cases} \quad N_- > N_+ \quad \delta +$$

$\boldsymbol{\sigma_\gamma}$ − , $\boldsymbol{p_\gamma}$ −

$$\begin{cases} N_+ \rightarrow \sigma_e - \rightarrow \text{para} \\ N_- \rightarrow \sigma_e + \rightarrow \text{anti} \end{cases} \quad \begin{cases} N_+ = Aexp(\sigma_{para}\rho x) \\ N_- = Aexp(\sigma_{anti}\rho x) \end{cases} \quad N_- < N_+ \quad \delta -$$

Fe peripheral electron : 2

density : $7.09 \times 10^{-6} m^3/mol \rightarrow 0.141 mol/cm^3$

$$\rho = 2 \times 0.141 \times 6.02 \times 10^{23} = 1.70 \times 10^{23} cm^{-3}$$