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LEVELS IN ^{123}I AND ^{125}I FROM (^{3}He,d) REACTIONS

by

A. Szanto de Toledo†, M.N. Rao, N. Ueta and
O. Sala

Instituto de Física, Universidade de São Paulo,
São Paulo, Brasil

† This work is part of a thesis submited in partial fulfillment of the requirements for the doctoral degree at the University of São Paulo.

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Instituto de Física, Universidade de São Paulo, São Paulo, Brasil

Proton states in ^{123}I and ^{125}I have been observed by means of the ^{123,124}Te(^{3}He,d)^{123,125}I reactions at a bombarding energy of 19.5 MeV. Results regarding spin assignments and spectroscopic factors are presented.

NUCLEAR REACTIONS ^{122,124}Te(^{3}He,d),E = 19.5 MeV; measured $\sigma(E_d,\theta)$, $\theta = 10^{o}-90^{o}$, $\Delta\theta = 5^{o}$, enriched targets, ΔE-E telescopes, resolution 35 keV. ^{123,125}I deduced levels ℓ, J,π,S; DWBA analysis.

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I. INTRODUCTION

Nuclear structure information on the excited levels of the odd isotopes of iodine has been obtained mainly from radioactive decay measurements. The levels of $^{127,129,131}I$ have also been studied by the (^3He,d) reactions by Auble et al.[1] Theoretical interpretations of the properties of the odd-mass iodine nuclei have been performed i) within the framework of the quasiparticle plus-phonon model[2,3], ii) by coupling a proton to even core tellurium nuclei (intermediate coupling model)[4], and iii) in terms of a three proton cluster coupled to a harmonic quadrupole vibrator field[5,6,7]. All three approaches take into account both the shell-model and the collective degrees of freedom. However, only the last one includes explicitly the Pauli principle in the valence shell and the anharmonicities induced in the even tellurium core by the interaction of the two protons with the tin core.

The adopted level schemes of the lighter iodine isotopes[8,9] are based on the decay studies by Gföller et al.[10] and Stippler et al.[11] for ^{123}I and by Geiger[12] and Ludziejewski et al.[13] for ^{125}I. No information exists on direct proton transfer reactions to the levels of $^{123,125}I$.

The present work is a report on the results of (^3He,d) reactions on ^{122}Te and ^{124}Te nuclei. An interpretation of the present experimental results in terms of the three proton cluster-phonon coupling scheme mentioned above will be given in a forthcoming article[14].

II. EXPERIMENTAL PROCEDURE

The experiments were performed with the 19.52-MeV ^{3}He beam from the Pelletron 8UD accelerator of the University of São Paulo[15]. Targets of 100-150 $\mu g/cm^2$ thickness were obtained by evaporation of enriched (>96%) metallic tellurium isotope onto 20 $\mu g/cm^2$ carbon foils. Spectra of the outgoing deuterons were measured from 10^{o} to 90^{o} in steps of 5^{o}, utilizing two ΔE-E solid state detector telescopes and analog particle identifiers[16]. An overall energy resolution of about 35 keV (FWHM) was obtained by applying a + 3 kv bias to the target support, thus preventing secondary electrons produced by the bombardment of the target from reaching the detectors.

A least-squares peak fitting program was employed to obtain the areas under the peaks corresponding to the deuteron groups leading to the various excited levels of the residual nuclei. The statistical errors in the data points in the angular distributions, including the errors due to background subtraction varied from 7% for the strong well-resolved peaks to 13% in the case of weakly populated levels. Typical results of the peak fitting program are presented in Fig. 1, which shows the deuteron spectra leading to the levels of ^{123}I and ^{125}I.

Angular distributions of elastically scattered ^{3}He

particles from ^{122}Te and ^{124}Te were also measured in order to obtain the optical-model parameters for the entrance channel (Te + ^{3}He). At the incident energy of 19.52 MeV, the ratio of elastic to Rutherford scattering remains essentially unity up to about 45°, permitting absolute cross sections to be obtained assuming pure Coulomb scattering for the forward angle cross sections.

III. ANALYSIS OF DATA

The elastic scattering angular distributions were analysed using an optical-model search code MODOPT[17]. The initial set of parameters were those used in the description of the 29.5-MeV ^{3}He elastic scattering from ^{116}Sn [18]. No spin-orbit coupling was included in the entrance channel. The deuteron optical-model parameters were taken from Perey and Perey[19]. A spin-orbit strength of V_{so}= 6 MeV was included in the deuteron channel parameters. The transferred proton was described as moving in a Saxon well with a Thomas spin-orbit factor of λ_{so}= 25. The optical-model parameters as well as the bound state parameters used in the present analyses are given in Table I, and the best fits to the elastic scattering angular distributions are shown in Fig. 2.

The experimental deuteron angular distributions were compared with the distorted-wave Born-approximation (DWBA) predictions in order to obtain the orbital angular momentum transferred (ℓ_p) and the spectroscopic factors (S_j) for most of the observed levels. The DWBA calculations were performed with the code DWUCK[20] in the zero-range approximation. Nonlocality corrections were not made. The cross section for the (^3He,d) stripping reaction on an even-even target may be written,

$$\frac{d\sigma}{d\Omega}(\theta) = N \frac{2J_f+1}{2J_i+1} C^2 S_j \frac{\sigma^j_{DW}(\theta)}{(2j+1)}$$

where the reduced cross section is the single-particle cross section obtained from DWBA calculations, C is the isospin Clebsch-Gordan coupling coefficient and J_i, J_f and j are the total angular momenta of the target nucleus, residual nucleus and the transferred proton, respectively. A zero-range renormalization factor[21] of N= 4.42 was used in obtaining the spectroscopic factors.

The experimental angular distributions are compared with the DWBA predictions in Figs. 3 and 4.

Unambiguous assignments of the transferred orbital angular momenta were obtained for many of the observed transitions. The observed energy levels in ^{123}I and ^{125}I together with ℓ_p values and the spectroscopic factors are presented in Tables II and III. Errors from the peak fitting procedure, uncertainties in the measurement of target thickness and possible nonuniformities in the target contribute to an estimated experimental uncertainty of about 15% in the spectroscopic factors. Uncertainties in the zero-range DWBA have not been included in this present estimate.

In the case of the unresolved triplet (0.138, 0.148 and 0.178 MeV) in ^{123}I, and the unresolved doublet (1.09 MeV) in ^{125}I , the separation of the corresponding peaks by the peak fitting program, introduces additional uncertainties in the experimental cross sections of the order of 30%.

IV. RESULTS

LEVELS IN ^{123}I

The spin of the ground state of ^{123}I (J= 5/2) has been measured by atomic beam methods[22], and a positive parity has been assigned[8] to this state on account of the allowed β-decay to the 0.159-MeV $3/2^+$ level in ^{123}Te.

Based on the systematics of low-lying levels in the heavier iodine isotopes, probable multipolarity assignments obtained from the measured conversion coefficients and log ft values from the decay of the ground state of ^{133}Xe (probable spin and parity $1/2^+$), spins and parities of $7/2^+$, $1/2^+$ and $3/2^+$ have been tentatively assigned[8], to the first three excited states of ^{123}I, respectively. The results obtained in the present work confirm these assignments.

A level at 0.33 MeV is populated extremely weakly in the present ^{122}Te (^3He,d) measurement. Stippler et al.[11], have assigned $J^{\pi}= 3/2^+$ to this level on the basis of the measured conversion coefficient of the 0.3302 MeV γ-ray. No conclusion about the spin and parity of this level could be drawn from the present measurement.

No spins and parities are known from previous measurements for any of the higher excited states in ^{123}I.

In the present measurement a level at 0.94 MeV excitation energy has been observed with a transferred orbital angular momentum of $\ell_p = 5$. On the basis of the single-particle shell-model and from the systematics of low-lying levels of the odd-mass antimony and iodine isotopes, this level is likely to have $J^{\pi} = 11/2^-$.

The (^{3}He,d) transitions leading to the levels with excitation enrgies of 1.01, 1.15, 1.49 and 1.71 MeV have been assigned $\ell_p = 2$ in the present work. A weak transition to a level at 1.31 MeV has also been tentatively assigned $\ell_p = 2$. Between the excitation energies of 1.0 to 2.3 MeV, six $\ell_p = 0$ transitions have been observed, of which five are considered unambiguous, based on the predicted DWBA shapes. Most of the $\ell_p = 0$ and 2 transitions seen in this work could be identified with the levels known from decay studies. The energy levels of ^{123}I observed in the present work, together with the transferred angular momenta and the absolute spectroscopic factors are presented in Table II, which also shows the previously known levels in ^{123}I taken from the Nuclear Data Sheets[8].

LEVELS IN ^{125}I

The ground and the first three excited states of ^{125}I have been assigned[9] spins and parities of $5/2^+$, $7/2^+$, $3/2^+$ and $1/2^+$, respectively. The present work confirms these assignments.

Two weak transitions have been observed in the (^3He,d) reaction to levels with excitation energies of 0.37 and 0.45 MeV, the first of which has been tentatively assigned an $\ell_p=2$.

For the higher excited states in ^{125}I no spins and parities are known from other work.

Attempts were made to fit the angular distribution for the transition to the unresolved doublet at 1.09 MeV with combinations of ($\ell_p=2$ + $\ell_p=5$) and ($\ell_p=2$ + $\ell_p=4$), the former resulting in a better fit. By the arguments utilized in the case of the 0.94-MeV level in ^{123}I, the $\ell_p=5$ transition to the unresolved level at 1.09 MeV in ^{125}I has been tentatively assigned $J^\pi=11/2^-$.

Between 1.0 and 1.5 MeV excitation energies in ^{125}I, one $\ell_p=0$ and five $\ell_p=2$ transitions have been observed. The attribution of $\ell_p=2$ to the 1.26 MeV transition is tentative. Six new levels have been populated in the present (^3He,d) reaction above an excitation energy of 1.5 MeV.

A summary of these results is presented in Table III, along with the previously known[9] energy levels in ^{125}I from decay studies.

MASS EXCESS OF ^{123}I

As part of the present work, the ground state Q-value for the ^{122}Te (^{3}He,d) ^{123}I reaction was measured to within an uncertainty of ±8 keV. A Q-value of 712.0±3.9 keV for the ^{126}Te (^{3}He,d) ^{127}I (g.s.) reaction[23], was used as a reference for the present measurement.

Targets of ^{122}Te and ^{126}Te of ≃90 μg/cm^2 thickness were bombarded with a ^{3}He beam and deuteron spectra were obtained at a laboratory angle of 70°. The measured thicknesses of the two targets differed by 17%, giving rise to a difference of a maximum of 3 keV in the energy loss of the beam in the two targets. The channel difference between the positions of the two ground state peaks was converted into difference in energy using the same energy calibration,yielding a value of 1290 ± 7 keV.

With the known value of 712.0 ± 3.9 keV for the ^{126}Te (^{3}He,d) ^{127}I ground state Q-value, the above result, after an estimated correction of 1.5 keV due to the difference in target thicknesses, yields a value of -577±8 keV for the g.s. Q-value of the ^{122}Te (^{3}He,d) ^{123}I reaction. The previously accepted[23] value was -550±100 keV. The present measurement corresponds to a mass excess of ^{123}I of -87932±9 keV.

V. DISCUSSION

In the last columns of Tables II and III, the calculated spectroscopic factors for proton transfer, on the basis of the cluster-phonon coupling scheme[14], are presented, for the levels below 1 MeV excitation. Having in view the large experimental uncertainties for the unresolved triplet around 0.14 - 0.18 MeV excitation in ^{123}I and the unresolved doublet at 1.09 MeV in ^{125}I, it could be concluded that the model is able to predict reasonably well the spectroscopic factors for the low-lying states in both the nuclei.

A second $5/2^+$ level has been observed[1] in all the heavier iodine isotopes around 0.5 MeV excitation energy. The level at 0.33 MeV in ^{123}I has a $3/2^+$ assignment based on internal conversion data, while in ^{125}I, the 0.37-MeV level has been tentatively assigned $3/2^+$ or $5/2^+$ in the present work. The predicted[14] second $3/2^+$ and second $5/2^+$ levels in ^{123}I and ^{125}I are at excitation energies of ~1MeV and ~0.6MeV, respectively. It may be remarked that if the 0.33 MeV γ-ray is pure M1, the measured[24] half-life of the 0.33-MeV level ($T_{1/2}$ = 42±13 ps) corresponds to $B(M1)\downarrow$ = 0.25±0.08 μ_N^2, in excellent agreement with the calculated $B(M1;\ 3/2^+_2 \rightarrow g.s.)$ value of 0.25 μ_N^2, on the basis of the cluster-phonon model[14]. A spin assignment of $5/2^+$ to this level yields a B(M1) of 0.15 μ_N^2. No data on the transition probability from the 0.37-MeV level in ^{125}I are available.

It should be noted that eventhough the spectroscopic factors predicted for the $1h_{11/2}$ level are in good agreement with the measured values, the predicted excitation energies are almost twice the observed values. Above the excitation energy of 1 MeV, the correspondence between the experimental and the calculated level schemes becomes less obvious.

A more detailed discussion on the wave functions of the ground states of the even Te targets and the ground and the excited levels of $^{123, 125}I$, as well as a comparison with the predicted spectroscopic sum-rule limits will be given in Ref.14.

ACKNOWLEDGMENTS

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TABLE I. Optical-model parameters used in the $^{122,124}Te(^{3}He,d)^{123,125}I$ analyses

Channel	V (MeV)	r_o (fm)	a (fm)	W (MeV)	W' (MeV)	r_o' (fm)	a' (fm)	r_{oc} (fm)	λ_{so}
$^{122}Te+^{3}He$	163.29	1.24	0.667	23.07	0	1.46	0.781	1.25	
$^{124}Te+^{3}He$	163.58	1.24	0.657	22.178	0	1.46	0.776	1.25	
$^{123,125}I+d$ a)	101.0	1.15	0.81	0	66.5	1.34	0.68	1.30	5.37
p	b)	1.20	0.65					1.25	25

The optical potential used was of the form

$$U(r) = -V(1+e^{x})^{-1} - i(W - W'\frac{d}{dx'})(1+e^{x'})^{-1} + (\frac{\hbar}{m_\pi c})^2 V_{so}\frac{1}{r}\frac{d}{dr}(1+e^{x})^{-1} \times \vec{\ell}\cdot\vec{\sigma}$$

$$\text{with } x = \frac{r - r_o A^{1/3}}{a}, \quad x' = \frac{r - r_o' A^{1/3}}{a'}, \quad r_c = r_{oc} A^{1/3}$$

and $\vec{\sigma} = 2\vec{S}/\hbar$ for spin 1/2 and $\vec{\sigma} = \vec{S}/\hbar$ for spin 1.

a) obtained from Perey and Perey (Ref. 19).

b) the well depth for the transferred proton is adjusted to give a binding energy equal to the experimental separation energy.

TABLE II. Results Obtained from the ^{122}Te (^3He,d) ^{123}I Reaction

ENERGY[a)] (MeV)	ENERGY[b)] (MeV)	θ^o cm	$d\sigma/d\Omega$ (μb/sr)	ℓ_p	j[c)]	S_{EXP}	S_{Theory}
0.0	0.0	25.5	253	2	5/2	0.37	0.29
0.138*	0.138	45.8	81	4	7/2	0.75	0.32
0.148*	0.148	35.7	49	0	1/2	0.08	0.23
0.178*	0.178	35.7	46	2	3/2	0.05	0.10
0.33	0.330	35.7	6				
0.94		51.0	78	5	11/2	0.35	0.33
1.01	1.011	35.7	233	2	5/2,3/2	0.22,0.43	
1.05	1.049	46.0	135	0	1/2	0.17	
1.15	1.113	35.7	148	2	3/2,5/2	0.27,0.14	
	(1.154)						
	(1.190)						
1.24	1.243	41.0	40	0	1/2	0.05	
1.31	1.310	41.0	29	(2)	3/2,5/2	0.04,0.02	
1.37	1.391	35.7	29	(0)	1/2	0.04	
1.49		41.0	45	2	3/2,5/2	0.07,0.04	
1.57 } 1.63 }	1.657	46.0	28				
1.71		41.0	49	2	3/2,5/2	0.07,0.03	
1.87	1.865	41.0	170	0	1/2	0.17	
1.93	1.934	41.0	25				
1.95	1.956	46.0	42	0	1/2	0.04	
	2.063						
	2.152						
	2.201						
2.27	2.250	41.0	56	0	1/2	0.05	
	2.286						

a) Present measurements;uncertainty in excitation energies is ±8 to ±10 KeV, except in the case of very weak levels. Levels marked with an asterisk were not resolved and their energies were taken from ref. 8.

b) Nuclear Data sheets. ref. 8.

c) Total angular momentum of the transferred proton used in the DWBA calculations.

TABLE III. Results Obtained from the ^{124}Te (^{3}He,d) ^{125}I Reaction

ENERGY[a)] (MeV)	ENERGY[b)] (MeV)	θ^{o} cm	$d\sigma/d\Omega$ (μb/sr)	ℓ_p	j[c)]	S_{EXP}	S_{Theory}
0.0	0.0	30.6	267	2	5/2	0.40	0.30
0.114	0.114	45.8	49	4	7/2	0.51	0.34
0.188	0.188	40.7	18	(2)	3/2	0.06	0.10
0.243	0.243	40.7	84	0	1/2	0.17	0.24
0.37	0.372	35.6	19	(2)	5/2,3/2	0.03,0.06	
0.45	0.454	30.6	10				
1.01	1.007	40.7	103	0	1/2	0.16	
				(2)	5/2,3/2	0.24,0.48	
1.09†	1.090	40.7	311	+			
				(5)	11/2	0.60	0.41
	(1.108)						
1.21	1.181	35.6	55	2	3/2,5/2	0.12,1.06	
1.26	1.264	35.6	27	(2)	3/2,5/2	0.05,0.02	
1.36		30.6	69	2	3/2,5/2	0.12,0.06	
1.39	1.383	40.7	102	2	3/2,5/2	0.22,0.11	
1.44	1.442	40.7	43	2	3/2,5/2	0.10,0.05	
1.60	1.561	45.8	20				
1.70		35.6	78	2	3/2,5/2	0.13,0.06	
1.82		40.7	56	0	1/2	0.07	
1.95		40.7	139	0	1/2	0.16	
2.19		30.6	54	0	3/2,5/2	0.10,0.05	
2.22		40.7	57	(0)	1/2	0.07	

† unresolved doublet

a), b), c) same as in Table II

[1] R.L.Auble, J.B.Ball and C.B.Fulmer, Phys. Rev. 169,955(1968).

[2] L.S.Kisslinger and R.A.Sorensen, Rev. Mod. Phys. 35,853(1963).

[3] B.S.Reehal and R.A.Sorensen, Phys. Rev. C 2, 819(1970).

[4] M.Rustgi, J.Lucas and S.Mukherjee, Nucl. Phys. A117, 321(1968).

[5] R.Almar, O.Civitarese and F.Krmpotić, Phys. Rev. C 8,1518(1973).

[6] V.Paar, Nucl. Phys. A211, 29(1973).

[7] G.Vanden Berghe, Z.Physik 266, 139(1974).

[8] R.L.Auble, Nucl. Data Sheets 7, 363(1972).

[9] R.L.Auble, Nucl. Data Sheets 7, 465 (1972).

[10] D.Gföller, R.Schönenberg and A.Flammersfeld, Z.Physik 208,299 (1968).

[11] R.Stippler, D.Lode and H.Schrader, Z.Physik 242, 121(1971).

[12] J.S.Geiger, Phys. Rev. 158, 1094(1967).

[13] J.Ludziejewski, J.Kownacki, W.Klamra, J.Chwaszczewska and W. Przyborski, Acta Phys. Polon. 36, 939(1969).

[14] F.Krmpotić, M.N.Rao and A.Szanto de Toledo (To be published).

[15] O.Sala e G.Spalek, Nucl. Instr. and Meth. 122, 213(1974).

[16] F.S.Goulding, D.A.Landis, J.Cerny and R.H.Pehl, Nucl. Instr. and Meths. 31, 1(1964).

[17] J.M.Cohenca, A Computer programme for optical-model analysis of nuclear scattering (University of Oxford, Nuclear Physics Group Report nº 41, 1968).

[18] J.W.Luetzelschwab and J.C.Hafele, Phys. Rev. 180, 1023 (1969).

[19] C.M.Perey and F.G.Perey, Phys. Rev. 132, 755 (1963).

[20] P.D.Kunz, University of Colorado (1967), unpublished.

[21] R.H.Bassel, Phys. Rev. 149, 791 (1966).

[22] H.L.Garvin, T.M.Green and E.Lipworth, Phys. Rev. 111, 534 (1958).

[23] N.B.Gove and A.H.Wapstra, Nucl. Data Tables, 11, 211 (1972).

[24] A.Hogland, S.G.Malmskog, F.Munnich and H.Schrader, Nucl. Phys. A165, 513 (1971).

FIGURE CAPTIONS:

Figure 1: Typical results of the peak-fitting program showing the spectra from $^{122,124}Te$ (^3He,d) reactions.

Figure 2: Angular distributions of 19.52-MeV elastically scattered ^3He from ^{122}Te and ^{124}Te.

Figure 3: Experimental and calculated angular distributions for the ^{122}Te (^3He,d)^{123}I reactions.

Figure 4: Experimental and calculated angular distributions for the ^{124}Te (^3He,d)^{125}I reactions.

<u>NOTE</u>: The figures are numbered on the reverse.

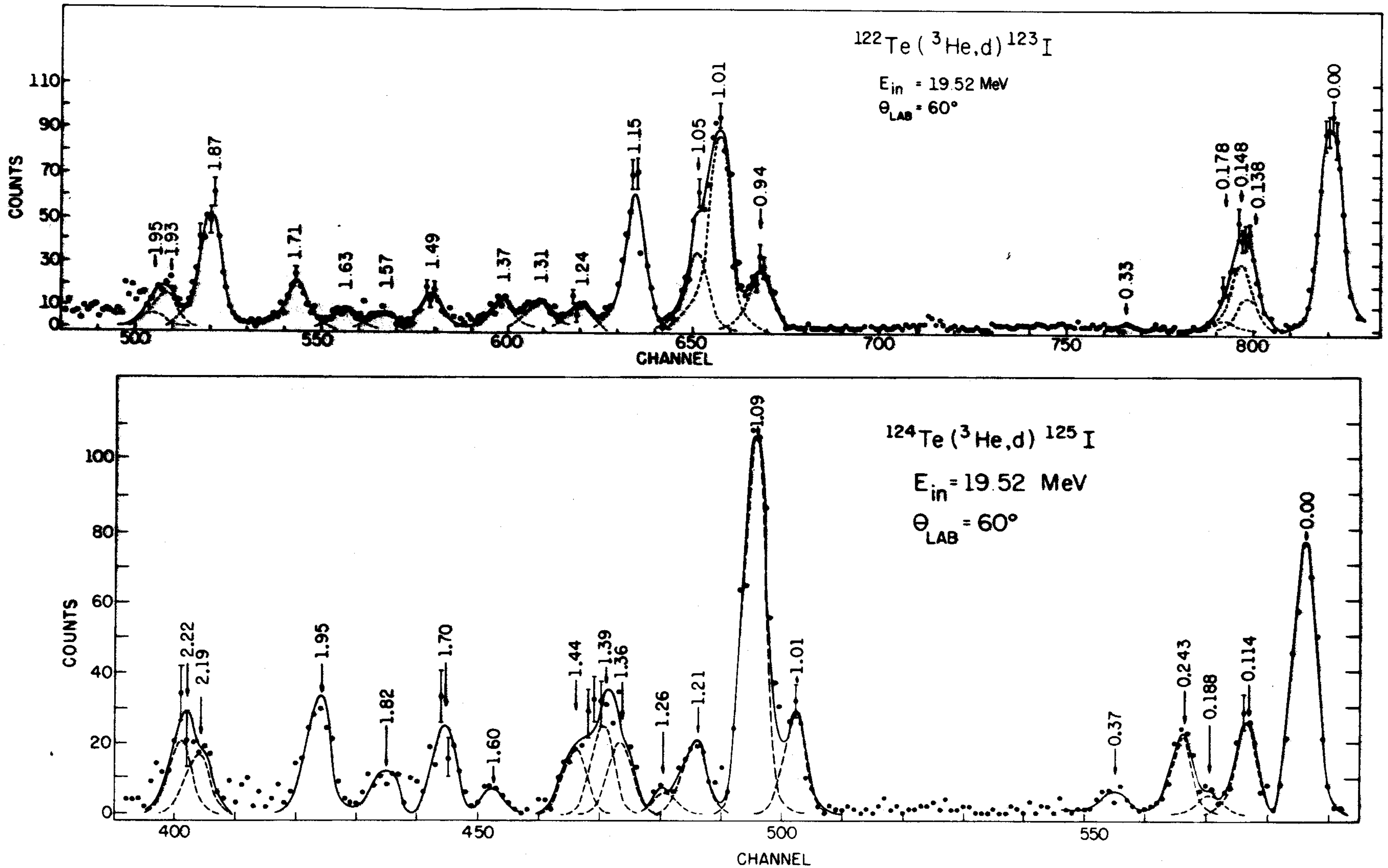

Figure 1: Typical results of the peak-fitting program showing the spectra from 122, ^{124}Te (^3He,d) reactions.

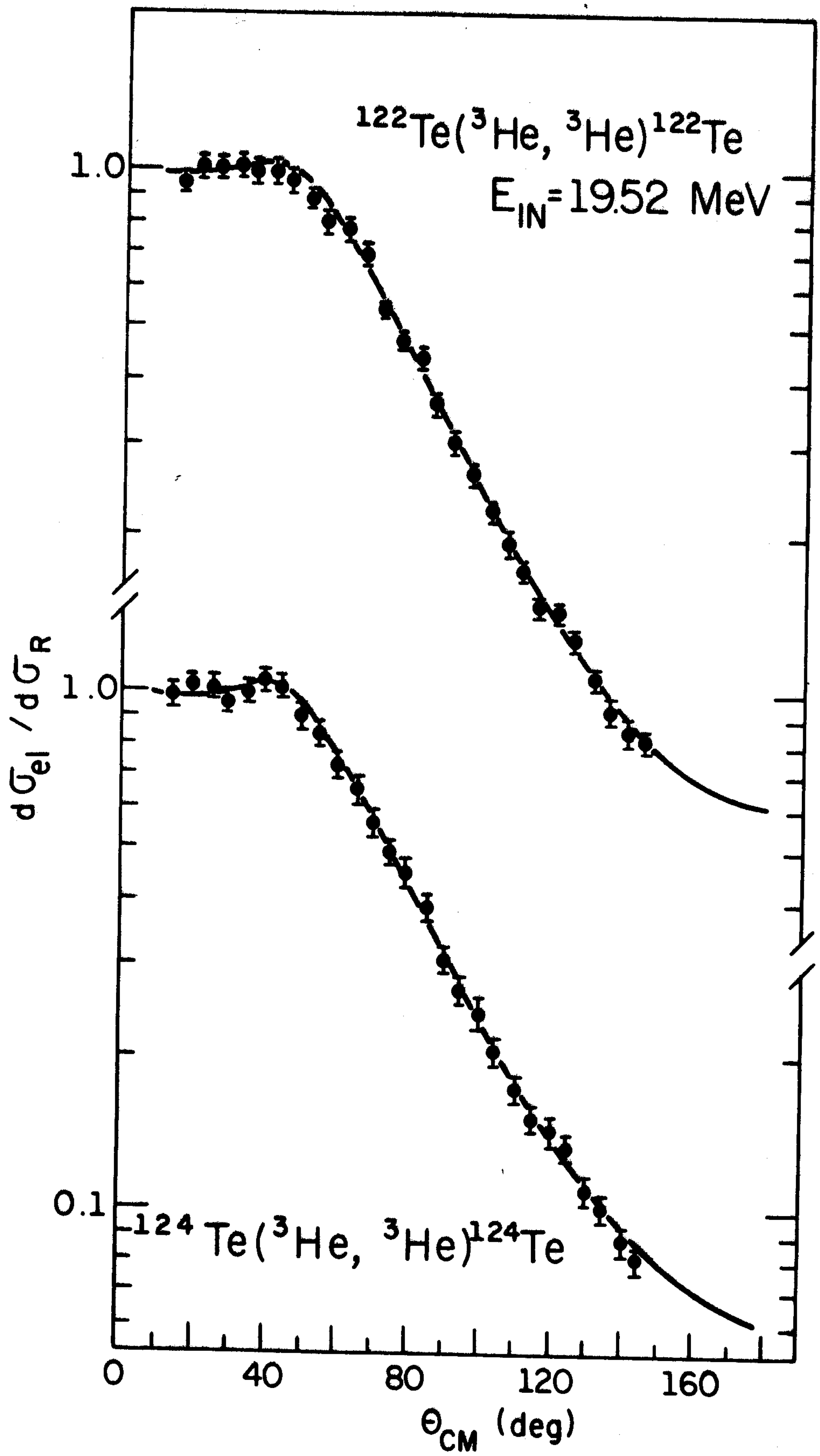

Figure 2: Angular distributions of 19.52-MeV elastically scattered ^3He from ^{122}Te and ^{124}Te.

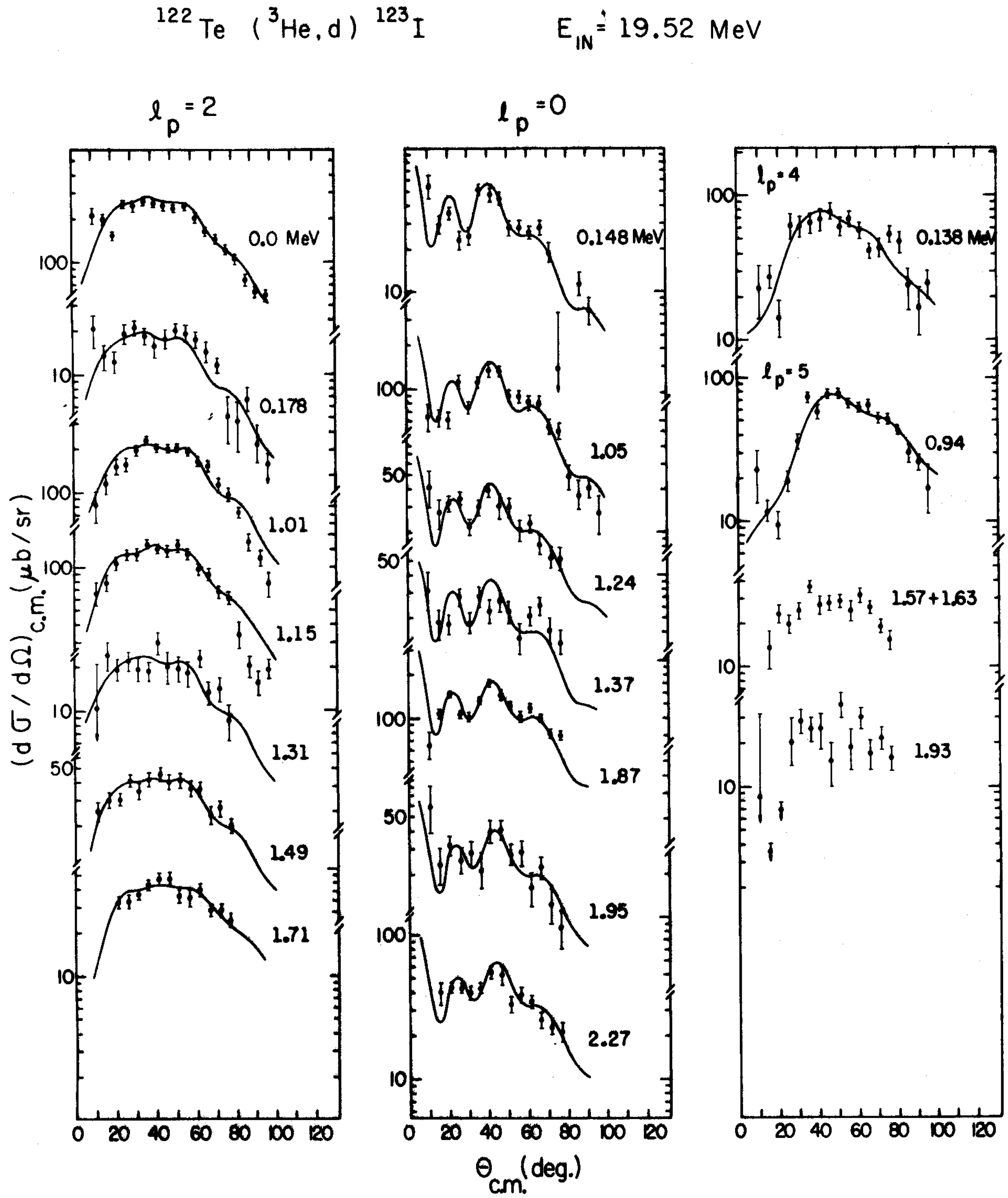

Figure 3: Experimental and calculated angular distributions for the ^{122}Te (^{3}He,d)^{123}I reactions.

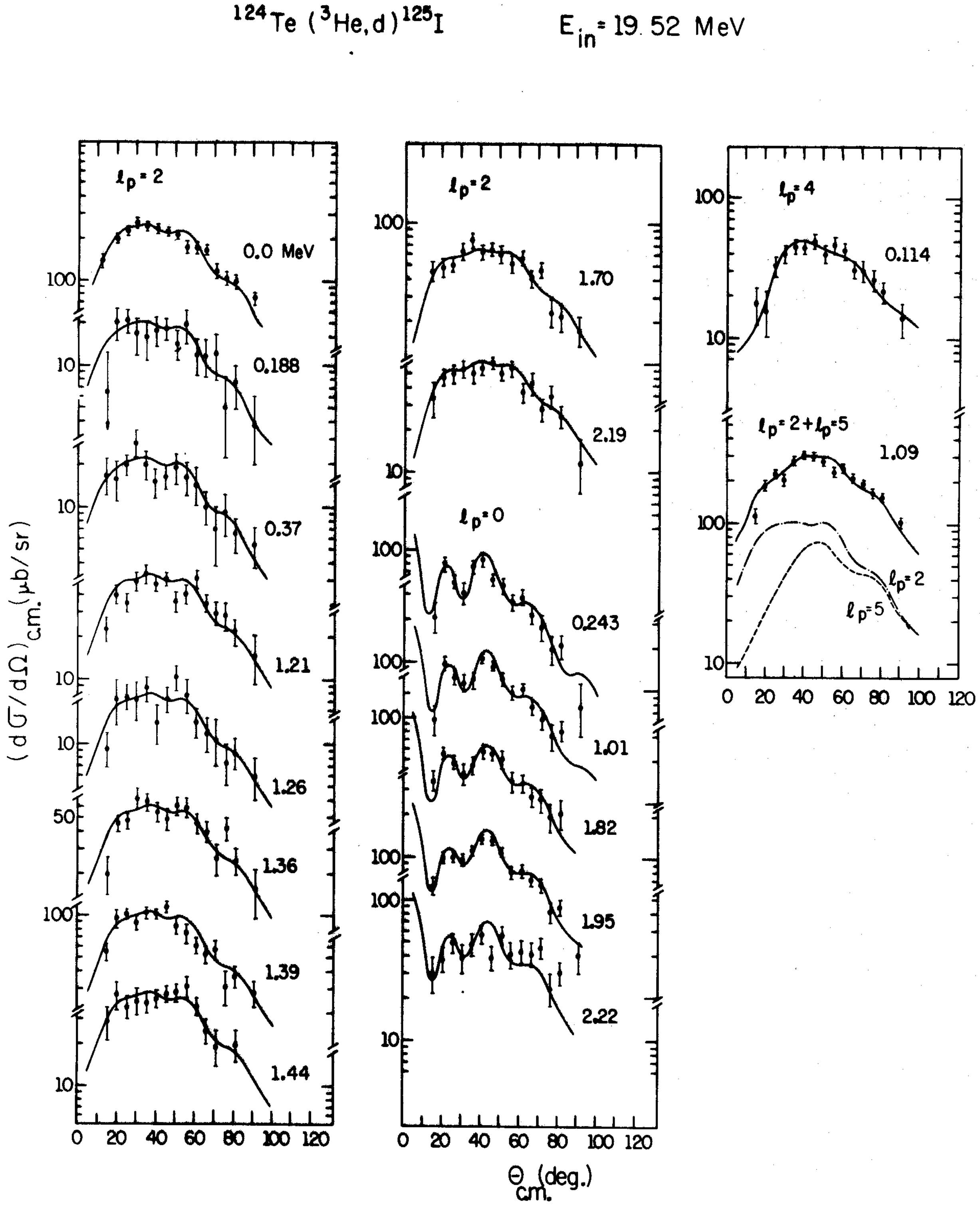

Figure 4: Experimental and calculated angular distributions for the $^{124}Te(^{3}He,d)^{125}I$ reactions.