Mott Scattering of ^{58}Ni Ions as a Demonstration of Quantum Effects

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Differential cross sections for Coulomb scattering of indistinguishable particles with spin s are described by the well known Mott formula. For nuclei with charge Z and ground state spin 0^+ the Mott formula reads in the CM:

$$\frac{d\sigma_M}{d\Omega} = \frac{d\sigma_R}{d\Omega} + A \cdot \cos\left(\frac{Z^2 e^2}{4\pi\epsilon_0 \hbar v} ln\left(tan^2\frac{\theta}{2}\right)\right) \qquad (1)$$

$$A = \frac{Z^4 e^4}{4(4\pi\epsilon_0 E_{kin})^2} \cdot \frac{2}{sin^2(\frac{\theta}{2})cos^2(\frac{\theta}{2})} \qquad (2)$$

The additional term to the Rutherford elastic scattering cross section $d\sigma_R/d\Omega$ is due to the symmetrisation of the wavefunction against particle exchange and results in an oscillating angular distribution. The oscillation amplitude A depends strongly on Z and the particle velocity v and should become visible in heavy ion scattering if nuclear excitations of the collision partners are suppressed, i.e. in pure elastic scattering at energies below the Coulomb barrier.

In continuation of an earlier ^{58}Ni + ^{58}Ni experiment [1] we have rearranged and extended the detector setup and started a series of new measurements with a twofold motivation: First, they allow to demonstrate elementary quantum mechanical effects in an impressive way using primary observables. Therefore these experiments are performed within a regular practical course by a selected number of undergraduate students. Second, the earlier measurements can be complemented also with angular distributions for inelastic scattering in which one or both colliding ^{58}Ni nuclei are excited to the first 2^+ state.

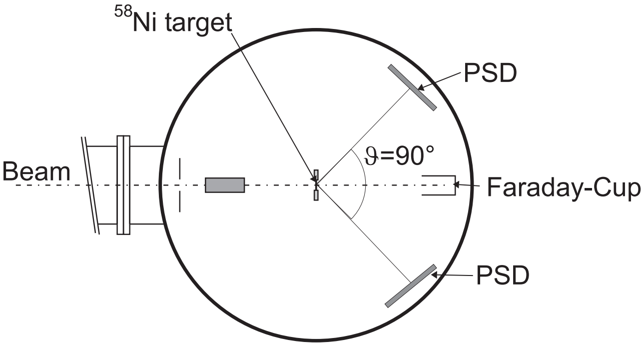

Fig. 1: Experimental setup at the II − 10° beam line.

The measurements are performed twice a year within a one day beam time using the scattering chamber at the II − 10° beam line (see fig. 1). A ^{58}Ni beam of 180 MeV is directed and focussed to an enriched ^{58}Ni strip target (12 μg/cm^2). The scattered ions are registered by two position sensitive silicon detectors (PSD) with an active area of 90×10 mm^2 corresponding to an angular coverage of $\Delta\vartheta \approx 19°$ each. Both PSD detectors are arranged with a mean opening angle of $\vartheta_{sum} = 90°$ and centered at $\Theta_{Lab} \approx 45°$, where the maximum amplitude of the oscillation pattern is expected and coincident detection of both reaction partners with similar energies is possible. The resulting position spectrum deduced from both pulse height signals of one detector is shown in fig. 2 and clearly demonstrates the expected structure in the angular distribution.

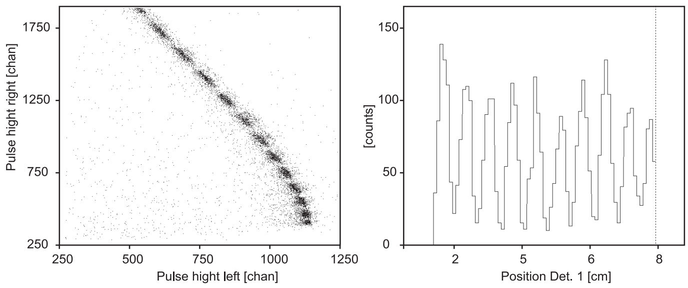

Fig. 2: *left*: Correlation of left and right side PSD signals for ^{58}Ni +^{58} Ni scattering at 180 MeV. *right*: Position distribution in a single PSD detector.

Making use of both detectors, i.e. application of the kinematical coincidence method, then allows to extract also the reaction Q-value and to separate the elastic scattering (Q=0) from inelastic channels. This is demonstrated in fig. 3. The left part of this figure shows the sum of measured angles correlated with the total kinetic energy of both scattered particles. The separation is clearly visible in both observables and peaks for the inelastic scattering at an opening angle $\vartheta_{sum} \approx 89.5°$ (see right panel of fig. 3) and at a missing kinetic energy of ≈ 1.5 MeV which corresponds well to the expected exitation energy of 1.4544 MeV for the 2^+ state of ^{58}Ni [2].

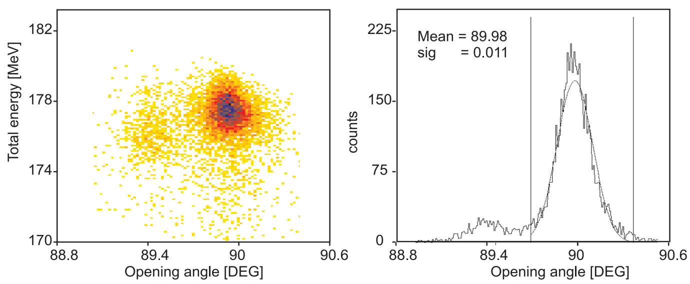

Fig. 3: *left*: Total kinetic energy vs. opening angle for ^{58}Ni +^{58} Ni at 180 MeV. *right*: Distribution of opening angles ϑ_{sum}

So far, the statistics for the inelastic scattering is not sufficient to conclude about appearence or disappearence of any pronounced structures in the angular distribution. We will address this question in further measurements.

References

[1] H. Gilg, diploma thesis, TU München, 1993 and Jahresbericht 1993, p. 40
[2] C.M. Lederer, V.S. Shirley; Tab. of Isot., 7th ed., Berkeley 1978