PROPERTIES OF EXCITED F^{19} LEVELS BETWEEN 8.5 AND 10.5 MeV

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The $O^{18}(p, \alpha) N^{15}$ reaction was studied using 1100—2600 keV protons. Approximately 120 angular distributions were obtained and were expanded in series of Legendre polynomials. The analysis shows that states having spins and parities $1/2^+$ and $3/2^+$ make the main contribution to the reaction cross section. The properties of 14 resonances corresponding to F^{19} states in the excitation region 9—10.5 MeV were also derived. The reduced α-particle widths exhibit a very narrow distribution centered about $5 \times 10^{-3} \times (3\hbar^2/2\mu r^2)$.

MANY theoretical and experimental investigations of the properties of excited F^{19} states have been published.[1-16] However, such important properties as the spin, parity, and especially the reduced widths of different channels, which are of the greatest importance for understanding the structure of the nucleus, have been determined for only a small number of levels. The present work is a continuation of [15]. The angular distributions of α particles from the reaction $O^{18}(p, \alpha) N^{15}$ were measured for the 1100—2600 keV proton range, and the properties of fourteen resonances were determined from the subsequent analysis.

I. EXPERIMENTAL RESULTS

The technique of [15] was used, but the energy dependence of the cross section was measured with a solid target instead of a gas. A magnetic separator was used to prepare the target by driving O^{18} ions into a thin film of aluminum oxide. The target thickness was $\sim 20\ \mu g/cm^2$, which in the case of 2-MeV protons corresponds to a mean energy loss of ~ 3 keV in the target.

The angular distributions were measured mainly with the gas target. About 120 angular distributions were obtained in the investigated energy range; typical distributions, registered at the peaks of separate resonances, are shown in Fig. 1. The curves represent Legendre polynomial series with coefficients obtained by a least squares analysis of the experimental data.

In addition to the angular distributions, near some resonances we measured the energy dependence of the sum of α-particle yields at 54.5° and 125.5° in the c.m. system. It can easily be shown that if the ratio A_4/A_0 (where A_4 and A_0 are the coefficients of the zeroth and fourth degree Legendre polynomials) does not exceed 0.3 in absolute value and even Legendre polynomials above the fourth degree are absent, this dependence agrees with the energy dependence of the total cross section to within 10%.

II. ANALYSIS OF EXPERIMENTAL DATA

1. Analysis of angular distributions

The ground states of O^{18} and N^{15} have the spins and parities 0^+ and $1/2^-$, respectively, so that the entrance and exit channels of the investigated reaction have spin $1/2$. Corresponding to these values of the total angular momentum and parity (J, π) there are only single values of the orbital angular momentum of the entrance and exit channels $[l = J \pm 1/2,\ l' = J \mp 1/2,\ \pi = (-1)^l = (-1)^{l'+1}]$, and therefore only a single element of the reaction matrix $S(J, \pi)$. The analysis of the angular distributions is thus greatly simplified. The differential cross section for the reaction is obtained from [15]

$$\frac{d\sigma}{d\Omega} = \sum_{i=1}^{N} \sigma_i f_{J_i}(\theta) + \sum_{\substack{i,k=1 \\ i<k}}^{N} 2\sqrt{\sigma_i \sigma_k} \cos\psi_{ik} g_{J_i J_k \pi_{ik}}(\theta), \quad (1)$$

where N is the number of states of different spins and parities that contribute appreciably to the reaction; $f_{J_i}(\theta)$ is the angular distribution that would be observed if only one matrix element $S(J_i, \pi_i)$, corresponding to the spin J_i, were different from zero; $g_{J_i J_k \pi_{ik}}(\theta)$ is a function describing the interference of the i-th and k-th states; σ_i is the contribution of the i-th state to the total cross section $\sum_i \sigma_i = \sigma_t$, where σ_t is the total cross section; ψ_{ik} is the phase difference between the i-th and k-th matrix elements. The energy dependence of σ_i at resonance is given by the Breit-Wigner formula, and the phase of the

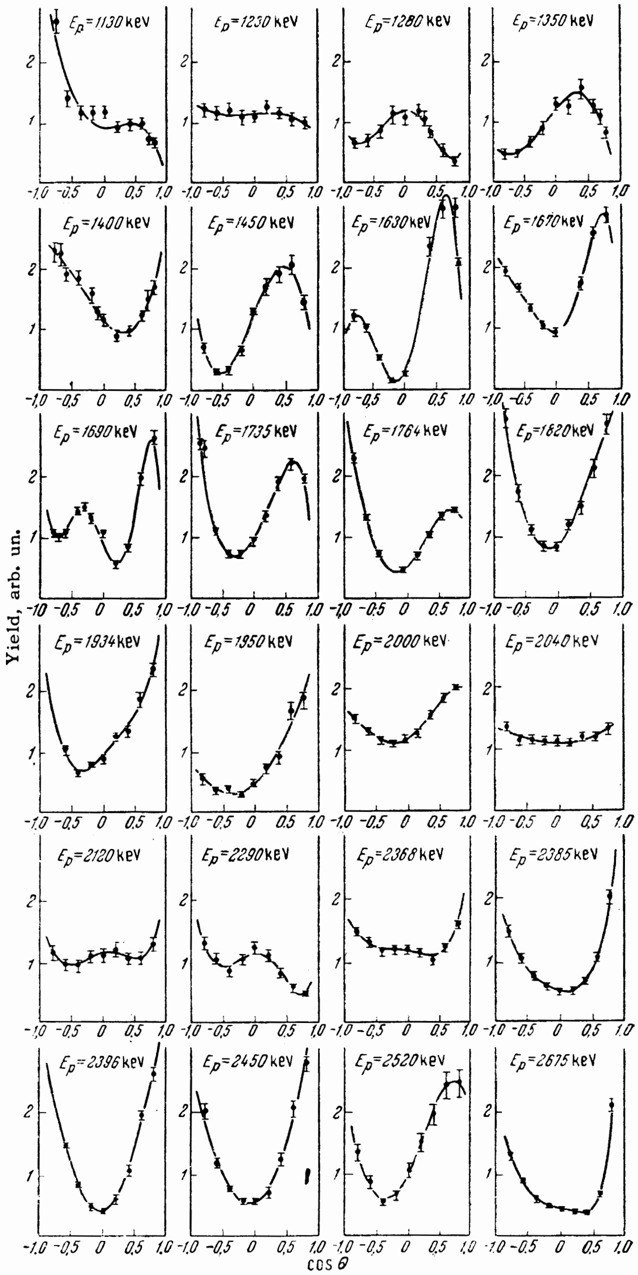

FIG. 1. Typical angular distributions of α particles.

matrix element is the sum of the potential and resonance phases. The function $f_J(\theta)$ depends only on the total spin J (and is independent of the parity), and $g_{J_iJ_k\pi_{ik}}$ depends on the spins J_i and J_k of the interfering states and on their relative parity π_{ik}. We gave explicit expressions for all these functions in the general case in [15]. It must here be noted that $f_J(\theta)$ contains only Legendre polynomials of maximum degree 2J – 1. Also, the expansions of f and g in Legendre polynomials have only positive coefficients.

In the general case, when only a few states of different spins and parities participate in the reaction, the angular distribution, even at a resonance peak, can differ greatly from the "pure" case $f_J(\theta)$; a very small (~1–5%) admixture of other states is sufficient. To determine the spin, parity, and partial widths of a resonance we must then know the energy dependence of the coefficients of the different Legendre polynomials. Around an isolated resonance the differential reaction cross section can be represented by

$$\frac{d\sigma}{d\Omega}(\theta) = \sigma_{res} f_{J_{res}}(\theta) + \sum 2\sqrt{\sigma_{res}\sigma_i}\cos\psi_{ik} g_{J_{res}J_i\pi_i} + \left[\frac{d\sigma}{d\Omega}(\theta)\right]_0, \qquad (2)$$

where σ_{res} is the contribution of the given resonance to the total cross section, J_{res} is the total spin of the corresponding compound-nucleus level, and $[d\sigma(\theta)/d\Omega(\theta)]_0$ is the nonresonance part of the differential cross section, determined by all other states. The second term in (2) results from the interference of the resonance level with these states.

It is clear that the coefficients of the even polynomials in $f_{J_{res}}(\theta)$ should exhibit resonant behavior in accordance with the Breit-Wigner formula. When the highest even degree polynomial passing through resonance is thus known, the spin of the corresponding compound-nucleus level is easily determined. It should be noted, however, that in some cases interference with a state of the same parity but with spin differing by unity can distort this simple dependence so that the analysis is no longer unique.

The angular distributions were analyzed using the M-20 high-speed computer. The finite sizes of the target and detectors were taken into account accurately by means of suitable corrections. We began by attempting to represent each angular distribution in the form

$$F_T(\theta) = \alpha_1 f_{J_1}(\theta) + \alpha_2 f_{J_2}(\theta) + 2\sqrt{\alpha_1\alpha_2}\cos\psi g_{J_1J_2\pi_{12}}(\theta),$$

which corresponds to the case of interference between two states. The parameters α_1 ($\alpha_2 = 1 - \alpha_1$) and ψ were determined by least squares, and spins up to $^9/_2$ were considered. It was found that good agreement with experiment could not generally be obtained. Whenever agreement was obtained, the analysis for neighboring energies yielded contradictory results. It follows that at all energies at least three matrix elements are different from zero. If we attempt to represent each angular distribution in a form corresponding to the interference of three states, the number of parameters increases sharply and in most cases the analysis becomes ambiguous. Therefore all angular distributions were expanded in Legendre polynomials and we analyzed the energy dependences of the coefficients of the different polynomials. The highest degree was selected to give maximum probability of any given expansion according to Pearson's criterion. From the values of the relative coefficients A_n/A_0 obtained in this way we calculated the ratio $A_0/\sigma(90°) = \sigma_t/4\pi\sigma(90°)$, where $\sigma(90°)$ is the c.m. differential cross section at 90°, and σ_t is the total reaction cross section. To determine the energy dependence of the absolute value of A_0, the coefficient of the zeroth degree polynomial, we used the energy dependence of the absolute differential cross section for the reaction $O^{18}(p, \alpha)N^{15}$ at 90°, which is given in [10]. We then plotted the energy dependences, shown in Fig. 2, of the coefficients of all the Legendre polynomials.

2. Properties of excited F^{19} states

Figure 2 shows that five Legendre polynomials (from the zeroth to the fourth degree) were sufficient to describe the angular distributions at practically all energies. The fifth degree polynomial affects only a narrow energy range around 1690 keV. Therefore the maximum spin participating in the reaction does not exceed $^5/_2$. We also note that in cases where $A_4/A_0 > 0$ its absolute value is generally small, but that where this ratio is negative its absolute value is large. It follows that the presence of the fourth degree polynomial in the angular distributions results mainly from interference, and that spin $^5/_2$ states make only a small contribution to the cross section. The energy dependence of the coefficient of the second Legendre polynomial shows that spin $^3/_2$ states make a large

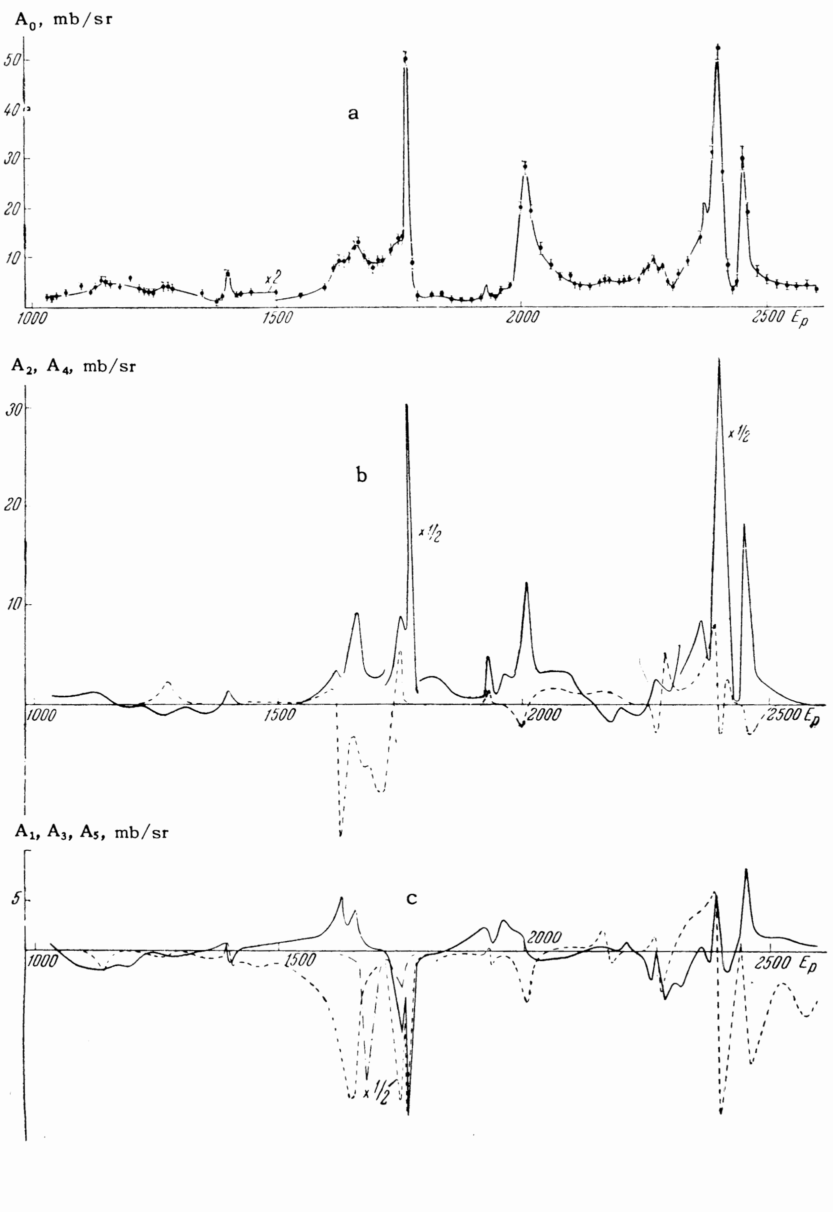

FIG. 2. Energy dependences of the coefficients in Legendre polynomial expansions of the angular distributions. a – energy dependence of coefficient A_0; b – continuous curve – for coefficient A_2, dashed curve – for A_4; c – continuous curve – for A_1, dashed curve – for A_3, dot-dash curve – for A_5.

Properties of excited F^{19} states in the energy range 8.5—10.5 MeV

E_p, keV	E_x, MeV	J^π	Γ, keV	Γ_p, keV	Γ_α, keV	Θ^2_p	Θ^2_α
633a	8.591	$3/2^-$	2	0.065	2	$2\cdot10^{-3}$	$1\cdot10^{-3}$
680a	8.636	$1/2^+$	100	5	95	$2.5\cdot10^{-2}$	$3.5\cdot10^{-2}$
840a	8.787	$1/2^+$	47	26	21	$9\cdot10^{-2}$	$7\cdot10^{-3}$
990 b	8.929	$1/2^+$	17	0.20	16.8	$3\cdot10^{-4}$	$5\cdot10^{-3}$
1169a	9.099	$7/2^+$	0.6	0.005	0.595	$1\cdot10^{-3}$	$3\cdot10^{-4}$
1240a	9.166	$1/2^+$	6.1	0.4	5.7	$2\cdot10^{-4}$	$2\cdot10^{-3}$
1275	9.199	$5/2$	35	0.08	34.2	$2\cdot10^{-3}$c / $4\cdot10^{-2}$d	$2\cdot10^{-2}$c / $1\cdot10^{-2}$d
1402	9.320	$1/2^+$	6	0.13	5.87	$7.6\cdot10^{-5}$	$1.6\cdot10^{-3}$
1630	9.536	$(5/2)$					
1670	9.573	$3/2$					
1690	9.592	$(7/2)$					
1745	9.645	$3/2^-$					
1764	9.663	$3/2^+$	5	1.4e / 3.6	3.6e / 1.4	$7.9\cdot10^{-3}$e / $2\cdot10^{-2}$	$9.5\cdot10^{-4}$e / $3.6\cdot10^{-4}$
1934	9.823	$(5/2)$	1.5				
2005	9.891	$1/2^+$	35	12	23	$3.6\cdot10^{-3}$	$5.8\cdot10^{-3}$
2270	10.142	$1/2$					
2290	10.161	$(5/2)$					
2368	10.234	$1/2^+$	9	1.3	7.7	$2.1\cdot10^{-4}$	$1.8\cdot10^{-3}$
2396	10.261	$3/2^+$	24	12	12	$1.9\cdot10^{-2}$	$2.4\cdot10^{-3}$
2450	10.312	$3/2^+$	14	3.1	10.9	$5\cdot10^{-3}$	$2.5\cdot10^{-3}$

a — from[13], b — from[15], c — for positive parity, d — for negative parity, e — more probable.

contribution to the cross section in the entire investigated energy range. It is interesting to compare the quantities $\int A_0 dE$ and $\int A_2 dE$. The first integral is the energy-averaged cross section, while the second integral is the energy-averaged contribution of spin $3/2$ states. (It is to be expected that the terms corresponding to interference will make no contribution to integration over a broad energy range.) The ratio of the second integral to the first is ~ 0.6 for the curves in Fig. 2. Therefore about 60% of the cross section on the average is attributable to matrix elements for spin $3/2$.

The table and the curves in Fig. 2 show that the coefficients of the odd Legendre polynomials are generally small in the entire investigated energy range. It follows that at each energy the main contribution to the cross section comes from states of like parity. The calculations performed at different energies show that the average contribution of states of opposite parities does not exceed 10—15%. Since most of the determinable parities are positive (shown in the table) and the corresponding levels are strongly resonant, the foregoing discussion suggests that on the average the $1/2^+$ and $3/2^+$ states make the principal contribution to the cross section.

In addition to the foregoing general conclusions, the experimental data permitted a more detailed analysis of individual resonances and yielded the spins, parities, and reduced widths of the corresponding levels of the compound nucleus F^{19}. The widths and locations of the resonances as well as the cross sections at resonance energies were obtained, as a rule, by analyzing the observed energy dependence of the total cross section. It was assumed that this dependence can be represented at resonance by the single-level Breit-Wigner formula:

$$\sigma_T(E) = \sigma_{\text{nonres}} + \sum_\mu \frac{E_\mu}{E} \frac{\sigma_\mu}{1 + [2(E - E_\mu)/\Gamma_\mu]^2},$$

where σ_{nonres} is the nonresonance cross section, which was assumed to be independent of the energy; σ_μ, E_μ, and Γ_μ are, respectively, the cross sections, energies, and total widths of the resonances making the main contribution to the cross section in the considered energy region. The values of σ_{nonres}, σ_μ, E_μ, and Γ_μ were chosen to minimize the quadratic form

$$\chi^2 = \sum_i [\sigma_e(E_i) - \sigma_T(E_i)]^2 / [\Delta\sigma(E_i)]^2,$$

where $\sigma_e(E)$ and $\sigma_T(E_i)$ are, respectively, the experimental and the theoretical total cross section at the energy E_i, and $\Delta\sigma(E_i)$ is the absolute error. Corrections were introduced for the energy spread due to the slowing of protons in the target. χ^2 was also minimized on the M-20 by the method of descent against the gradient. The reduced widths were calculated from the values of σ_μ and Γ_μ using the channel radii $r_p = 4.9 \times 10^{-13}$ cm and $r_\alpha = 5.48 \times 10^{-13}$ cm. The reduced widths are given in units of $3\hbar^2/2\mu r^2$, where μ and r are the reduced mass and radius of the channel. The properties of all the investigated resonances are given in the table. We shall now analyze the individual resonances.

1. The resonance at 1275 keV. This resonance is characterized by the fact that, because of its relatively great width and low intensity, it has only a very slight influence on the total cross section and is observed only in the energy dependence of the coefficient of the fourth degree Legendre polynomial. It follows directly that the corresponding level has spin $^5/_2$. The values of A_4/A_0 indicate that 65—70% of the resonance cross section is contributed by a spin $^5/_2$ state, with the remaining contribution coming from states of lower spin. We should thus observe strong interference between the spin $^5/_2$ state and the other states. This agrees with the behavior of the coefficient of the second degree polynomial, which is negative and dips slightly in the resonance region. This behavior can be accounted for only if an essential contribution to the cross section in this energy region comes from the matrix element corresponding to spin $^1/_2$ and parity like that of the spin $^5/_2$ level. This hypothesis also agrees well with the angular distributions in the regions on both sides of the resonance, which indicate that a spin $^1/_2$ state makes the main contribution to the cross section in these regions.

The total resonance width at 1275 keV was determined from the energy dependence of the coefficient of the fourth degree polynomial. The partial widths were obtained from the total resonance cross section, considering that the spin $^5/_2$ state contributes 65% and does not influence the elastic scattering cross section (i.e., $\Gamma_p/\Gamma \ll 1$). The reduced widths were calculated for two different parity assumptions. It is seen from the table that the reduced α-particle widths are here almost identical, whereas the proton width depends greatly on the assumed parity.

2. The resonance at 1402 keV. This resonance clearly affects the total cross section. A small peak is also observed in the energy dependence of the coefficient of the second degree Legendre polynomial. However, the small ratio A_2/A_0 and the distinct asymmetry of this peak indicate that spin $^3/_2$ cannot be assigned to the corresponding level. The spin must therefore be $^1/_2$, confirming the result in [13] based on elastic proton scattering data, which indicate positive parity.

To explain the behavior of the first, second, and third degree Legendre polynomials in this energy region it is sufficient to assume the existence of matrix elements corresponding to $^1/_2^-$, $^3/_2^+$, and $^5/_2^-$ states which contribute ~ 0.01 to the total cross section.

The total resonance width was determined by analyzing the energy dependence of the sum of α-particle yields at 54.5° and 125.5° in the c.m. system. Figure 3 is the theoretical curve corresponding to the optimal resonance parameters, which were used to determine the partial and reduced widths. Data on the elastic scattering of protons were used,[10] which indicate $\Gamma_p/\Gamma \ll 1$.

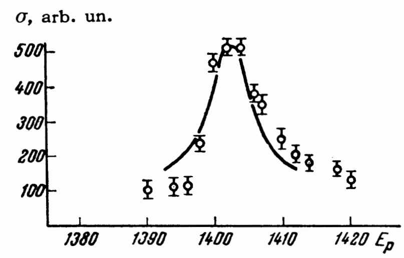

FIG. 3. Energy dependence of the total cross section at the 1402-keV resonance. E_{res} = 1402.5 keV, Γ = 6 keV, σ = 470, σ_{nonres} = 120.

3. Resonances in the interval 1600—1680 keV. In this interval the energy dependences of the coefficients of different polynomials are very complicated; this indicates the strong interference of several states. The large coefficient of the fourth degree polynomial is characteristic, indicating that matrix elements corresponding to spin $^5/_2$ contribute up to 20% to the cross section. However, this coefficient is negative in almost the entire range, and we must conclude that it results from interference and that the main contribution to the cross section comes from $^3/_2$ states. The location of the level (or levels) of spin $^5/_2$ cannot be determined, although the sharp dip in the energy dependence of the coefficient of the fourth degree polynomial at 1630 keV apparently indicates that one level lies at this energy but is manifested only by a steep enhancement of interference.

More definite conclusions can be reached regarding the resonance at 1670 keV, where the coefficient of the second degree polynomial exhibits resonance. We can therefore assign spin $^3/_2$ to the corresponding compound-nucleus level. This value is also consistent with a sharp anomaly in the behavior of the coefficient of the third degree polynomial, which can be interpreted only as the interference of two spin $^3/_2$ states having opposite parities, one of which makes the principal contribution to the cross section. It should also be noticed that since the ratio A_2/A_0 is less than unity in this region we must assume that a small

(~5%) contribution to the cross section comes from a matrix element for spin ½ and parity like that of the 1670-keV resonance. Therefore at least four matrix elements make essential contributions to the cross section in the given energy region. We were therefore unable to separate reliably the contributions of individual resonances and to determine their widths.

4. The resonance at 1690 keV. In the interval 1680–1730 keV a fifth degree Legendre polynomial is included in the angular-distribution expansion. The coefficient of this polynomial exhibits a pronounced anomaly in its energy dependence, which indicates a compound-nucleus level of higher spin at 1690 keV. It is interesting that this level has practically no effect on the energy dependences of the differential cross sections at angles greater than 60°, or on the behavior of the coefficients of even degree Legendre polynomials. This evidently prevented its observation in earlier work. It follows from the foregoing that the given level makes a small contribution to the cross section and is therefore manifested only by a sharp enhancement of interference. Assuming that in this energy interval the main contribution to the cross section comes from a matrix element corresponding to spin $^3/_2$, we must assign spin $^7/_2$ to the 1690-keV resonance. The contribution of this resonance to the cross section need be only ~10% to account for the size of the anomaly in the energy dependence of the coefficient of the fifth degree polynomial.

5. The resonances at 1745 keV and 1764 keV. We observe resonances at these energies in the energy dependences of the coefficients of the zeroth and second degree Legendre polynomials. It follows that spin $^3/_2$ must be assigned to both levels. The sharp anomaly in the behavior of the coefficient of the third degree polynomial can only be accounted for by opposite parities of these levels. These results confirm the findings in [10], where, on the basis of the two α-particle angular distributions at the resonance peaks and the energy dependence of the elastic proton scattering, $^3/_2^-$ for 1745 keV and $^3/_2^+$ for 1764 keV are indicated.

The parameters of the 1764-keV resonance were also obtained in the same way as for the 1402-keV resonance. Figure 4 shows the energy dependence of the total cross section in the interval 1700–1800 keV. The curve in the resonance region at 1764 keV corresponds to the optimal parameters of this resonance, and was calculated assuming that at resonance the combined contribution of the remaining matrix elements of the cross section remains constant and equal to its value at the 1764-keV resonance. By analyzing

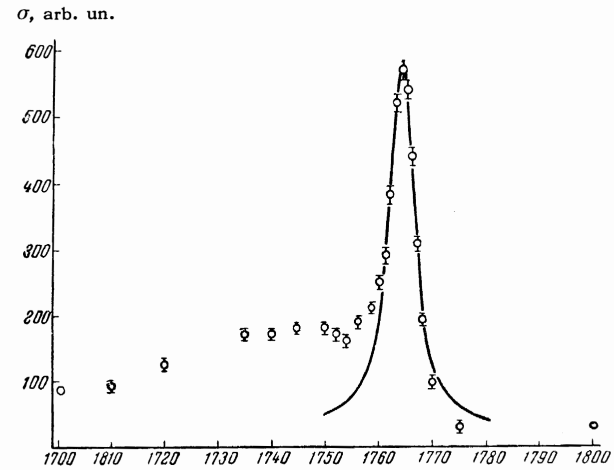

FIG. 4. Energy dependence of the total cross section in the interval 1700-1800 keV; E_{res} = 1764 keV; Γ = 5 keV; σ = 600; σ_{nonres} = 30.

the angular distribution we find that this contribution is ~6% of the total cross section.

Figure 4 shows that the 1745-keV resonance is only slightly evident in the energy dependence of the total cross section. We were therefore unable to distinguish its contribution reliably or to determine its total and partial widths.

From the magnitude and total width of the 1764-keV resonance we obtain two possible sets of partial widths: 1) Γ_α = 3.6 keV, Γ_p = 1.4 keV; 2) Γ_α = 1.4 keV, Γ_p = 3.6 keV. On the basis of the data in [10] concerning the anomaly in the energy dependence of the differential cross section for elastic proton scattering at 159.5° we give preference to the first set; the second set would lead to an excessive difference between the maximum and minimum cross sections. It should be noted, however, that the target used by Carlson et al. was about twice as thick as ours and that the energy spread due to loss in the target exceeded the resonance width. This could have reduced the anomaly; therefore the second possibility cannot be regarded as entirely excluded, and we calculated the reduced width for both cases.

6. The resonance at 1934 keV. At this energy resonances are observed in the energy dependences of the coefficients of the zeroth, second, and fourth degree Legendre polynomials. This appears to indicate spin $^5/_2$ for the corresponding level of the F^{19} compound nucleus. It should be noted, however, that A_4/A_0 is smaller than the value 0.86 corresponding to $f_{5/2}(\theta)$. This can result, first of all, from interference of the given resonance with a state of spin $^3/_2$ and the same parity; a ~5% contribution of this state would be sufficient. Such a hypothesis is consistent with the angular distributions at energies above and

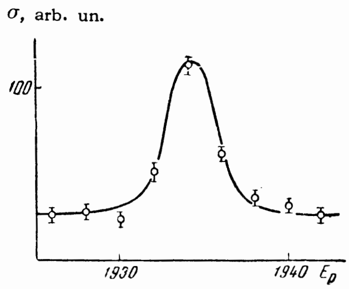

FIG. 5. Energy dependence of the total cross section at the 1934-keV resonance; E_{res} = 1934 keV; Γ = 1.5 keV; σ = 162; σ_{nonres} = 26.

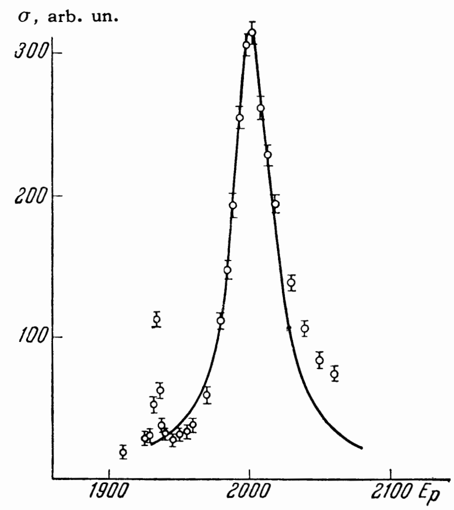

FIG. 6. Energy dependence of the total cross section in the interval 1900-2060 keV. E_{res} = 2004 keV; Γ = 35 keV; σ = 310; σ_{nonres} = 6.

below resonance, from which it follows that in this region the matrix elements corresponding to spin $^3\!/_2$ make an essential contribution to the cross section. Secondly, the reduced value of A_4/A_0 can be associated with a small resonance width 1.5 ± 0.5 keV, the target thickness being ~ 3 keV.

Figure 5 shows the energy dependence of the total reaction cross section in the resonance region. The curve corresponds to the optimal parameter values. Since the total resonance width is one-half of the target thickness, in order to determine the true resonance cross section a very large correction must be introduced, depending strongly on the ratio between the target thickness and the total resonance width. Since this could lead to great inaccuracy of the partial widths, we did not continue the analysis.

7. The resonance at 2005 keV. This resonance is observed distinctly in the energy dependence of the coefficient of the zeroth Legendre polynomial. A small peak is also observed in the energy dependence of the coefficient of the second degree polynomial, but A_2/A_0 is too small to permit the assignment of spin $^3\!/_2$ to the F^{19} level corresponding to this resonance. Therefore this level has spin $^1\!/_2$, and the anomaly results from interference with a state of spin $^3\!/_2$ and the same parity. This result confirms the conclusion ($^1\!/_2^+$) obtained in [10] from an analysis of elastic proton scattering.

Figure 6 shows the energy dependence of the total cross section in the interval 1900—2060 keV. The curve corresponds to the optimal resonance parameters. The partial widths were calculated from the intensity and total width of the resonance.

8. The resonances at 2270 keV and 2290 keV. At 2290 keV a distinct resonance is observed in the energy dependence of the coefficient of the fourth degree Legendre polynomial. Spin $^5\!/_2$ must therefore be assigned to the corresponding compound-nucleus level. Some conclusions can be reached regarding the 2270-keV resonance properties on the basis of the following facts. The energy dependence of the coefficient of the fourth-degree polynomial at the 2290-keV resonance differs greatly from the Breit-Wigner formula, thus indicating interference with a state of spin $^3\!/_2$. In addition, the small coefficient of the second polynomial indicates a large admixture of a spin $^1\!/_2$ state. Therefore the level corresponding to the 2270-keV resonance must have a spin of either $^1\!/_2$ or $^3\!/_2$. Since the main contribution to the cross section below 2260 keV comes from spin $^1\!/_2$ states, while above 2300 keV the main contribution comes from spin $^3\!/_2$ states, the first value seems more likely.

9. The resonances at 2368 keV and 2396 keV. At 2396 keV strong resonance is observed in the energy dependences of the coefficients of the zeroth and second degree Legendre polynomials. The corresponding level of the compound nucleus therefore has spin $^3\!/_2$. The parity of this level is easily determined from the elastic proton scattering data in [10]. The energy dependence of the differential scattering cross section at 90° exhibits a dip in the resonance region which indicates positive parity.

In addition to the 2396-keV resonance, a resonance is observed at 2368 keV, which is most pronounced in the energy dependence of the α-particle yield at 90°. The angular distribution at the resonance energy is very nearly isotropic, whereas neighboring angular distributions (at 2355 and 2385 keV) are characterized by a strong increase of the α-particle yield in the backward and forward directions. Spin $^1\!/_2$ must therefore be assigned to the 2368-keV resonance level. The energy dependence of the coefficient of the second

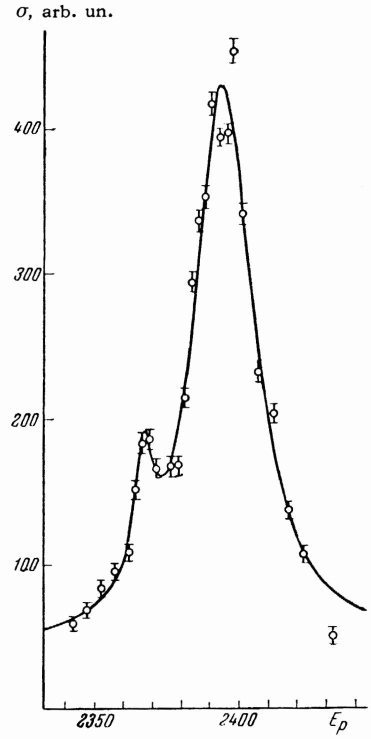

FIG. 7. Energy dependence of the total cross section in the interval 2350-2420; $E_{res}^{(1)} = 2368$ keV; $E_{res}^{(2)} = 2396$ keV; $\Gamma^{(1)} = 9$ keV; $\Gamma^{(2)} = 24$ keV; $\sigma^{(1)} = 385$; $\sigma^{(2)} = 85$; $\sigma_{nonres} = 42$.

Legendre polynomial exhibits a deep dip at this resonance, which apparently results from interference with the 2396-keV resonance. Therefore the spin $\frac{1}{2}$ level (the 2368-keV resonance) has the same positive parity as the $\frac{3}{2}^+$ level (the 2396-keV resonance).

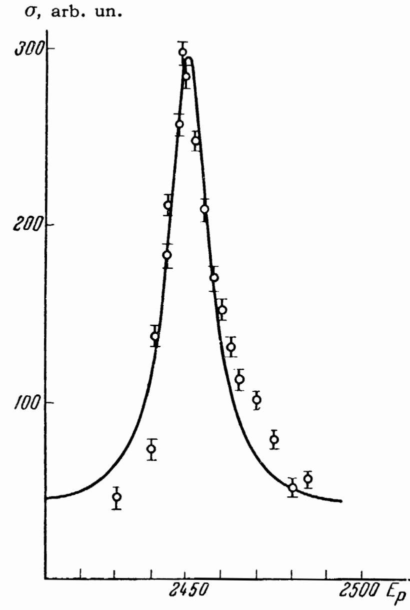

FIG. 8. Energy dependence of the total cross section at the 2450-keV resonance; $E_{res} = 2450$ keV; $\Gamma = 14$ keV; $\sigma = 260$; $\sigma_{nonres} = 40$.

The parameters of these resonances were determined in the same way as for the 1402-keV resonance. Figure 7 shows the energy dependence of the sum of α-particle yields at 54.5° and 125.5° in the c.m. system. The curve corresponds to the optimal parameter values. The cross section of the (p, α) reaction at the 2398-keV resonance peak there reaches its maximum possible value $4\pi\lambda^2(J + \frac{1}{2})$. Thus for this resonance we have $\Gamma_p = \Gamma_\alpha = \Gamma/2$.

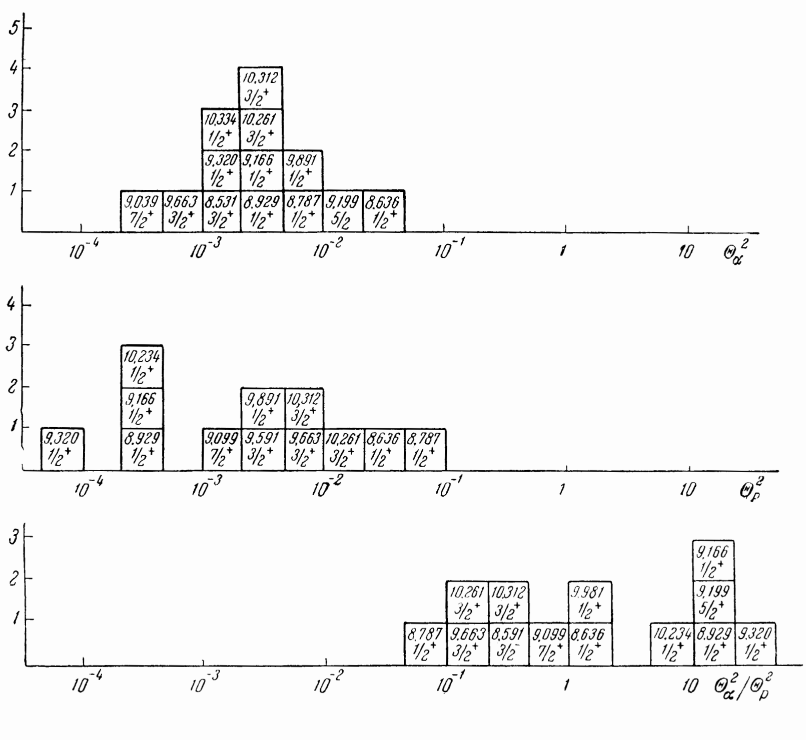

FIG. 9. Histograms for the distributions of reduced α-particle and proton widths and of the ratio $\Theta_\alpha^2/\Theta_p^2$.

The partial widths of the 2368-keV resonance were calculated from its contribution to the total resonance cross section and from the total width, taking into account that this resonance appears only weakly in the elastic scattering of protons, i.e., $\Gamma_p \ll \Gamma$.

10. The resonance at 2450 keV. At this energy we observe strong resonance in the energy dependences of the coefficients of the zeroth and second degree Legendre polynomials. Spin $^3/_2$ must therefore be assigned to the corresponding level of the F^{19} compound nucleus. Its positive parity is easily established from the same data as in the case of the 2398-keV resonance. The resonance parameters were determined in the same way as for the preceding case; the curve in Fig. 8 corresponds to their optimal values. From the total cross section and total width at resonance we obtain two possible sets of partial widths: 1) $\Gamma_p = 3.1$ keV, $\Gamma_\alpha = 10.9$ keV; 2) $\Gamma_p = 10.9$ keV, $\Gamma_\alpha = 3.1$ keV. The first of these appears preferable on the basis of the anomaly in the cross section for elastic proton scattering reported in [10].

CONCLUSION

The properties of the excited F^{19} levels investigated here are given in the table. The table also gives the properties of levels at 8.591, 8.636, 8.787, 8.929, 9.009, and 9.166 MeV taken from [13,15]. Figure 9 shows histograms of the distributions of the reduced widths Θ^2_α and Θ^2_p and of the ratios $\Theta^2_\alpha/\Theta^2_p$, with J^π and the excitation energy of the corresponding levels indicated for each case. The figure shows that Θ^2_α has a very narrow distribution about the value 5×10^{-3}. This suggests that the probability of finding an α particle on the nuclear surface can be regarded as a characteristic of the given nucleus (or, possibly, of a broad range of excitation energies) and depends only slightly on the structure of the given level. The same Fig. 9 also shows that for many levels the ratios $\Theta^2_\alpha/\Theta^2_p$ greatly exceed unity, but that the mean ratio is ~1. This indicates equal probabilities that an α particle or a nucleon will appear on the surface of the nucleus.

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