ELASTIC SCATTERING OF PROTONS BY Si^{30} NUCLEI

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The differential cross section for elastic scattering of protons by Si^{30} nuclei is measured for proton energies between 1000 and 3650 keV and at c.m.s. angles 90, 125, and 141°. In the energy range investigated, 52 resonances were observed which are related to the excited states of the P^{31} nucleus. The most pronounced resonances are analyzed in the single-level approximation of dispersion theory.

INTRODUCTION

THE capture of protons by Si^{30} nuclei has been the subject of many investigations, the results of which are summarized in the review of Endt and Van der Leun[1]. In the proton energy interval from 1.0 to 2.7 MeV, the (p, γ) reaction was previously investigated in our laboratory[2]. Barnard et al[3] investigated the reactions (p, γ) and $(p, p'\gamma)$ at proton energies from 1.0 to 4.25 MeV.

The preceding investigations of the (p, γ) reactions have established uniquely the characteristics of the low-lying levels of P^{31}. Information on the high-lying levels is scanty in these reports. The purpose of the present investigation was a study of the elastic scattering $Si^{30}(p, p)Si^{30}$ at proton energies from 1 to 3.65 MeV.

MEASUREMENT PROCEDURE

The relatively high level density of P^{31} in the investigated excitation-energy interval calls for a good energy resolution. Monoenergetic protons were obtained in the electrostatic accelerator of the Physico-technical Institute of the Ukrainian Academy of Sciences. The proton energies were measured with an electrostatic analyzer accurate to ± 0.05 per cent. The scattered protons were analyzed with a magnetic spectrometer and detected with a thin CsI(Tl) crystal. The primary-beam proton current was measured with a Faraday cup and a current integrator.

A thin Si^{30} target was prepared in a magnetic separator by intrusion of Si^{30} into a substrate of pure graphite. The surface of the graphite substrate was carefully polished and rid of contaminations.

The spectrum of the protons elastically scattered by the elements contained in the target is shown in Fig. 1. The graphite substrates turn out to be much better than the previously employed beryllium substrates for the following reasons:

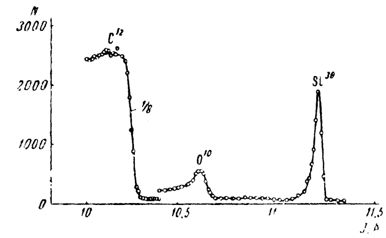

FIG. 1. Spectrum of protons elastically scattered from a target containing Si^{30} at an angle $\theta = 141°$ and an energy $E_p = 2025$ keV.

1) The Si^{30} contents in the graphite substrate is eight times larger than in the beryllium substrate for the same exposure in the magnetic separator.

2) No side reactions (p, n), (p, d), and (p, α) take place, so that the experiment is appreciably simplified.

The thicknesses of the employed Si^{30} targets were from 2 to 3 keV for protons with energy 3 MeV. The number of nuclei in the target was estimated from an experiment wherein the protons were scattered at 141° at low energies, where the main contribution to the cross section is made

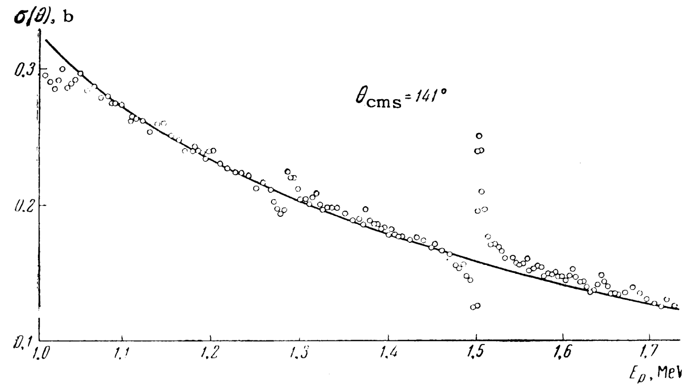

FIG. 2. Cross section for the elastic scattering of $Si^{30}(p, p)Si^{30}$ at 141° in the center of mass. The thick line shows the cross section of the Rutherford scattering.

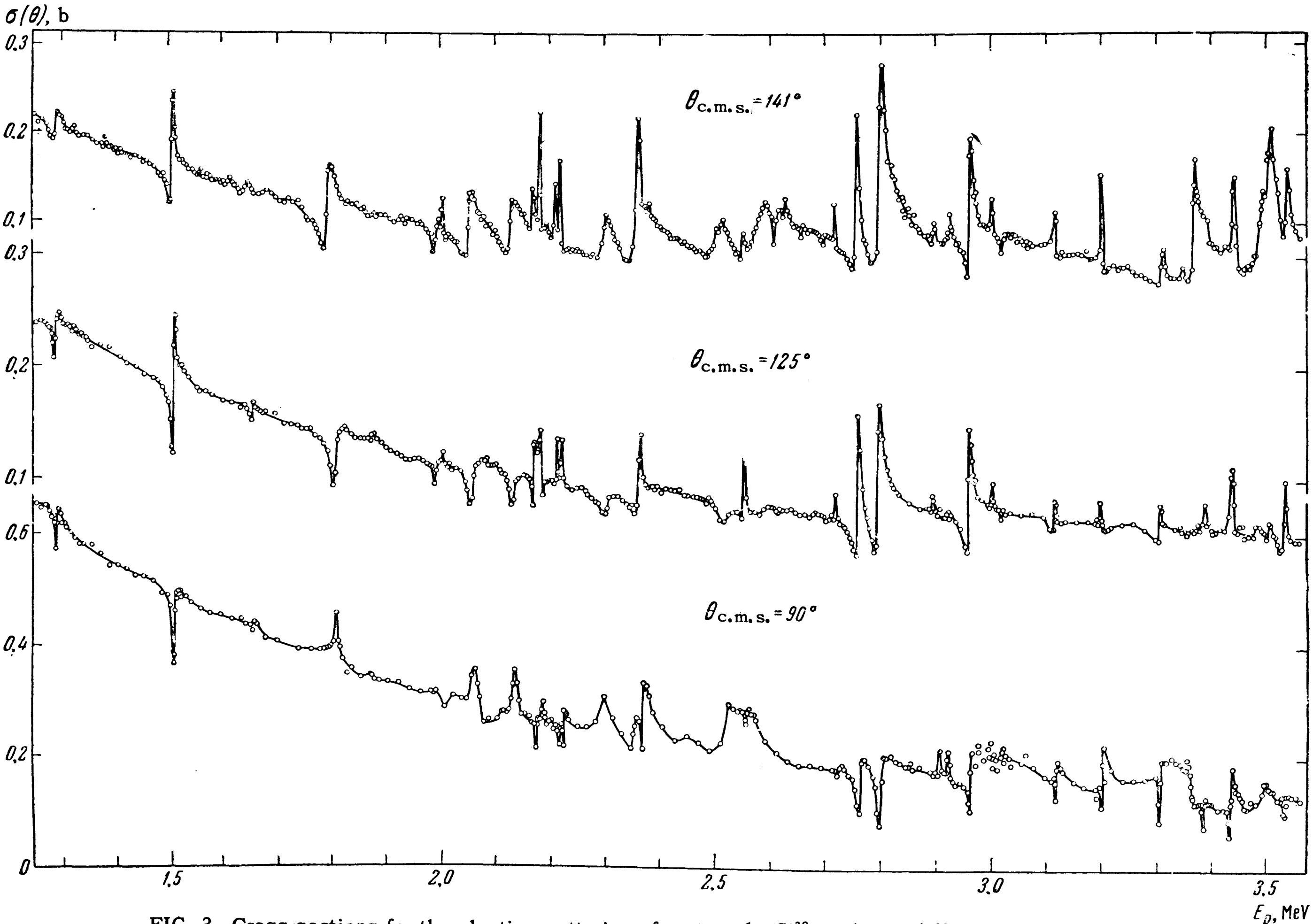

FIG. 3. Cross sections for the elastic scattering of protons by Si^{30} nuclei at different angles (c.m.s.).

Number	E_p, keV	E_{exc}, keV	Γ, keV	l	$J\pi$	Number	E_p, keV	E_{exc}, keV	Γ, keV	l	$J\pi$
1	1030	8283				27	2620	9821			
2	1292	8536	<3	0	$1/2^+$	28	2632	9833			
3	1325	8568				29	2660	9860			
4	1514	8751	4	0	$1/2^+$	30	2700	9900			
5	1660	8892				31	2722	9920	<3	2	$3/2^+$, $5/2^+$
6	1812	9039	7	1	$3/2^-$	32	2762	9959	10	0	$1/2^+$
7	1879	9104				33	2798	9994	13	0	$1/2^+$
8	1996	9217	6	0,1	$1/2$, $3/2^-$	34	2851	10045			
9	2011	9232	<3	2	$3/2^+$, $5/2^+$	35	2908	10100	<3	3	$5/2^-$, $7/2^-$
10	2025	9245				36	2924	10115	<3	3	$5/2^-$, $7/2^-$
11	2062	9281	15	1	$3/2^-$	37	2962	10152	6	0	$1/2^+$
12	2092	9310				38	3005	10194	<3	2	$3/2^+$, $5/2^+$
13	2125	9342				39	3021	10209	<3	1	$1/2^-$
14	2138	9355	11	1	$3/2^-$	40	3118	10303	<3	2	$3/2^+$, $5/2^+$
15	2176	9392	<3	0	$1/2^+$	41	3202	10385	4	2	$5/2^+$
16	2189	9404	<3	3	$5/2^-$, $7/2^-$	42	3308	10487	<3	0	$1/2^+$
17	2192	9407				43	3349	10527			
18	2217	9431	<3	2	$3/2^+$, $5/2^+$	44	3370	10547			
19	2225	9439	<3	2	$3/2^+$, $5/2^+$	45	3389	10565	<3	2	$3/2^+$, $5/2^+$
20	2302	9514	14	1	$3/2^-$	46	3438	10614	6	2	$3/2^+$
21	2361	9571				47	3462	10636			
22	2374	9583				48	3496	10669			
23	2502	9707				49	3505	10678			
24	2517	9722				50	3511	10684			
25	2557	9760				51	3535	10707	5	0,2	$1/2^+$, $3/2^+$, $5/2^+$
26	2592	9794				52	3637	10806	<3	1	$1/2^-$, $3/2^-$

by Coulomb scattering (Fig. 2). The errors in the determination of the relative cross section do not exceed 3 per cent.

MEASUREMENT RESULTS

Figures 2 and 3 show the differential cross section for the $Si^{30}(p, p)Si^{30}$ elastic scattering at 90, 125, and 141° in the center of mass, in the proton energy interval from 1.0 to 3.6 MeV. The good energy resolution has made it possible to observe a relatively sharp resonant pattern in the elastic scattering. A considerable contribution to this was made by the fact that most resonances observed were narrow.

The table lists information on the positions of the resonances and the corresponding P^{31} levels. In the calculation of the excitation energy of the levels we used 7.286 MeV for the binding energy of the proton in the P^{31} nucleus. Data on the positions of the resonances are in good agreement with the results of the cited investigations [2,3]. The appreciable number of resonances observed in the (p, γ) reactions do not occur in elastic scattering. This can be attributed to the fact that the P^{31} levels with large momenta manifest themselves weakly in elastic scattering, inasmuch as the penetrability of the Coulomb barrier for protons with large orbital momenta is small.

An analysis of the resonances was made by the method described by the Laubenstains [4]. Only the most clear-cut resonances were subjected to the analysis. Figure 4 shows the theoretical forms of the resonances of the $Si^{30}(p, p)Si^{30}$ reaction at $E_p = 1.7$ MeV for $l < 4$. Inasmuch as the nonresonant phases vary smoothly with energy, it was enough

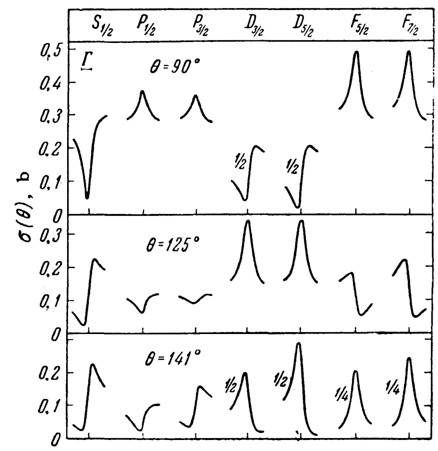

FIG. 4. Theoretical forms of the resonances of the $Si^{30}(p, p)Si^{30}$ reaction at $E_p = 1.7$ MeV for $l = 0$, 1, 2, and 3 (the markers on the abscissa axis represent E_{res}).

to carry out similar calculations at $E_p = 3.4$ MeV. The possible values of the spins and parities of the P^{31} levels were determined by comparison of the theoretical and calculated forms of the resonances. An analysis of the resonances in elastic scattering at energies less than 2.5 MeV was facilitated by the fact that there are no other channels for the $Si^{30} + p$ reaction, except for radiative capture. In this case it is natural to assume that $\Gamma_p = \Gamma$. The table lists the values of the widths, spins, and parities of the P^{31} levels obtained in our work.

DISCUSSION OF RESULTS

Of all the previously analyzed [2] resonances, only one, at $E_p = 1514$ keV, manifests itself clearly in elastic scattering. Our measurements have made it possible to make more precise the spin and parity of the corresponding P^{31} level with excitation energy 8.751 MeV. The form of this resonance is in very good agreement with the assumption that $l = 0$ and $J = 1/2^+$. It is also interesting to compare our data with the results of Barnard et al [3] on inelastic scattering. As follows from the cited work, all the levels in the excitation-energy intervals between 10.3 and 10.7 MeV have odd parity. Our data on elastic scattering show that some of these levels have even parity.

Resonance at $E_p = 3202$ keV. The minimum at 90° in the elastic-scattering section shows that the resonance is connected with the even value of the orbital momentum. The form of this resonance at other angles agrees with the assumption that $l = 2$. The angular distribution of the gamma rays in the reaction $(p, p'\gamma)$, as follows from [3], has the form $W(\theta) = 1 + 0.478 P_2 - 0.426 P_4$, and the theoretical distribution for the case $J = 5/2^+$ will be $W(\theta) = 1 + 0.57 P_2 - 0.57 P_4$ (P_2 and P_4 are Legendre polynomials). The difference in the coefficients can be due to interference with the closely-lying resonance at $E_p = 3223$ keV, the characteristics of which are unknown. We can thus conclude that the 10.385-MeV level has spin and parity $5/2^+$.

Resonance at $E_p = 3308$ keV. According to our measurements, this resonance is connected with a capture of an S-state proton, while the spin and parity corresponding to 10.487 MeV are $1/2^+$. The angular distribution of the gamma rays should be isotropic in this case, which does not agree with the measurements of [3].

Resonance at $E_p = 3438$ keV. This resonance manifests itself very clearly in elastic and inelastic scattering. Its form in elastic scattering agrees well with the assumption $l = 2$. The angular distribution of the gamma rays, measured in [3], has a form $W(\theta) = 1 + 0.447 P_2$, and that theoretically determined for the case $J = 3/2^+$ has the form $W(\theta) = 1 + 0.5 P_2$. The absence of a term with P_4 from the angular distribution enables us to exclude the value of $5/2^+$ for the spin of the 10.614-MeV level. Consequently, the spin and parity of the 10.614 MeV level are $3/2^+$.

The information obtained in the present investigation on the high-lying levels of P^{31} may prove useful for a further study of the capture of protons by Si^{30} nuclei.

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