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Location of a polarization extremum in triton-alpha scattering and its application to a new polarized triton source*

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We have experimentally located a polarization extremum ($A_y = -1$) in triton-α elastic scattering near $E_t = 11.1$ MeV, $\theta_{\text{c.m.}} = 95°$. This is the first application and test of a Lamb-shift polarized tritium ion source which has been installed on the Los Alamos tandem accelerator. The results verify the accuracy of the quench-ratio method for the determination of the polarization of the triton beam.

[NUCLEAR REACTIONS $^4\text{He}(\vec{t},t)$; $E_t = 10.2\text{–}11.7$ MeV, measured $A_y(\theta)$. Demonstrated existence of $A_y = -1$ point.]

I. INTRODUCTION

This paper reports the operation of the first polarized triton source and presents data which locate a point in triton-α elastic scattering where the analyzing power A_y reaches its minimum possible value of -1. Together with the new source of polarized ^{3}He ions reported only last year,[1] the polarized triton source will allow new investigations of polarization phenomena in scattering and reactions induced by mass-3 projectiles. Applications of the polarized triton beam to spectroscopy,[2] to studies of few nucleon problems,[3-6] and to studies of the optical model spin-orbit potential for tritons,[7] are presently underway.

II. POLARIZED TRITON SOURCE

Figure 1 is a diagram of the Lamb-shift polarized source used to produce polarized $^3\text{H}^-$ ions at the Los Alamos Scientific Laboratory (LASL) tandem Van de Graaff facility. The basic principles of operation are the same used in the older Lamb-shift source at LASL,[8] but several innovations have been made,[9] some of which were necessary for safe operation with tritium.

The source is oriented vertically, and the beam is inflected into the tandem accelerator via a single 90° electrostatic bend. An intense beam of 1-1.5 keV atomic tritium ions ($^3\text{H}^+$) is produced by a duoplasmatron and accel-decel extraction system.[10] Charge exchange in the cesium cell produces metastable ($2S_{1/2}$) tritium atoms which are polarized in a nuclear spin filter[11] and ionized in a cryogenically pumped argon cell to produce nuclear-polarized $^3\text{H}^-$ ions. After focusing and acceleration to ground potential, these ions are

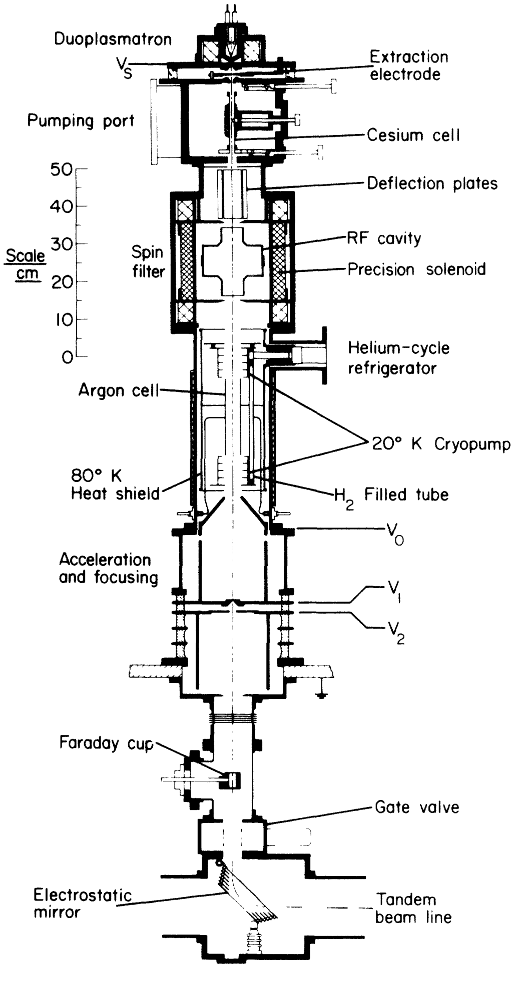

FIG. 1. Schematic diagram of the polarized triton source.

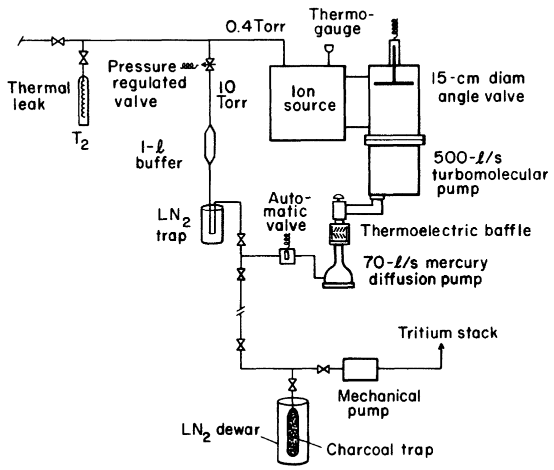

FIG. 2. Diagram of the tritium gas handling system used in the polarized triton source. The mercury booster pump allows direct recirculation of tritium to the ion source during operation and absorption in a charcoal trap after shutdown.

inflected by an electrostatic mirror into the accelerator at a point 115 cm from its low-energy end. The polarization symmetry axis, which is along the vertical axis of the source, is unaffected by the electrostatic mirror or by subsequent horizontal bending in the accelerator analyzing and switching magnets. Thus, the triton beam has vertical polarization at the target, and this polarization can be reversed from "up" to "down" by reversing the polarity of the solenoidal magnetic fields in the spin filter and ionization regions of the source. Beam currents on target of 60 nA with a polarization of 0.8 have been obtained.

In order to reduce tritium consumption, the source uses a recirculation system which recycles the gas used by the duoplasmatron. Figure 2 is a schematic diagram of this system, which also includes a liquid-nitrogen-cooled charcoal trap[12] for collecting the tritium after source shutdown. The mercury booster pump has a forepressure tolerance of 30 Torr. This allows the pressure differential necessary for recirculating the tritium to the arc region, where a pressure of ~0.2 Torr is maintained by an automatic valve. The tritium flow to the duoplasmatron is about 60 atm cm^3/h, and about 5 atm cm^3 of $^3H_2$ gas is contained in the system under operating conditions. Other details on the polarized triton source can be found in Ref. 9.

III. QUENCH-RATIO METHOD

In a Lamb-shift source equipped with a nuclear spin filter, it is possible to determine the absolute beam polarization by a simple measurement of a ratio of beam currents known as the quench ratio.[13] Briefly, this method involves altering conditions in the spin filter in such a way that the polarized component of the beam current is removed or "quenched". The beam polarization is then given by $1 - 1/Q$, where Q is the ratio of the normal to the quenched beam current. This measurement is made periodically on the accelerated beam during experimental runs, and we usually observe a variation in beam polarization less than 0.01 for extended periods.

The application of the quench-ratio method for a polarized proton beam is discussed in Ref. 10, and measurements with protons and deuterons have demonstrated its accuracy to at least 1% on many occasions. Although the principles involved are identical for a $^3H^-$ source, we thought it desirable to measure the triton beam polarization in an independent manner. Our approach was to seek a reaction whose analyzing power could be proved to be unity.

IV. POLARIZATION EXTREMUM

Plattner and Bacher[14] first showed, for spin-$\frac{1}{2}$–spin-0 scattering, how one could demonstrate whether a point of very large analyzing power was or was not an $A_y = \pm 1$ point. If such points are known to exist, and the energies and angles at which they occur are roughly located from phase shift calculations, they can then be found experimentally by merely searching for maxima in the observed asymmetry. If the observed asymmetry is denoted by ϵ and the beam polarization by p_y, the analyzing power is given by

$$A_y = \epsilon / p_y ,$$

so that at extrema where $A_y = \pm 1$,

$$p_y = \pm \epsilon .$$

In the above, of course, it is assumed that experimental false asymmetries are eliminated by an appropriate technique.[15] This method has been widely used for calibrating polarized proton beams, and several energies and angles in proton-α elastic scattering for which $A_y = 1$ are well established.[13,14,16] Extensions to pion-proton scattering[17] and to deuteron-α scattering[18] have been made.

In our search for a possible $A_y = \pm 1$ point for tritons, we investigated ^{4}He$(t, t)^4$He elastic scattering where large analyzing powers are known to exist.[19,20] To prove that A_y actually reaches ±1, it is convenient to use the model-independent quadratic relation[17,21] for spin-$\frac{1}{2}$ on spin-0 scattering

$$(A_y)^2 + (K_x^{x'})^2 + (K_z^{x'})^2 = 1 ,$$

where $K_x^{x'}$ and $K_z^{x'}$ are identical with the Wolfenstein parameters[22] R and A, respectively. From this relation it is apparent that $A_y = \pm 1$ if and only if $K_x^{x'} = K_z^{x'} = 0$.

In Fig. 3 we have plotted predicted contours of $K_x^{x'}$ vs $K_z^{x'}$ at $E_t = 11$ and 12 MeV with $\theta_{\text{c.m.}}$ as the independent variable. These predictions were obtained from the extensive R-matrix analysis of the seven-nucleon system by Hale and Dodder.[23] Although triton-α analyzing power data were not included in their analysis, new angular distribution and excitation function data[5] in the 7–12 MeV range are well predicted, so that one has a high degree of confidence in the qualitative correctness of the parametrization. Thus, since the two calculated contours pass on opposite sides of the origin, and since these contours must be continuous functions of energy, the analysis indicates that at some energy between 11 and 12 MeV a contour must pass through the origin, i.e., we must have an $A_y = \pm 1$ point. The cross marks on the contours are drawn at 5° (c.m.) intervals to give an estimate of the angle where "crossing" occurs. The sign of A_y is found to be negative in this angular range, so the crossing corresponds to $A_y = -1$. It has been found that the qualitative behavior of the contours we have plotted is not sensitive to moderate changes in the R-matrix parameters used in the calculation. Thus, although the precise energy and angle may not be correctly predicted, the existence of an $A_y = \pm 1$ point is definitely established.

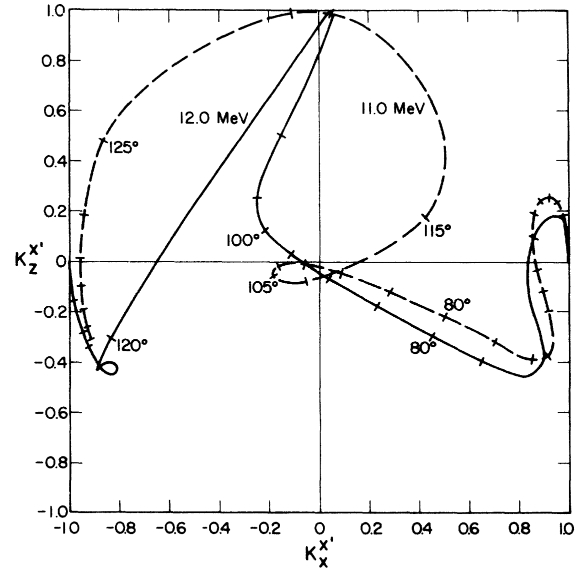

FIG. 3. Contours of $K_x^{x'}(\theta)$ and $K_z^{x'}(\theta)$ (Wolfenstein parameters R and A) are plotted at two energies with c.m. angle as the independent variable. The two curves pass on opposite sides of the origin, indicating that at some intermediate energy $K_x^{x'}$ and $K_z^{x'}$ are simultaneously zero.

V. EXPERIMENTAL RESULTS

To locate the $A_y = -1$ point experimentally, we measured[24] asymmetries at a large number of energies and angles near the expected minimum. Figure 4 shows the values of A_y calculated from these asymmetries under the assumption that the value of the beam polarization is correctly given

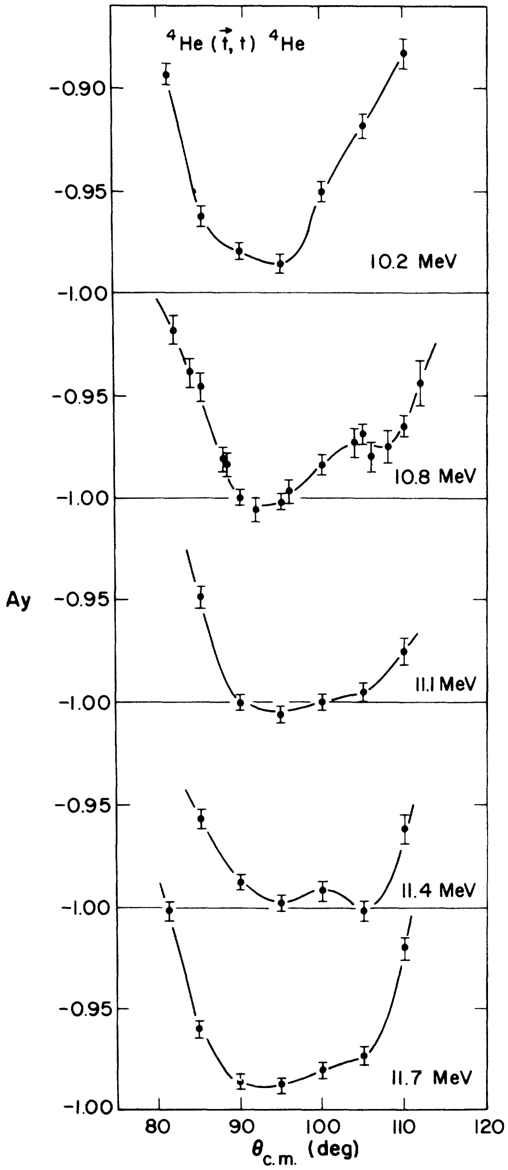

FIG. 4. Data obtained near the energy where A_y is expected to reach its minimum possible value of -1. The plotted points were calculated using the quench ratio for triton beam polarization and have absolute errors of about ± 0.005.

by the quench-ratio method. The lines through the data are to guide the eye. Within the statistical errors, these values of A_y reach -1 at several places in the expected region. Only one datum $[-1.006\pm 0.005]$ exceeded the minimum possible value for A_y by more than one standard deviation. We conclude from these results that there are no unforeseen problems with the quench-ratio method for tritons, and that the accuracy of the method is verified to better than one percent.

The unusual "double humps" in the 10.8 MeV data and in the 11.4 MeV data are related to "loops" in the $K_x^{x'}$, $K_z^{x'}$ contours and have been reproduced by preliminary calculations. It is possible for several $A_y=-1$ points to occur if such a loop moves through the origin as the bombarding energy is varied. A more precise location of the $A_y=-1$ minimum (or minima) in this region will be determined by an R-matrix analysis which includes these and other available data.

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