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A new calibration method for the analyzing power of spin-1/2 - spin-0 scattering applied to $p-\alpha$ scattering at 25.68 MeV and θ_{lab}=117.5°

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Abstract: A new general method for the precise absolute calibration of the analyzing power of spin-1/2 - spin-0 elastic scattering is presented. This calibration method uses the double scattering technique and an incident beam with at least two different polarization states. It is not limited to particular energies and scattering angles. An application of the method to $p-\alpha$ elastic scattering at 25.68 MeV and a lab. angle of 117.5° is described.

Introduction: In the course of a high precision p-p scattering experiment [1], we encountered the problem of the absolute calibration of the p-^{4}He reaction, which was used as a beam polarization monitor.

For modern polarized ion sources, like atomic beam sources, a calibrated polarimeter, using a nuclear reaction with known analyzing power, is the only possibility to measure the beam polarization. However the absolute accuracy is limited to the knowledge of the analyzing power. Due to the absence of a general powerful calibration method we developped a new double scattering method, adapted to modern polarized ion source technique.

Method: For a double scattering, the number of particles scattered from the first target to the left and entering into the polarimeter (second scattering) is:

$$N_1^a = I_1^a n_1 \Omega \sigma_1^o [1 + p_1^a A_y(\theta)] \tag{1}$$

where the superscript (a) denotes the polarization state of the beam, I_1^a is the number of incident particles in the primary beam in the state (a), n_1 is the number of target nuclei per unit area, and Ω is the acceptance solid angle of the polarimeter. The yields in the left and right detector of the polarimeter are for a polarization state (a):

$$N_L^a = I_1^a n_1 n_2 \Omega \Omega_L E_L \sigma_1^o \sigma_2^o [1 + p_1^a A_1 + (A_1 + p_1^a) A_2](1 + \epsilon') \tag{2}$$

$$N_R^a = I_1^a n_1 n_2 \Omega \Omega_R E_R \sigma_1^o \sigma_2^o [1 + p_1^a A_1 - (A_1 + p_1^a) A_2](1 - \epsilon') \tag{3}$$

where E_L,E_R and Ω_L,Ω_R are the efficiencies and the solid angles of the left and right detectors. In the first order, ϵ' is the false asymmetry [2] that may result from instrumental misalignement of the polarimeter with respect to the scattered beam. We get similar relations for a polarization state (b). Assuming equal number of incident particles I_1^a and I_1^b the following asymmetries

$$\epsilon_1 = \frac{N_1^a - N_1^b}{N_1^a + N_1^b} \; ; \quad \epsilon_2^L = \frac{N_L^a - N_L^b}{N_L^a + N_L^b} \; ; \quad \epsilon_2^R = \frac{N_R^a - N_R^b}{N_R^a + N_R^b} \; ; \tag{4}$$

only contain the four unknowns p_1^a, p_1^b, A_1 and A_2, ϵ' cancels out. Measuring the ratio R of the two polarization states (a) and (b)

$$R = p_1^b/p_1^a = \epsilon_1^b/\epsilon_1^a \tag{5}$$

is sufficient to uniquely determine the four polarization observables. An important simplification can be gained if $p_1^a = -p_1^b = p_1$, which can be realized with an atomic beam source with rf-transitions. We then get

$$\begin{aligned} A_1 &= \pm\left[\frac{(\epsilon_2^R + \epsilon_2^L - 2\epsilon_1)\epsilon_1}{\epsilon_2^L(2\epsilon_2^R - \epsilon_1) - \epsilon_2^R\epsilon_1}\right]^{1/2} && (6) \\ p_1 &= \frac{\epsilon_1}{A_1} && (7) \\ A_2 &= \frac{A_1(\epsilon_1 - \epsilon_2^R)}{\epsilon_1 - \epsilon_2^R A_1^2} = -\frac{A_1(\epsilon_1 - \epsilon_2^L)}{\epsilon_1 - \epsilon_2^L A_1^2} && (8) \end{aligned}$$

Application to p-α scattering: The apparatus used in the calibration experiment is described in ref. [3]. Since the required accuracy may depend critically on systematic errors, we performed two independent sets of measurement.

i) Switching between positive and negative polarization states, which have the same value of polarization ($R = -1$).

ii) Switching between the negative polarization state and the unpolarized beam, which has in fact a small remaining positive polarization (about 7%), due to the operation of our ion source.

The results for A_1 and A_2 of the two sets are in excellent agreement allowing to take the weighted average. The false asymmetry ϵ' was found to be statistically compatible with zero. An extensive investigation of possible other systematical errors for A_1 was carried out as well. The final result for A_1 corrected for the finite geometry of our double scattering apparatus is

$$A_1 = 0.8119 \pm 0.0071(\pm 0.0076)$$

where the first uncertainty is purely statistical, and the number in parentheses the total uncertainty from the quadratic sum of the systematic and statistical uncertainties. More details about the method and the experiment are given in ref. [4].

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