Determination of the helicity of neutrinos

Parity violation of the weak interaction

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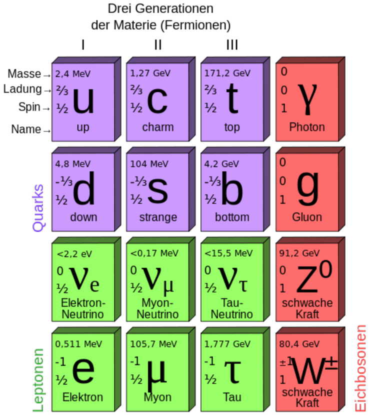
Neutrinos overview

- spin 1/2 particles
- colourless
- electrically neutral

$\Rightarrow$ only weak interaction via massive vector bosons ($W^{\pm}$, Z^0)

- 3 neutrinos, associated with e, μ, τ
- lepton number of each family conserved
- neutrinos are left handed and antineutrinos right handed



Helicity and handedness

- helicity:
  - projection of particle's spin $\vec{S}$ along direction of motion $\vec{p}$

$$\vec{s} \cdot \vec{p} \quad \Rightarrow \quad \begin{array}{ll} \vec{S} \uparrow\downarrow \vec{p} & \text{negative, left helicity} \\ \vec{S} \uparrow\uparrow \vec{p} & \text{positive, right helicity} \end{array}$$

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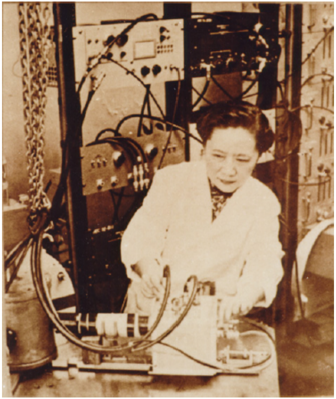
  - for massive particles: sign of helicity depends on frame
- handedness:
  - Lorentz invariant analogue of helicity
  - two states: left handed (LH) and right handed (RH)
    - massless particles: either pure RH or LH, can appear in either states
    - massive particles: both LH+RH components
      $\Rightarrow$ helicity eigenstate is combination of handedness states
- for $E \to \infty$ can neglect mass $\Rightarrow$ handedness $\equiv$ helicity

Parity violation of the weak interaction

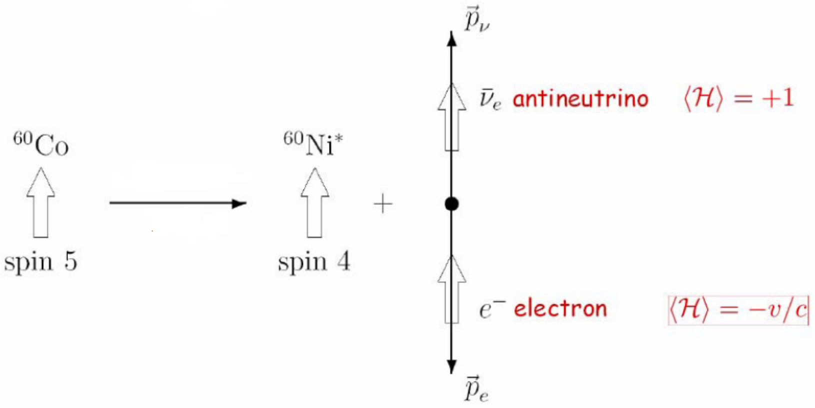
first hint that there are only LH neutrinos and RH antineutrinos

1956: T. D. Lee and C. N. Yang predict P violation



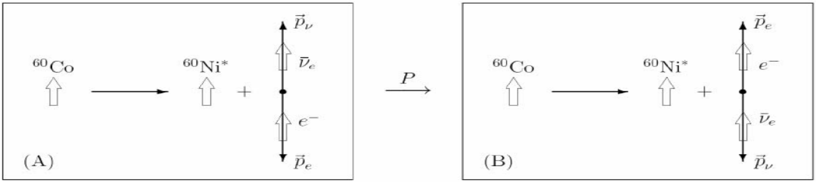
1957: Wu et al. observed maximum P violation

Wu-Experiment



Helicity: $\mathcal{H} = \frac{\vec{s} \cdot \vec{p}}{|\vec{p}|}$

Wu-Experiment



parity transformation:

- polar vectors change sign: $\vec{p} \rightarrow -\vec{p}$
- axial vectors don't change sign: $\vec{s} \rightarrow \vec{s}$

experiment:

- nuclear spins are aligned through magnetic field, measurement of the electrons
- reverse magnetic field for other scenario

result:
beta emisssion is preferentially in the direction opposite to the nuclear spin $\Rightarrow$ parity is violated

Goldhaber-Experiment

- 1957: experiment to determine the helicity of the neutrino (Goldhaber et al.)
- used electron capture of the nucleus ^{152}Eu:

$$^{152m}Eu + e^- \rightarrow {}^{152}Sm^* + \nu_e \rightarrow {}^{152}Sm + \gamma + \nu_e$$

0	½	1	- ½	0	1	- ½
0	- ½	-1	½	0	-1	½

$\Rightarrow \vec{s}(\gamma) \uparrow\downarrow \vec{s}(\nu_e)$

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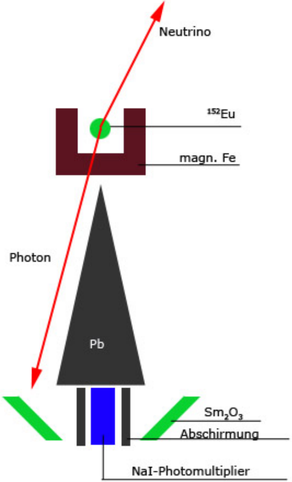
0	**- ½**	**-1**	**½**	**0**	**-1**	**½**

$\Rightarrow \vec{s}(\gamma) \uparrow\downarrow \vec{s}(\nu_e)$

- if neutrino and photon are „back-to-back“

$\Rightarrow H(\nu_e) = H(\gamma)$

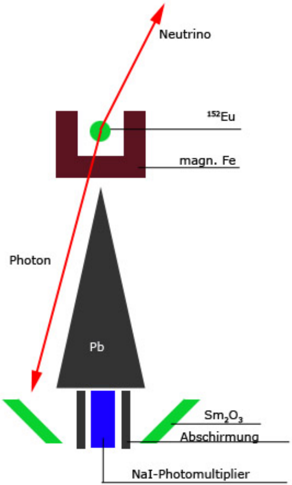
Goldhaber-Experiment



$$Eu + e^- \rightarrow Sm^* + \nu_e \rightarrow Sm + \gamma + \nu_e$$

- energy of Sm^* is distributed on Sm and γ
  $\rightarrow \gamma$ has to less energy to excite another Sm nucleus
- but: Sm^* gets a recoil when the ν_e is emitted $\rightarrow$ doesn't decay in rest
- γ emitted in moving direction of Sm^* nucleus
  $\rightarrow$ gets additional energy
  $\rightarrow$ can be absorbed by another Sm nucleus
  $\Rightarrow$ **resonant absorption possible**

Goldhaber-Experiment



measurement of helicity:

- Eu-source in iron magnet
- photons Compton scattered on electrons of Fe
- $d\sigma/d\Omega(\uparrow\downarrow) > d\sigma/d\Omega(\uparrow\uparrow)$
- reverse magnetic field and count detected photons
  $\Rightarrow$ polarisation of photons
  $\Rightarrow H(\nu) = -1.0 \pm 0.3$

$\Rightarrow$ neutrinos are left handed

Summary

- parity violation of weak interaction:
    - 1956 predicted by T. D. Lee and C. N. Yang
    - 1957 showed by Wu et al.
- Goldhaber-Experiment
    - experiment to determine the helicity of neutrinos
    - showed that neutrinos are LH and antineutrinos RH
- no evidence for RH neutrinos, LH antineutrinos