Karlsruhe Institute of Technology

# Paritätsverletzung beim $\beta$-Zerfall

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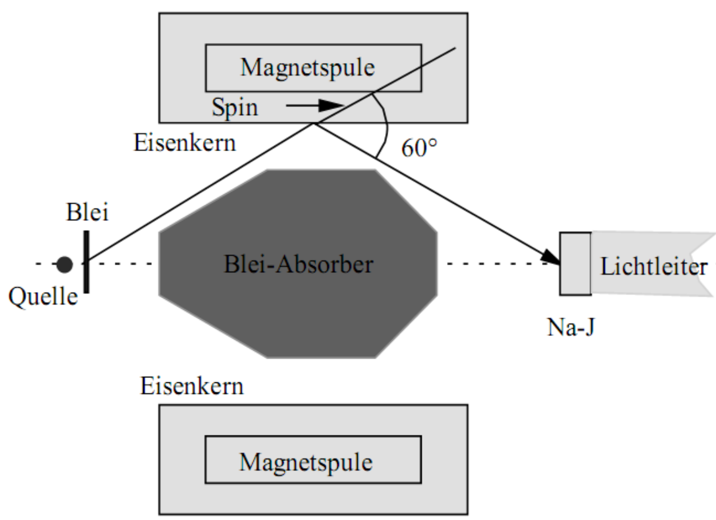
# 1 Introduction

In this experiment, we want to show that parity is violated in the beta decay. Gravitational or electromagnetic processes are parity invariant; if one flips the signs of all spacial coordinates (this is the parity transformation) in such a process, the ”flipped” process is also allowed. However, the beta decay is caused by weak interaction and therefore can violate parity. In the original experiment of Wu, the beta source was placed in a magnetic field at low temperatures, to align the spins of decaying nuclei. In this setup, an asymmetry can directly be detected in the intensity of radiation; more beta particles (electrons) are directed antiparallel to the spin than parallel.
Because it is difficult to reach such low temperatures and high fields, we use a simpler setup that indirectly measures the helicity (longitudinal spin-polarization)

$$H = \frac{\vec{S} \cdot \vec{P}}{|\vec{S}||\vec{P}|}$$

of beta particles. H is a pseudoscalar that changes signs under the parity transformation. Therefore the expected value of H would be zero if the beta-decay were parity symmetric.

# 2 Experimental setup




The beta particles from a $^{90}$Sr+$^{90}$Y source are at first shot at a lead target. The resulting bremsstrahlung is then scattered by a cylindrical magnetic core and detected by a NaJ-Scintillation counter. Unscattered Photons are absorbed by lead. The detector (photomultiplier) is connected to the NaJ-crystal by a long waveguide, so that it is not affected by the magnetic field.
The magnetic core acts as a polarizer, since the cross-section of compton scattering depends on the

angle between the polarized photons and the spins of electrons in the iron, which are partly aligned by the magnetic field.
Since the polarisation of the bremsstrahlung is correlated to the polarisation of the initial beta-particles, we can detect asymmetries by simply reversing the magnetic field and calculating the relative difference between count rates

$$E = \frac{N_- - N_+}{N_- + N_+}$$

Since $E$ is expected to be higher at high energies (see the theoretical discussion below), an energy discriminator only counts photons with energies higher than 1MeV.

# 3 Theoretical discussion

## 3.1 Polarization of electrons

Because of their spin 1/2, single electrons are always polarized in a particular orientation. We want to show that there is a preferred longitudinal polarization $H$. Because of rotational symmetry (the source has no preferred orientation), the transversal polarization is randomly distributed and has an expected value of zero.

## 3.2 Polarization of photons

Because photons are relativistic particles, their Helicity is always $H = \pm 1$; they cannot have a transversal spin-polarization.
Because the sum of spins must be conserved, polarization of electrons is transferred to the bremsstrahlung.
If the electron doesn't stop completely and moves on in another direction, the bremsstrahlung shows linear polarization. Transversal polarization of the electrons is also transferred to the photons, resulting in elliptical polarization.
At higher energies, the photon is emitted roughly in the same direction as the electron and therefore transversal polarizazion cannot be transferred. The energy of the photon is maximal if the electron stops completely. In this case the spin of the electron flips completely and the photon gets the same helicity as the electron before.
Since we only want to measure longitudinal polarization, a discriminator cuts off lower energies.

## 3.3 compton scattering

As mentioned before, the cross-section of compton scattering in the magnetic core depends on the polarization of photons:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{r_0^2 k^2}{2k_0^2} \left(\Phi_0 + f \cdot P_C \cdot \Phi_C\right)$$
$$\Phi_0 = 1 + \cos^2\Theta + (k_0 - k) \cdot (1 - cos\Theta)$$
$$\Phi_C = -(1 - \cos\Theta) \cdot ((k_0 + k)\cos\Theta\cos\Psi + k\sin\Theta\sin\Psi\cos\Phi)$$

where f is the fraction of aligned electrons in the iron, $k_0$ and $k$ is the momentum of photons before and after the scattering, $P_C$ is the polarization of photons, and $r_0$ is the electron radius.
The relative difference between count rates is approximately

$$E = \frac{N_- - N_+}{N_- + N_+} \approx f \cdot P_C \frac{\Phi_C}{\Phi_0}$$

In order to maxmize $E$, we use energies greater than 1MeV (high $k_0$ and $k$); the optimal scattering angle is then $\Theta \approx 60°$ (see the figure above).

### 3.4 Discussion and errors

To prevent errors caused by drifts, we change the orientation of the magnetic field often and calculate $E$ for each pair of measurements. The mean $\overline{E}$ and statistical error $\sigma_{\overline{E}}$ is then calculated out of the $E$'s. To proof parity violation we have to discuss these values in comparison.

## Quellen

**"Blaues Buch"**
**en.wikipedia.org**