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POLARIZATION OF PROTONS SCATTERED BY O^{16} SPIN AND PARITY OF THE 3.11-Mev LEVEL OF THE F^{17} NUCLEUS

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The polarization of protons scattered by O^{16} nuclei is investigated in the 2.6 – 2.8 Mev energy range. The measured value of the polarization, its resonance character, and its sign imply that the 3.11-Mev level of F^{17} has the characteristics $(1/2)^-$.

INTRODUCTION

THE levels of the F^{17} nucleus have been studied in investigations on the elastic scattering of protons by O^{16}. In the work of Ref. 1, carried out with an electrostatic generator, the p–O^{16} scattering was studied in the energy interval 0.6 – 4.5 Mev at a center-of-mass angle of 165°.

The determination of the characteristics of the levels of F^{17}, using the data of Ref. 1, are presented in Ref. 2 and are based on the resonance theory[3] with the help of the method of vector diagrams. As is shown in Ref. 2, the parameters of the low-lying levels of F^{17} are the most reliably determined: the 0.55-Mev $(1/2)^+$, 3.11-Mev $(1/2)^+$, and 3.88-Mev $(7/2)^-$ levels. References 4 and 5 are fairly short communications on experiments on p–O^{16} scattering, also carried out with electrostatic generators. In Ref. 4, the p–O^{16} scattering was investigated in the interval 0.28–4.6 Mev for nine values of the scattering angle, and in Ref. 5 in the interval 2.5–5.6 Mev for four values of the angle. The results of the measurements and their analysis in these investigations are not presented. Instead it is only indicated that, in disagreement with Ref. 2, the 3.11-Mev level of F^{17} is a $(1/2)^-$ state. The work of Ref. 6 was carried out with a cyclotron in the energy interval 3 – 7 Mev for eight values of the scattering angle.

The published information on the F^{17} levels is far from being complete and is not completely unambiguous. It appears expedient to use for the analysis of the levels of F^{17} information on the polarization of protons after p–O^{16} elastic scattering. The complete and unique phase analysis of the p–O^{16} scattering might be carried out if one could determine the angular dependence both for the effective scattering cross section and for polarization over a large interval of proton energies. However, even in the frame of resonance theory information on polarization is of value. The parameters of the levels of the compound nucleus, determined with the help of this theory, from the analysis of the energy dependence of the scattering cross section are related directly to the magnitudes of the phase shifts in scattering, and therefore, also with the values of the polarization.

We undertook the investigation of the polarization of protons upon p–O^{16} elastic scattering with the goal of the unambiguous solution of the question of the spin and parity of the 3.11-Mev level of the F^{17} nucleus.

1. RELATION BETWEEN THE POLARIZATION OF THE PROTONS AND THE CHARACTERISTICS OF THE 3.11-Mev LEVEL OF THE F^{17} NUCLEUS

According to Ref. 2, the resonance in the p–O^{16} scattering cross section at an energy of 2.66 Mev locates a 3.11-Mev level in the F^{17} nucleus, where this level is a $(1/2)^+$ state. The possibility of $(1/2)^-$, $(3/2)^-$, and $(3/2)^+$ states for this level are rejected by means of a comparison of the detailed form of the experimental curve with theoretical predictions. In Refs. 4 and 5 from measurements of the scattering cross section at an angle of 90° a deduction is made that this level has the characteristics $(1/2)^-$. However, it should be remarked that on the basis of the measurements at 90° one can eliminate the possibility $(3/2)^+$ but one cannot make an unambiguous choice between $(1/2)^-$ and $(3/2)^-$ states, since the energy

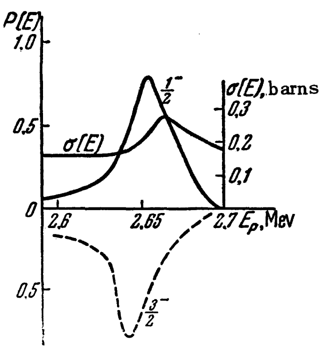

FIG. 1. $\theta = 60°$ in the center of mass system.

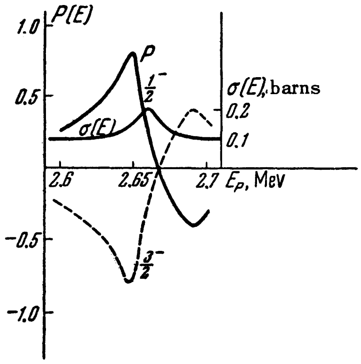

FIG. 2. $\theta = 90°$ in the center of mass system.

dependences of the cross section at this angle are exactly the same for the two possibilities indicated.

In order to identify nuclear levels, information on the analogous levels of mirror nuclei is often used. However information on the spin and parity of the 3.06-Mev level of the mirror nucleus O^{17} is not available.

We carried out calculations on the energy dependence of the polarization of the protons near the 2.66-Mev resonance for three assumptions of the spin and parity of the 3.11-Mev level. The calculations were carried out on the basis of the resonance theory for the following values of the parameters:[2] the radius of the potential scattering was taken to be 6.9×10^{-13} cm for S–waves, and 5.31×10^{-13} cm for P– and D-waves; for the lower $S_{1/2}$-resonance $E_\lambda = -0.436$ Mev; $\gamma_\lambda^2 = 7 \times 10^{-13}$ Mev-cm.

For the resonance studied $E_R = 2.66$ Mev, $\Gamma = 19.9$ kev. Figures 1 and 2 show the calculated energy dependence of the polarization for angles of 60° and 90° in the c.m.s. under the assumptions that the 3.11-Mev level is either a $(1/2)^-$ or a $(3/2)^-$ state. If the 3.11-Mev level has a $(1/2)^+$ character, the polarization must be equal to zero.

The weak effect of the levels located higher than 3.11 Mev was not taken into account in these calculations. It is possible that the influence of the higher levels will result in a deviation from zero polarization even in the case of a 3.11-Mev $(1/2)^+$ state. However, an estimate made by us shows that the magnitude of the polarization in this case will not be greater than 5 — 10%, and the dependence of the polarization on energy near 2.66 Mev will not have a resonance character. The form of the curves also changes little upon calculations (including) the upper levels.

One can make the deduction that in order to make a choice between the various values of the spin and parity of the 3.11-Mev level it is enough to carry out measurements of the polarization of the protons at some one angle of the p–O^{16} scattering at energies near the 2.66 Mev resonance.

2. EXPERIMENTAL METHOD AND RESULTS

The measurements of the polarization of the protons were carried out with the aid of the equipment used in Ref. 7 for the investigation of the polarization of protons in scattering from C^{12}. The work was done with the electrostatic generator of the Physico-Technical Institute of the Academy of Sciences of the Ukrainian S.S.R.

The beam of protons from the electrostatic generator passed in a chamber where the scattering of the protons from an Al_2O_3 target took place. The protons, scattered through an angle of 60° in the center of mass system, passed into a helium analyzer with the aid of which the extent of the polarization of the scattered beam was determined. The 60° angle was chosen because the polarization at this angle does not change sign in the region of the resonance.

The Al_2O_3 target was prepared by anode oxidation of an aluminum foil in a weak solution of sulphuric acid. Non-oxidized aluminum was removed by dissolving it in concentrated hydrochloric acid. In this way a very clean and uniform film of Al_2O_3 was obtained. The thickness of the target used in the measurements was 0.47 mg/cm². The presence of aluminum in the Al_2O_3 target made it necessary to make a special investigation under the same conditions of the polarization of protons scattered elastically from aluminum. In these experiments an aluminum target of 0.27 mg/cm² thickness was used. The targets, over an appreciable period of time, were not destroyed for beam currents of 2 — 3 μa.

E_p, Mev	R for Al_2O_3	R for Al	R for C^{12}
2.500	—	0.94±0.03	—
2.600	1.01±0.03	0.96±0.03	—
2.650	1.17±0.03	0.96±0.03	—
2.675	1.14±0.03	0.93±0.03	1.32±0.03
2.700	1.12±0.03	1.01±0.03	—
2.725	1.13±0.03	1.01±0.03	—
2.750	1.05±0.03	1.10±0.03	—
2.800	1.03±0.03	1.07±0.03	1.35±0.03
3.060	—	1.00±0.03	—

Measurements were made on the magnitude of the asymmetry R upon scattering from He^4 of protons incident in the helium analyzer chamber after primary scattering on targets of Al_2O_3, Al and on a C^{12} film of 2 mg/cm^2 thickness. The measurements with carbon were made with the aim of calibrating the helium analyzer. The results of these measurements are presented in the table. E_p is the energy of the protons incident on the first target. The errors shown are root mean square errors.

3. DISCUSSION OF THE RESULTS

From the data presented in the table it follows definitely that the asymmetry observed in the case of the Al_2O_3 target is related to the polarization of protons scattered by O^{16} nuclei. The resonance character and the presence of this asymmetry show that the investigated resonance cannot be related to the excitation of a $(1/2)^+$ state of the F^{17} nucleus.

The value of $\overline{P}_{ox}$, the polarization in $p-O^{16}$ scattering, averaged over the energy interval, corresponding to the ionization energy loss of the protons in the target, was calculated from the obtained values of R. The asymmetry observed in the case of the Al_2O_3 target is related to the polarization of the scattered beam according to the formula

$$R = (1 - \overline{P}P_{\text{eff}})/(1 + \overline{P}P_{\text{eff}}),$$

where P_{eff} is the effective value of the polarization of the protons scattered in the helium analyzer, $\overline{P}$ is the polarization of the proton beam scattered by the target. The value P_{eff} was determined in the experiments with the carbon target. The value of the polarization in proton scattering from C^{12} at an angle of 60° in the energy interval 2.6 — 2.8 Mev was taken from Ref. 8. The results of Ref. 7 were also used. The value P_{eff} is a constant in the 2.6 — 2.8 Mev interval and is equal to 0.80 ± 0.07.

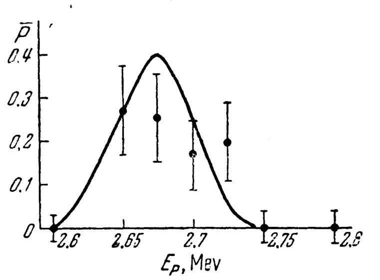

FIG. 3

The value of the polarization in $p-O^{16}$, $\overline{P}_{ox}$, is related to $\overline{P}$ by the formula

$$\overline{P}_{ox} = \left[\overline{P}\left(1 + \frac{3}{2}\frac{\sigma_{ox}}{\sigma_a}\right) - \overline{P}_a\right] \Big/ (3\sigma_{ox}/2\sigma_a),$$

where $\overline{P}_a$, the value of the polarization in proton scattering from aluminum nuclei in the Al_2O_3 target, was determined from the experiments with the pure Al; σ_{ox} is the scattering cross section of the protons on oxygen at an angle of 60°; σ_a is the same quantity for aluminum. The ratio σ_{ox}/σ_a was determined by us experimentally. The experimental values of $\overline{P}_{ox}$ are presented in Fig. 3. The full curve represents the theoretical dependence of $\overline{P}_{ox}$ with energy, computed with the aid of the $(1/2)^-$ curve of Fig. 1 and the data on the energy loss of protons in Al_2O_3.

The errors in the experimental points are determined from the errors in the determinations of R for the Al_2O_3 and Al targets and also the magnitudes of the errors in P_{eff} and σ_{ox}/σ_a. Because of the relatively large errors in the experimental values of $\overline{P}_{ox}$, a detailed comparison of the form of the theoretical curve for $\overline{P}_{ox}$ with the results of the investigation are not useful particularly since it is not required for an unambiguous conclusion on the character of the 3.11 Mev level.

The measurement of the magnitude of the polarization, its resonance character and its sign permit the conclusion that the 3.11-Mev level of the F^{17} nucleus can be neither a $(1/2)^+$ nor a $(3/2)^-$ state, and is a $(1/2)^-$ state.

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122

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THE PHASE DIAGRAM FOR CERIUM

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The p–T diagram of 99.8% pure cerium has been measured from – 150° to + 100°C over a pressure interval up to 12,000 kg/cm^2. In the p–T plane the phase equilibrium line is a straight line whose slope is 43 kg/cm^2–°C. It is shown that the transition at atmospheric pressure and low temperature is the same as that which occurs at room temperature and high pressure.

BRIDGMAN has observed a polymorphous transition in cerium at high pressure. His data on the transition pressure, however, is inconsistent. In 1927 he found[1] that the transition pressure was 7600 kg/cm^2 at 30°C and 9400 kg/cm^2 at 75°C. Later data[2] gave 12,430 kg/cm^2 at room temperature, which Bridgman explained in terms of the insufficient purity of his old sample. Later measurements of the electric resistance[3] showed, however, that the transition lies in the vicinity of 7000 kg/cm^2 at room temperature.

Lawson[4] has used x-ray methods to investigate the structure of cerium above the transition pressure, and found that on passing through the transition the lattice remains face-centered cubic. All that happens is that the lattice constant decreases by amount corresponding to the sum of the volume change in the transition and the compressibility of cerium. In addition, it is known that at atmospheric pressure cerium undergoes a transition with a volume change of the order of 10%; when the temperature is lowered, this transition takes place at – 164°C, and when it is raised, the transition occurs at – 98°C. All the data with respect to this transition has been collated by Trombe and Foëx.[5] X-ray investigations[6] have shown that the lattice again remains face-centered cubic and that only the lattice constant changes.

It is known that at room temperature cerium has two modifications, the face-centered cubic and the close-packed hexagonal. This latter modification is obtained by slow cooling from 400°C, and for it no low-temperature polymorphous transition is observed. Up to the present, however, the question of the relation between the low-temperature and the high-pressure transitions has remained unanswered. In order to clarify this subject we have measured the temperature dependence of the cerium transition pressure in the temperature range from – 185 to + 100°C on an instrument designed for measuring compressibility of solids.

This instrument (Fig. 1) is a multiplier whose low-pressure press has a piston 1 without packing, so that friction losses are reduced to a minimum. This piston is carefully ground to fit a cylinder 2 with a clearance of about 0.05 mm for a diameter of 192 mm. This high piston diameter makes it possible to operate at relatively low oil pressures in the cylinder (of the order of tenths of a kg/cm^2), so that with a highly viscous oil (in our case, castor oil) there is little leakage through the clearance. The leakage losses are compensated for by a fine regulation valve leading to a reservoir in which the oil pressure is maintained by an air cushion. In this way one may maintain a given constant pressure on the cylinder, or