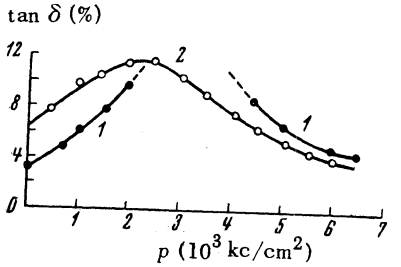

FIG. 8. The dependence of the tangent of the loss angle on pressure at different frequencies ($t = 7°$) $1 - f = 464$ kc/sec; $2 - f = 1.48$ mc/sec.

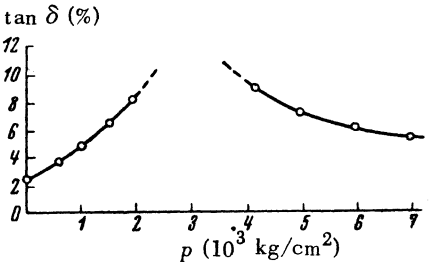

FIG. 9. The dependence of the tangent of the loss angle on pressure at temperature 5° and $f = 144$ kc/sec.

polar molecules in liquids which are under high pressure. As is seen in Figs. 8 and 9, where the dependence of tanδ on the pressure at temperatures of 5° and 7° at different frequencies is shown, the value of tanδ in relation to the pressure passes through a maximum and then at even higher pressure diminishes. It is clear that the values of the phase angle are relatively small at both low pressures and very high pressures due to the strong interactions between molecules. In this way at low pressures tanδ will be small, then the value of the tangent of the phase angle will rise with an increase in pressure and pass through a maximum beyond which it will diminish, when the strong interactions between molecules reach the value where the external high frequency electric field can not turn the polar molecules through a significant angle.

As was to be expected, at increased temperatures the measurements (see Fig. 7) lead to lower values of tanδ, which follows from the dependence of the viscosity of liquids on temperature.

We express thanks to laboratory mechanic S. J Vlasov, who made the necessary apparatus.

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SOVIET PHYSICS JETP VOLUME 3, NUMBER 4 NOVEMBER, 1956

Magnetic Analysis of the (d,p) Reaction Products in the Investigation of Spin and Parity of Levels of the Daughter Nucleus

IU. A. NEMILOV AND V. F. LITVIN
Radium Institute, Academy of Sciences, USSR
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The energy dependence of the intensity ratio of different proton groups from the reaction $Al^{27}(d,p)Al^{28}$ has been utilized to determine possible spin and parity values of some levels in Al^{28}. The obtained results give for the level at 1.625 mev; even parity, spin between 0 and 5; at 5.128 mev: odd parity, spin between 0 and 6, and at 5.435 mev: odd parity, and spin between 1 and 4.

BY observing the angular distribution of proton or neutron groups in stripping reactions it is possible to limit the possible values of spin and to determine the parity of excited states of the daughter nucleus.[1]

In this way the characteristics of excited states of light nuclei and of some low levels of heavier nuclei have been determined. However, it is not possible to employ the usual techniques of determining the angular distributions in the region of higher excitation in heavier nuclei, where the levels lie close together. The methods usually employed are energy analysis by stopping in foils or by measuring of track length in thick photographic

emulsions.

The aim of the present work is to utilize the method of magnetic analysis of the reaction products which allows one to obtain a higher energy resolution. However, the immediate application of this method in angular distribution experiments meets with a number of technical difficulties. Therefore, a slightly different approach was chosen. As is well known the most probable angle with which the proton leaves the target with respect to the incoming particle direction in a stripping reaction depends on the orbital angular momentum of the captured neutron, on the reaction energy, and on the kinetic energy of the incoming deuterons. One therefore can observe at a fixed angle and vary the energy of the primary deuterons. The dependence of the intensity of a particular proton group on the primary energy therefore will have a well defined form which will depend on the characteristics of the particular excited level of the daughter nucleus.

The experimental arrangement used was similar to that described in Ref. 2. An assembly of sampleholder, defining slits, and plateholder was placed inside of the vacuum chamber of a cyclotron. The energies and intensities were determined by track counting under the microscope. The setup was calibrated by the (d,p) reaction on carbon and oxygen whose reaction energies are known with great accuracy. The first experiments were conducted with Al. This element was chosen because it is monoisotopic. Further, it is easy to make thin foils for the target; finally, the (d,p) reaction leads to Al^{28} whose complicated level scheme has been well investigated. Therefore there exists a good amount of information with which to compare the obtained results.

The angle of observation was $109^\circ \pm 3^\circ$ in the laboratory system. The deuteron energy could be varied from 1 to 5.6 mev. One of the curves, showing the proton energy distribution at a primary deuteron energy of 1.71 mev is shown in Fig. 1. All told there were found 31 proton groups which agreed with the positions of levels as given in Refs. 2,3,4, although many of the levels found in Ref. 4 could not be resolved. Additionally, one new level was observed at an excitation energy of 8.24 mev.

The energy dependence of the intensities of the various proton groups can be most accurately determined relative to the intensity of an arbitrary group, preferably one with a known angular distribution. For this purpose the group p_0 was chosen which corresponds to the transition to the ground state doublet ($\Delta E = 31$ kev) which was not resolved in our case. It follows both from shell theory and from analysis of experimentally obtained angular distributions[6] that this transition has an orbital angular momentum $l=0$. We determined the ratio of the intensity of the proton groups corresponding to the levels of Al^{28} at 0.974, 1.015, 1.367, 1.625, 5.128, and 5.435 mev (the groups p_1, p_2, p_3, p_4, and p_5 respectively) to that of the ground state group at deuteron energies of 1.12, 1.71, 2.43, 3.15, 3.81, 4.54, 5.17, and 5.59 mev. The distributions obtained are plotted in Fig. 2. We either could not separate the remaining groups because of the rather poor energy resolution of our arrangement ($\approx$100 kev) or could observe them with sufficient intensity only at some deuteron energies and so were not able to obtain enough points to construct the curves.

The energy dependence of different proton groups could have had arbitrary shapes if compound nucleus formation would have played an important part in the process. However, the stripping cross sections usually are much larger than the compound nucleus cross sections, and up to now no resonance phenomena have been observed in (d, p) processes in neighboring Z nuclei. All maxima actually observed in the intensity ratios of different groups are sufficiently broad to correspond to the shape one would expect in stripping reactions. These shapes could scarcely obtain in compound nucleus processes. We therefore shall assume that the observed intensity ratios are due exclusively to the stripping process.

For a rigorous interpretation of the obtained results one has to know the dependence of the intensity at the particular angle of observation on the deuteron energy for different values of the angular momentum l transferred to the nucleus in the capture of the neutron. In an accurate solution of this problem one has to take into account the influence of the coulomb interaction and the nuclear interaction and the deformation of the wave function of the deuteron in its approach to the nucleus. Such calculations have not yet been performed. An experimental determination of these dependencies could be possible in some cases. This would be so if one could find a neighboring Z nucleus with fewer levels which then could be investigated by the method of angular distributions. The energy dependence of the intensity of the same proton groups can then be determined with the present method. Since the l-values connected with these proton groups would be known having been obtained from the angular distributions, one

now could use these shapes in the analysis of levels which can be studied only by means of magnetic analysis.

At present it is possible to estimate the spin and parity only for those few levels whose dependence of the intensity of their proton groups on the deuteron energy show prominent features and which can be determined using data from Refs. 1, 7. These papers give theoretical angular distributions. By means of graphical extrapolation into the region of Z,Q, and deuteron energy of interest here, it is possible to predict roughly the place at which the maximum of the intensity will occur for different l.

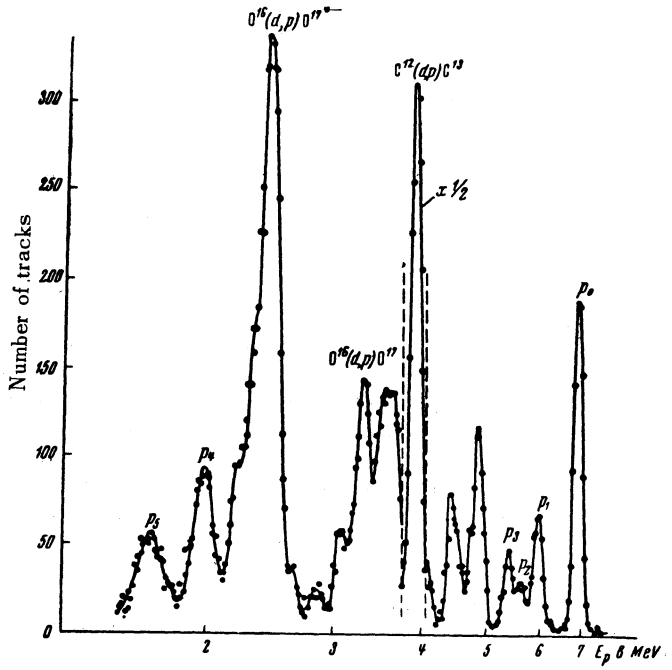

FIG. 1. Energy spectrum of protons from the reaction Al^{27} (d,p) Al^{28} at a primary deuteron energy E_d=1.71 mev. (Scale between the dotted vertical lines decreased by a factor of 2).

In Ref. 6 it was found by means of angular distributions that the capture of neutrons into the states at 974 and 1015 kev, which were not resolved in their experiments, occurred with l=0 and l=2. In the present experiment these levels also were not resolved. The ratio of the intensity of this group to that of the group leading to the ground state doublet is shown as curve a in Fig. 2. From this curve we can only determine the presence of the l=2 transition, since an l=0 transition having the same l as the ground state transition would have to yield a constant value. From curve b of Fig. 2 one can see that the transition to the level at 1.625 mev in Al^{28} is also an l=2 transition. Hence its parity is even, and since the ground state spin of Al^{27} is 5/2 its spin can be between 0 and 5. Curve c of Fig. 2 shows the intensity of the proton group leading to the level at 1.37 mev of

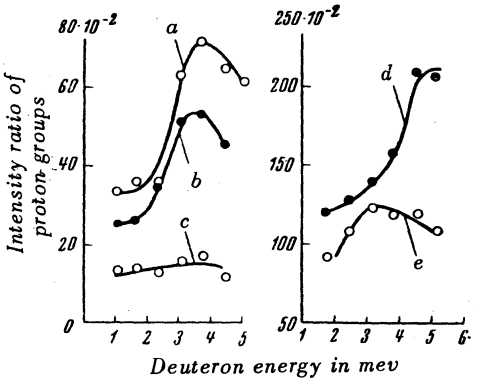

FIG. 2. Dependence of the intensity ratio of some proton groups on the primary deuteron energy.

Al.^{28} It is rather closely a straight line parallel

to the abscissa, thus indicating an l=0. However, the intensity is rather low and this result is not too certain.

We furthermore could obtain similar data for the levels of Al^{28} at 5.128 and 5.435 mev (curves d and e of Fig. 2). According to Ref. 4 there are some more levels in their vicinity which could not be resolved here. However, since according to the same work[4] the intensity of the groups we observed is almost an order of magnitude larger than that of the neighboring ones, the shape of the curves is mostly determined by these two groups. According to our estimates from Refs. 1, 7 as described above it seems likely that the transition to the level at 5.128 mev (curve d) involves an l=3, and hence the parity of this state would be odd while the spin could have a value between 0 and 6. Analogously, curve e indicates for the level at 5.435 mev a transfer of l=1 and hence odd parity and a spin between 1 and 4.

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The Interaction of the States of Two Zones in the Single-electron Scheme

Iu. M. SEIDOV AND V. S. GALISHEV
Institute of the Physics of Metals, Ural Affiliate. Academy of Sciences, USSR

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A generalization of the results of Bogoliubov [1] in the zone (single-electron) approximation is worked out for the case of the presence of an excited state. The expression obtained for the energy spectrum permits a direct judgment on the combination of two zone states.

1. INITIAL HAMILTONIAN OF THE PROBLEM

IN the well known investigations of Bogoliubov[1] on the theory of metals, the simplest case of s electrons was considered. The eigenfunction of the system of electrons in the crystal corresponding to this case was sought in the form of a linear combination of antisymmetrized products composed only of eigenfunctions of the lowest atomic energy level. Moreover, improvement of the accuracy of the method requires, as is well known, the consideration, along with the eigenfunctions, of the eigenfunctions of the succeeding energy levels, in particular when they are close to the ground state. Solution of a similar problem for the case of the excited state is also the purpose of the present research. In this case we limit ourselves only to the electron zone approximation, since calculation of the interaction of the electrons complicates all the considerations considerably, and requires independent consideration.

Following Bogoliubov, we consider the crystalline lattice with "frozen" positive ions, and limit ourselves to the case of monovalent metals. For such a crystalline lattice, the secular equations are written down in the monograph[1] cited above in the representation of second quantization and their detailed investigation is carried out for the case of the s-state. In this case the index $\lambda=(l,m)$(the aggregate of orbital and magnetic quantum numbers) drops out everywhere in general in the Bogoliubov formula. If we calculate the p-state along with the s-state, then the index λ will have four values: (0,0), (1,1), (1,0), (1,-1), which naturally complicate all the calculations greatly. Therefore, it seems quite appropriate to consider initially the simplest possible case – nondegenerate p-states, i.e., to consider that the p electron of the free atom is described by one real eigenfunction, and not by three. In this case, let λ=0