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THE ELASTIC SCATTERING OF POLARISED PROTONS BY ^{40}Ar

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Abstract

The analysing power of ^{40}Ar for polarised protons has been measured at energies of 25.1, 32.5 and 40.7 MeV at laboratory angles between 30° and 158° . The results are fitted with the optical model code SEEK3 and examined for a possible L-dependence of the optical potentials. The results also provide calibration points for a $p\text{-}^{40}\text{Ar}$ polarimeter.

NUCLEAR REACTIONS $^{40}\text{Ar} (\vec{p}, p)$, $E=25.1, 32.5$ and 40.7 MeV; measured A_y .

Optical Model analysis, L-dependence.

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1. Introduction.

It has been found¹⁻⁵ that the standard optical model analyses of the elastic scattering of medium energy protons from ^{15}N , ^{18}O , ^{24}Mg , ^{40}Ca and ^{40}Ar run into difficulties in fitting the cross-section at the minimum around 140° c.m. and the enhancements at larger angles. Evidence has been found recently for explicit angular momentum dependence of the proton optical model potential (OMP)⁶⁻⁸. Furthermore, it has been shown⁵ that inclusion of an L-dependent potential may in fact solve the problems in the optical model analysis of large-angle scattering at low energies.

Examination of the analysing powers predicted⁹ by the L-independent and L-dependent optical model calculations⁵ for $^{40}\text{Ar}(\vec{p}, p)^{40}\text{Ar}$ elastic scattering at $E_p = 32.5$ MeV leads to the conclusion that, at large angles, the effect of L-dependence in the OMP is reflected much more on the analysing power than the differential cross-section. Similar observations have been made by Kobos and Mackintosh⁶ for proton scattering from ^{16}O at 34.1 MeV. Therefore, analysing power as well as cross-section data are needed at various energies in order to arrive at more convincing results regarding the L-dependence of the optical model potential.

The purpose of the present work is to provide analysing power data for $^{40}\text{Ar}(\vec{p}, p)^{40}\text{Ar}$ scattering at 25.1, 32.5 and 40.7 MeV, complementing existing data³ at 30 and 50 MeV, and to examine a possible L-dependence of the optical model potential.

2. The Experiment.

Protons with a polarisation of approximately 82% were accelerated to the desired energies by the 88" cyclotron of the Lawrence Berkeley Laboratory.

The target consisted of argon gas contained in a cell at a pressure of 2 atmospheres. Four sets of detector telescopes were used. They were located symmetrically with respect to the incoming beam so that measurements of analysing power were made at two angles simultaneously. Each telescope comprised a 0.5mm passing detector (ΔE) and a stopping detector (E) with a total depletion depth of 8 mm. The ΔE -E systems were used for particle identification. Collimators defined a geometry factor¹⁰ of 3×10^{-6} cm.sr. and provided an angular resolution of $\pm 0.5^\circ$ (lab).

The beam polarimeter was downstream from the argon target and consisted of a gaseous ^4He target maintained at a pressure of 2 atmospheres. Elastically scattered protons were detected by two detector telescopes symmetrically positioned with respect to the beam direction at 77.5° at 25.1 and 32.5 MeV and at 120° at 40.7 MeV. The energy of the beam at the polarimeter was degraded by aluminium foils to values at which analysing power calibration points exist¹¹ (24.0, 32.2 and 39.8 MeV, respectively). The beam polarisation was flipped automatically after a fixed charge was accumulated in the Faraday cup (approximately once a second) and the data routed accordingly.

3. Results.

The scattering asymmetry was calculated from the number of counts, corrected for background, in the left and right telescopes for beam spin up and down, LU, RU, LD, RD, from the following relation,

$$\epsilon(\theta) = (r-1)/(r+1),$$

$$r = (LU \cdot RD / LD \cdot RU)^{1/2}$$

The proton analysing power $A_y(\theta)$ was then obtained from $A_y(\theta) = \epsilon(\theta)/P_b$,

where P_b is the beam polarisation. Results are shown in figs. 1-3 as a function of centre of mass angle. The error bars shown are due to counting statistics. Also shown are optical model fits including L-dependence (continuous curve) and predictions from L-dependent fits to differential cross-sections alone at the corresponding energies (dash-double dot curve). Fig. 2 also shows an L-independent fit (dashed curve, parameter set "e" of table 1) and the fit obtained from the latter with the addition of an L-dependent term with a strength of $V_e = 0.35 \text{ MeV}$ (dotted curve, parameter set 'f' of table 1).

The optical model searches were made with the code SEEK3¹². The L-dependence included in the calculation is of the form $V_e (-1)^L f(r_e, a_e)$, as used by Votta et al.¹³, Ohkubo¹⁴ and Nasr¹⁵. Here $f(r_e, a_e)$ is of Woods-Saxon form. The optical model parameters are given in Table 1.

The inclusion of an L-dependent term improves the quality of the fit to the data, as can be seen in fig.2 by comparing the L-independent fit (dashed curve) with the L-dependent result (dotted curve). However, the physical significance of such a term is not yet understood, but may be required to allow for residual effects of the Pauli principle not taken into account by the standard optical potential¹⁶. On the other hand, good fits to low energy p-⁴⁰Ca data have been obtained without such a term by following a Lorentz-invariant microscopic approach to derive an optical potential¹⁷. The energy dependence of the strength, V_e , of the L-dependent term used to fit our ⁴⁰Ar(p,p)⁴⁰Ar elastic scattering differential cross-section data is shown in fig. 4. V_e has its largest negative value near 25 MeV, its largest positive value near 32.5 MeV, and becomes negligible at beam energies above 45 MeV. A similar, but stronger, effect has been observed¹⁵ in ⁴⁰Ca(p,p)⁴⁰Ca scattering and is shown in fig. 4 for comparison.

Examination of the present $^{40}\text{Ar}(\vec{p},p)^{40}\text{Ar}$ data suggests that ^{40}Ar might be useful as a proton polarimeter in the energy range from 25 to 45 MeV. The analysing power from 105° to 125° lab. is large and does not vary rapidly with angle and the cross-section is reasonably large and constant. The figure of merit, $P_0^{1/2}$ is shown in fig. 5. The suggested calibration points are

$$A_y = 0.98 \pm 0.01 \text{ at } E_p = 25.1 \text{ MeV, } \theta_{\text{lab}} = 125^\circ,$$

$$A_y = 0.94 \pm 0.01 \text{ at } E_p = 32.5 \text{ MeV, } \theta_{\text{lab}} = 112^\circ,$$

$$A_y = 0.99 \pm 0.01 \text{ at } E_p = 40.7 \text{ MeV, } \theta_{\text{lab}} = 105^\circ.$$

The possibility that an extreme value of $A_y = 1.0$ exists in this region is being investigated.

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Figure Captions

- Fig.1 The analysing power for $^{40}\text{Ar}(\vec{p},p)^{40}\text{Ar}$ elastic scattering at 25.1 MeV. Continuous line - L-dependent fit (parameter set "a"), dash-double dot - L-independent prediction obtained by fitting the cross-section data (parameter set "b").
- Fig.2 The analysing power for $^{40}\text{Ar}(\vec{p},p)^{40}\text{Ar}$ at 32.5 MeV. Continuous line - parameter set "c", dash-double dot curve - L-dependent prediction from best fit to the cross-sections (parameter set "d"), dashed line - best fit without L-dependent term (parameter set "e"), dotted line - best fit with L-dependent term (parameter set "f").
- Fig.3 Same as fig.1, but at $E_p = 40.7$ MeV. Continuous line - parameter set "g", dashed line - parameter set "h".
- Fig.4 Variation of the strength of the L-dependent term as a function of proton energy. Dots - $^{40}\text{Ar}(p,p)^{40}\text{Ar}$, crosses - $^{40}\text{Ca}(p,p)^{40}\text{Ca}$ (ref.15).
- Fig.5 Variation of a) analysing power, b) figure of merit $P_{01}/2$, with θ_{lab} in the region $102^\circ \leq \theta_{\text{lab}} \leq 130^\circ$ for $E_p = 25.1$ MeV (squares) and $E_p = 32.5$ MeV (dots).

Table 1. ^{40}Ar (p,p) ^{40}Ar Optical Model Parameters

Energy, (MeV)	25.1		32.5				40.7	
Parameter set	a	b	c	d	e	f	g	h
Angular Region	18.5-165°	18.5-165°	18.5-165°	18.5-165°	18.5-165°	18.5-165°	20-155°	20-155°
V_o (MeV)	(51.7263)*	51.1721	(48.3666)	(46.349)	(48.0485)	48.0485	(45.7664)	(46.590)
r_o (fm)	1.14	1.14	1.14	1.16	1.14	1.14	1.14	1.14
a_o (fm)	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
W_V (MeV)	(1.6134)	(2.086)	(3.2844)	(5.0885)	(3.569)	3.569	(5.8337)	(5.2277)
W_D (MeV)	(6.687)	(6.0954)	(5.276)	(3.3481)	(5.079)	5.079	(3.8252)	(3.646)
r_w (fm)	1.30	1.30	1.30	1.37	1.30	1.30	1.30	1.30
a_w (fm)	0.66	0.66	0.66	0.63	0.66	0.66	0.66	0.66
V_{so} (MeV)	(5.536)	(3.74)	(5.4332)	(6.138)	(5.476)	5.476	(5.9325)	(4.2056)
r_{so} (fm)	1.01	1.01	1.01	1.064	1.01	1.01	1.01	1.01
a_{so} (fm)	(0.56)	0.56	0.56	0.738	0.56	0.56	0.56	0.56
V_e (MeV)	(-0.107)	-0.92	(0.3331)	(0.3335)	—	(0.35245)	(0.0746)	(0.0344)
r_e (fm)	0.9707	0.9707	0.9707	0.9707	—	0.9707	0.9707	0.9707
a_e (fm)	0.33	0.33	0.33	0.33	—	0.33	0.3018	0.3018
N_σ	60	60	72	72	72	72	33	33
N_p	42	—	43	—	43	43	31	—
χ_σ^2/N_σ	46.0	11.75	29.0	7.33	50.24	33.8	26.8	4.3
χ_p^2/N_p	11.7	—	30.3	—	94.4	37.3	32.0	—
χ^2/N	31.8	11.75	29.5	7.33	72.4	35.5	29.3	4.3
σ_t^r (mb)	1068	1056.8	999.5	994	997.2	997.2	944.0	918.1
$\langle r^2 \rangle_{OM}^{1/2}$ (fm)	4.11	4.11	4.11	4.149	4.11	4.11	4.11	4.11
J/A (MeV fm ³)	438.2	433.5	413.6	409.1	407.1	407.1	387.7	394.7

* Parentheses show the search parameters $r_c = 1.25$ fm.

Fig.1

Fig.3

Fig. 4

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