CERN LIBRARIES, GENEVA

---NIZATION FOR NUCLEAR RESEARCH

CM-P00063941

ELASTIC AND INELASTIC PROTON SCATTERING FROM ^{89}Y

A. Ingemarsson and G. Tibell*)

The Gustaf Werner Institute, University of Uppsala,
Uppsala, SwedenABSTRACT

Angular distributions have been obtained for the polarization in elastic scattering, and for the differential cross-section in elastic and inelastic scattering of 185 MeV protons from ^{89}Y . Only the first excited state at 0.908 MeV, usually considered to be a pure single-particle state, was studied. The elastic scattering data were fitted by optical model calculations and the optical potential obtained was used in DWIA and DWBA calculations for inelastic scattering. Good agreement with the angular distribution for the 0.908 MeV state was obtained both in DWIA and DWBA. However, the DWBA treatment gives abnormal values for the deformation parameters, a fact which can probably be traced back to the single-particle character of this state.

Geneva - 10 March 1978

(Submitted to Nuclear Physics)

*) Present address: Experimental Physics Division, CERN, Geneva, Switzerland.

1. INTRODUCTION

The level structure of ^{89}Y has been the subject of several experimental and theoretical investigations. Scattering and reaction experiments¹⁻³⁾ have been used to reach the excited states, and in particular those below an excitation energy of 3 MeV have been studied quite extensively in (p, p') , $(d, ^3\text{He})$, and $(^3\text{He}, d)$ reactions. The two latter reactions are particularly suitable for a study of the shell-model configurations of the ^{89}Y states. Thus it has been found, for instance, that the first state at 0.908 MeV, with spin-parity $\frac{9}{2}^+$, is well described by the promotion of a $2p_{1/2}$ proton to the $1g_{9/2}$ orbit.

At this Institute a series of experiments have been performed⁴⁾ on the elastic and inelastic scattering of 185 MeV protons, mostly on light or medium-heavy even-even nuclei, such as ^{12}C , ^{16}O , ^{24}Mg , ^{28}Si , ^{32}S , ^{40}Ca , and ^{90}Zr . In most cases both the polarization and the differential cross-section for elastic scattering have been measured, making it possible to carry out meaningful searches for optical potentials. Later these potentials have been used to calculate the distortion in DWIA or DWBA analyses, either of inelastic scattering or, for instance, of the angular distributions obtained in (p, d) experiments. For the nuclei mentioned above, the first few states are often strongly excited by inelastic proton scattering. Using collective models to describe the states, it has been possible to reproduce experimental data in distorted-wave calculations, and the collective parameters obtained (deformation lengths, etc.) agree well with those obtained by other methods.

In order to test the same procedure for a case where the single-particle nature of the state is well established, we chose to study the first excited state of ^{89}Y . We report here on differential cross-sections and polarizations obtained for elastic scattering, and on differential cross-sections for inelastic scattering to the 0.908 MeV state. An optical potential was obtained and used as input to distorted-wave calculations on the angular distribution in inelastic scattering.

2. EXPERIMENTAL DETAILS

The 185 MeV external proton beam of the Uppsala synchro-cyclotron was focused on a target of metallic ^{89}Y . Two target thicknesses were used: for angles below 24° (lab.), 10.6 mg/cm^2 , and for larger angles 112 mg/cm^2 . The beam intensity was about 3×10^{10} protons per sec over a surface of about 4 mm^2 .

Scattered protons were momentum analysed in a magnetic spectrometer and detected in a 16-scintillator hodoscope as described in earlier publications⁴⁾. The polarization measurements for elastically scattered protons were carried out by means of a polarimeter with carbon as the second scatterer. Data-handling procedures for both types of measurements have also been reported earlier^{4,5)}. The absolute calibration of the differential cross-sections was made using a ^{12}C target, where the cross-section for exciting the 4.4 MeV level at $\theta_{\text{lab}} = 17.5^\circ$ is assumed to be known quite accurately. Even so, the absolute error in the differential cross-section is of the order of 10%. However, the relative error between the points mostly amounts to a few percent.

As seen from Table 1, where all the experimental results are presented, the 0.908 MeV state could not be followed down below $\theta_{\text{cm}} \sim 20^\circ$. The reason for this is the relatively poor energy resolution ($\Delta E \sim 300 \text{ keV}$) in conjunction with the target contamination of light elements (mostly oxygen), which made the separation of the small peak due to the 0.908 MeV state impossible (with reasonable errors) for angles below 20° . In this respect the choice of a single-particle state is unfavourable, the cross-section being almost two orders of magnitude lower than for a typical collective level in a lighter nucleus.

3. ELASTIC SCATTERING RESULTS

Optical model calculations to fit the elastic scattering data were performed with a modified and extended version of the program ELSR⁶⁾. Full details about the method of analysis can be found elsewhere^{4,7)}. Corrections due to relativistic kinematics have been incorporated⁷⁾ by calculating the wave number k from the

relativistic momentum in the centre-of-mass system and by multiplying the strengths of the central potentials by the quantity γ_{rel} , given by

$$\gamma_{\text{rel}} = \frac{k^2}{E^2 - M_1^2} \frac{E}{\mu},$$

where E is the sum of the kinetic energies in the centre-of-mass system and the rest mass M_1 of the incident particle, and μ is the reduced mass. The value of γ_{rel} in these calculations was 1.192.

The potentials obtained from the elastic scattering data are found in Table 2 and the calculated angular distributions in Fig. 1. The potential denoted by I was obtained from a free search on all parameters, starting with the values of the parameters for ^{90}Zr reported in Ref. 4 and listed in Table 2.

As seen from the table the radius of the imaginary part of this potential is larger than that of the real part, whereas the opposite is true for the diffuseness parameter a . The same relation holds for the potential found at 100 MeV ⁸⁾ and 185 MeV ⁴⁾ for ^{90}Zr (see Table 2) as well as for many other optical potentials which have been published (see, for instance, Ref. 4).

However, in a recent analysis ⁹⁾ of the elastic scattering of 185 MeV protons from ^{12}C it was found that reasonable fits might be obtained with a smaller radius for the imaginary potential (r_2) than for the real potential (r_1). An optical analysis of elastic scattering results, using 156 MeV protons on eleven target nuclei, in several cases also gave smaller values for the radius of the imaginary potential ¹⁰⁾. Owing to these facts, a second potential was searched for by first performing a search with the fixed values $r_1 = 1.0$ and $r_2 = 1.40$ fm, after which all the parameters were varied. As seen in Table 2 and in Fig. 1 the resulting potential (II) gives a much better fit to the experimental data. In addition, in view of the systematics of neighbouring nuclei, and of the expected energy variation of this quantity, potential II gives a much more reasonable value for the volume integral of the real central potential (J/A in Table 2).

4. INELASTIC SCATTERING RESULTS

Even if the 0.908 MeV state in ^{89}Y is one of the best examples of a "pure" single-particle excitation, it was thought interesting to perform a collective model analysis in order to obtain a comparison with the microscopic results. This was done with the code DWBA¹¹⁾ which includes a deformed spin-orbit interaction of the full Thomas form. The importance of this latter feature was discussed in Ref. 9 for the case of ^{12}C . Figure 2 further illustrates the large contributions from a deformed spin-orbit interaction in the calculation of the differential cross-section in the inelastic scattering of 185 MeV protons. The solid curve shows a calculation with the full Thomas form, the dashed curve with the Oak Ridge (OR) form of the deformed spin-orbit interaction, and the dashed-dotted curve a calculation without any deformed spin-orbit interaction.

Since the code can only treat scattering from spin-zero nuclei, we have to rely on the excited core model. In this model the differential cross-section may be derived from the same quantity obtained for a spin-zero nucleus, and from the resulting deformation it is possible to define a partial deformation length according to

$$\delta_L(I_f) = \left[\frac{(2I_f + 1)}{(2I_i + 1)(2L + 1)} \right]^{\frac{1}{2}} \delta_L.$$

A similar relation holds for the deformation parameters, β_L . In these calculations, equal deformation lengths were used for all form factors. The resulting curves for potentials I and II are shown in Fig. 3, and it is seen that quite reasonable agreement with experimental data is achieved. The resulting deformation lengths quoted in Table 3 are seen to be very similar for the two potentials. The deformation parameters, however, differ much more, and we may observe that the trend pointed out by Scott et al.²⁾ of smaller values of β with increasing energy (see Table 3), seems to continue between 50 and 185 MeV, at least for potential II. It should be pointed out, however, that the calculations for the lower energies were performed with equal deformation parameters and not, as here, with equal deformation lengths.

The microscopic calculations were performed with the DWIA-code Reseda¹²⁾. Compared to earlier calculations with this code, the radial wave functions were now generated from a Woods-Saxon potential instead of from a harmonic oscillator. The radial parameters r and a in this potential were 1.1 and 0.7, respectively, and the spin orbit potential V_{so} was related to the central potential V_c by $V_{so} = -0.22 V_c$.

The 0.908 MeV state is described by the excitation of the single proton in the $2p_{1/2}$ state to the $1g_{9/2}$ state. There are thus four participating triads (LSJ), namely (505), (515), (514), and (314). As for the DWBA-code, this code can only be used for spin-zero nuclei. For this reason we performed two different calculations: one for the excitation ($0^+ \rightarrow 4^-$) and one for ($0^+ \rightarrow 5^-$). The results are shown in Fig. 4 for both potentials, and we observe that the shapes are rather different but that the magnitudes are about the same. It should also be noted that in some parts of the angular region studied, the ($0^+ \rightarrow 4^-$) transition gives considerable contributions to the cross-section, implying that it is very important to include the spin-flip contribution. Since the amplitudes belonging to different values of J were found to be rigorously incoherent for 14.7 MeV proton scattering¹³⁾, we simply added the results for the differential cross-sections. Figure 5 shows that the agreement with the experimental data is very good, in shape as well as in magnitude. There is some preference for potential II exactly as for the elastic scattering.

Thus as a conclusion it may be remarked that the scattering of 185 MeV protons from the $9/2^+$ state at 0.908 MeV in ^{89}Y is reasonably well reproduced by microscopic calculations in which this state is described as a single-particle state $(2p_{3/2})^{-1} 1g_{9/2}$. Macroscopic calculations, however, also give reasonable fits to the data, but the smallness of the deformation, together with the fact that there is a trend in the deformation parameter with energy, reflects the fact that this transition is a single-particle transition.

Acknowledgements

The authors are grateful to Dr. O. Sundberg for help with the calibration.

This work was financially supported by the Swedish Atomic Research Council.

REFERENCES

- 1) W. Benenson, S.M. Austin, R.A. Paddock and W.G. Love, Phys. Rev. 176 (1968) 1268.
- 2) A. Scott, M.L. Whiten and W.G. Love, Nuclear Phys. A137 (1969) 445.
- 3) M.M. Stautberg, J.J. Kraushaar and B.W. Ridley, Phys. Rev. 157 (1967) 977.
- 4) See, for instance: A. Ingemarsson and G. Tibell, Physica Scripta 4 (1971) 235, 10 (1974) 159, and references therein.
- 5) B. Höistad, A. Ingemarsson, A. Johansson and G. Tibell, Nuclear Phys. A119 (1968) 290.
- 6) W.R. Smith, Atlas Computer Laboratory, Nuclear Physics Programme Library, Report No 9, Los Angeles (February 1967).
- 7) A. Ingemarsson, Physica Scripta 9 (1974) 156.
- 8) K. Kwiatkowski and N.S. Wall, University of Maryland, Dept. of Physics and Astronomy Preprint PHY 76-6, September 1977.
- 9) A. Ingemarsson, A. Hallgren and O. Jonsson, Gustaf Werner Institute, Internal Report GWI-PH 4/76, June 1976.
- 10) V. Comparat, R. Frascaria, N. Marty, M. Morlet and A. Willis, Nuclear Phys. A221 (1974) 403.
- 11) H. Sherif, private communication, and Nuclear Phys. 131 (1969) 532.
- 12) A. Willis, private communication.
- 13) Y. Awaya, J. Phys. Soc. Japan 23 (1967) 673.

Table 1

Experimental results on 185 MeV proton scattering
from ^{89}Y : elastic and inelastic ($Q = -0.908$ MeV)

θ_{cm}	Elastic peak		0.908 MeV peak $\frac{d\sigma}{d\Omega_{\text{cm}}} \text{ (mb/sr)}$
	$\frac{d\sigma}{d\Omega_{\text{cm}}} \text{ (mb/sr)}$	Polarization	
5.07		0.325 ± 0.033	
7.60		0.533 ± 0.028	
10.14	814 ± 82	0.699 ± 0.030	
12.16	97.3 ± 4.9		
12.67		0.667 ± 0.036	
14.19	47.5 ± 1.9		
15.20		0.241 ± 0.037	
16.21	100.8 ± 3.0		
17.73	101.5 ± 0.5	0.689 ± 0.039	
18.24	105.7 ± 3.2		
20.27	53.8 ± 1.9	0.889 ± 0.032	0.12 ± 0.02
22.29	17.69 ± 0.53		0.099 ± 0.013
22.80		0.574 ± 0.050	
24.32	8.11 ± 0.22		0.103 ± 0.007
25.33		-0.145 ± 0.053	
26.34	8.46 ± 0.38		0.090 ± 0.009
27.86		0.386 ± 0.053	
28.36	8.25 ± 0.37		0.066 ± 0.008
30.39	5.60 ± 0.25	0.839 ± 0.045	0.043 ± 0.005
32.41	3.07 ± 0.11		0.032 ± 0.004
32.92		0.816 ± 0.053	
34.43	1.68 ± 0.06		0.015 ± 0.002
35.45		0.167 ± 0.057	
36.46	0.800 ± 0.020		0.0098 ± 0.0010
38.48	0.619 ± 0.025		0.0094 ± 0.0020
40.50	0.413 ± 0.015		0.0072 ± 0.0009

Table 2

Optical potentials obtained for ^{89}Y in the present work (I and II) and at 156 MeV ¹⁰⁾ together with potentials obtained for ^{90}Zr at 185 MeV ⁴⁾, 156 MeV ¹⁰⁾ and 100 MeV ⁸⁾

Nucleus	^{89}Y			^{90}Zr		
Parameter						
	Pot. I (present results)	Pot. II (present results)	Ref. 10 (156 MeV)	Ref. 4 (185 MeV)	Ref. 10 (156 MeV)	Ref. 8 (100 MeV)
V	7.15	13.3	15.7	10.2	12.0	32.4
r_1	1.07	1.28	1.31	1.14	1.41	1.15
a_1	0.72	0.65	0.60	0.55	0.56	0.78
W	16.4	18.0	17.0	10.8	12.0	7.95
r_2	1.29	1.10	1.09	1.36	1.25	1.46
a_2	0.58	0.92	0.95	0.42	0.43	0.41
V_{so}	3.95	2.90	2.46	2.10	2.00	4.32
W_{so}	-3.69	-2.98	-2.08	-2.49	-1.65	-2.07
r_{so}	1.04	1.05	1.08	1.10	1.08	1.07
a_{so}	0.61	0.64	0.63	0.68	0.71	0.58
σ_R	1057	1024	975	933	801	1085
J/A	52.7	158	163	71	150	251
χ_{total}	2.44	1.78		2.15		1.0

Table 3

Deformation parameters β_5 and deformation lengths δ_5 obtained from three proton scattering experiments at 24.5 ¹⁾, 61.2 ²⁾ and 185 MeV (present results)

Proton energy (MeV)	24.5	61.2	185	
			Pot. I	Pot. II
Parameter				
β_5	0.0604	0.0451	0.042	0.034
$\beta_5(^{9/2})$	0.0408	0.0305	0.028	0.023
δ_5			0.198	0.193
$\delta_5(^{9/2})$			0.133	0.130

Figure captions

- Fig. 1 : Differential cross-sections and polarization in elastic scattering of 185 MeV protons from ^{89}Y versus scattering angle. The curves are optical model fits with two different potentials I and II, given in Table 2.
- Fig. 2 : DWBA calculations for 185 MeV proton scattering to the 0.908 MeV state in ^{89}Y with different shapes of the deformed spin-orbit interaction (full Thomas form or OR-form) and without such a term.
- Fig. 3 : DWBA calculations for 185 MeV proton scattering to the 0.908 MeV state in ^{89}Y with the full Thomas form for the deformed spin-orbit interaction. The potentials used are listed in Table 2. The points represent the present experimental results.
- Fig. 4 : DWIA calculations for 185 MeV proton scattering to the 0.908 MeV state in ^{89}Y with two different distorting potentials (I and II of Table 2) and two different ΔJ values, 4 and 5. The experimental points are also shown.
- Fig. 5 : The same as Fig. 4, but with the results for $\Delta J = 4$ and 5 added. As in the previous figures, the points are the present experimental data.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5