INELASTIC SCATTERING OF PROTONS BY Ne^{20} *NUCLEI*

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We have measured the absolute cross sections for the $Ne^{20}(p, p'\gamma)$ reaction and the angular distributions of p′ and γ corresponding to the first excited state of Ne^{20}, for resonance energies of 2.15 and 2.72 Mev. The partial widths and reduced widths for the 4.5- and 5.05-Mev levels of Na^{21} were determined. It is shown that the inelastic scattering of protons at 2.72 Mev is associated with a single level of the Na^{21} nucleus, having spin and parity $^3/_2{}^+$.

AMONG the resonances observed in the cross section for elastic scattering of protons by Ne^{20} nuclei, there is a resonance at $E_p = 2.72$ Mev corresponding to a level at 5.05 Mev in Na^{21}.[1,2] Attempts to determine the quantum numbers of this level by an analysis of experimental data on elastic scattering of protons by Ne^{20} proved to be unsuccessful.[1,2] The difficulty in the analysis is explained by the fact that this resonance is associated with closely spaced levels.

In the present work we have studied inelastic scattering of protons for $E_p = 2.72$ Mev for the purpose of obtaining additional information concerning the levels corresponding to this resonance. We have also studied the inelastic scattering $Ne^{20}(p, p'\gamma)$ at an energy of 2.15 Mev, corresponding to the 4.50 Mev level of Na^{21}, whose quantum numbers are reliably determined from data on elastic scattering.

METHOD OF MEASUREMENT

For the measurement of the angular distributions of the protons we used the chamber which has been described earlier.[3] The volume of the chamber was separated from the accelerator tube by a mica foil 0.5 μ thick. The chamber was filled with a normal isotopic mixture of neon (91% Ne^{20}) at a pressure of 8 mm Hg.

The scattered protons were recorded with a CsI(Tl) crystal 0.1 mm thick and a FÉU-S photomultiplier. Pulses from the FÉU-S were analyzed by a 100-channel analyzer (AI-100). The energy resolution of the spectrometer was 6% for $E_p = 2$ Mev. In Fig. 1 we show the spectrum of protons scattered by Ne^{20} nuclei at an angle of 90° for the resonance energy $E_p = 2.72$ Mev.

In studying the γ rays from the $Ne^{20}(p, p'\gamma)$ reaction, the primary protons passed through a mica window 1 μ thick and entered a chamber 15 mm in diameter, filled with neon to a pressure of 10 mm Hg, which served as the target. The γ rays were recorded by a pair of FÉU-S photomultipliers with NaI(Tl) crystals of dimensions 40 × 40 mm. One of them was held fixed, while the other rotated around the target. Pulses from the fixed photomultiplier entered a single-channel analyzer which gave the full absorption peak which corresponded to an energy $E_\gamma = 1.64$ Mev. This photomultiplier was used as a monitor.

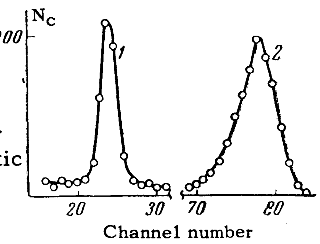

FIG. 1. Spectrum of protons scattered by Ne^{20} for $E_p = 2.72$ Mev. Peak 1 corresponds to inelastic scattering, peak 2 to elastic scattering (N_c is the number of pulses per channel).

The pulses from the movable photomultiplier were analyzed by an AI-100 100-channel pulse analyzer. The resolution of the γ spectrometer for the Cs^{137} γ rays was 9%. In Fig. 2 is shown part of the spectrum of the 1.64 Mev γ ray with the total absorption peak, taken for $E_p = 2.72$ Mev.

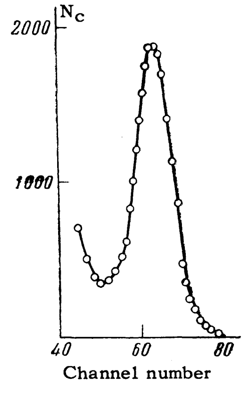

FIG. 2. Portion of the spectrum of γ rays around 1.64 Mev with total absorption peak, taken for $E_p = 2.72$ Mev.

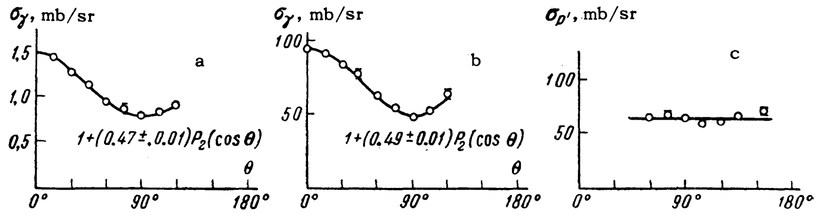

FIG. 3. Differential cross section for inelastic scattering of protons p′ and corresponding γ rays from the Ne^{20} (p,p′ γ) reaction: a – for E_r = 2.15 Mev; b – for E_r = 2.72 Mev.

For accelerating the protons we used the 4-Mev Van de Graaff accelerator of the Physico-Technical Institute of the Academy of Sciences of the Ukrainian S.S.R. The proton current at the target was $\sim 1\ \mu$a.

RESULTS OF THE MEASUREMENTS

In Fig. 3 are shown the results of measurements of the cross section for inelastic scattering Ne^{20} (p, p′γ) for protons p′ and γ rays as a function of the angle of scattering, at resonance energies E_r equal to 2.15 and 2.72 Mev. In the figure we show only the statistical errors which determine the precision of measurement of the angular distributions. The curves are drawn through the experimental points using the least squares method. Analytic expressions for the angular distributions are also shown in Fig. 3. The total cross sections are given in the table.

From data on elastic scattering it has been established[1,2] that the 4.50 Mev level of Na^{21}, corresponding to the resonance at 2.15 Mev, is formed by capture of a proton with orbital angular momentum $l = 2$; the spin and parity of this level is $3/2^+$. Using these data and assuming that the inelastically scattered proton emerges with orbital angular momentum $l' = 0$ and that the transition between the first excited 2^+ state and the ground 0^+ state of Ne^{20} is a pure E2-transition, we have calculated the angular distributions of the protons p′ and γ rays from the formulas given in the paper of Kraus et al.[4] From the table we see that the computed value of the coefficient A_2 in the angular distribution of the γ rays, $1 + A_2P_2(\cos\theta)$, is in good agreement with experiment. This agreement on the one hand is a check of the method, and on the other, what is more important, it shows the validity of the assumptions made in computing the angular distributions.

As one sees from the table, the angular distributions of the protons p′ (which are close to isotropic) and the γ rays for the resonance energy 2.72 Mev are in very good agreement with the computations if one assumes that there corresponds to this resonance a single level with spin and parity $3/2^+$. The result obtained does not agree with the data on elastic scattering, according to which this resonance cannot be explained by the presence of a single level.

In order to find other levels we carefully studied the shape of the resonance. Significant deviations from the shape corresponding to a single level were not found. We also measured the angular distributions of the γ rays for various energies of protons around the resonance. We still found the same results. All of this shows that only a single level is effective in the inelastic scattering at E_p = 2.72 Mev.

Using the expression for the area A under the resonance

$$A = 2\pi^2\lambda\!\!\!^-{}^2 (J + 1/2)\, \Gamma_p\Gamma_{p'}/\Gamma,$$

where $\lambda\!\!\!^-$ is the wave length of the impinging protons, J the spin of the intermediate state, Γ the total width of the level, Γ_p and $\Gamma_{p'}$ widths corresponding to elastic and inelastic scattering, we calculated the values of $\Gamma_p\Gamma_{p'}/\Gamma$. The results of these computations (cf. the table) do not depend on the target thickness or the sharpness of energy of the impinging protons.

Analysis of the γ ray spectrum shows that the cross section for radiative capture, Ne^{20}(p, γ)Na^{21}, for the resonances studied is very small. We can therefore assume that for the corresponding levels $\Gamma = \Gamma_p + \Gamma_{p'}$. From a comparison of the value Γ_p^2/Γ = 18 kev² and $\Gamma_p\Gamma_{p'}/\Gamma$ (cf. the table) for the 4.5-Mev level it follows that $\Gamma_{p'}/\Gamma_p = 0.005$. This shows that for this level $\Gamma_p = \Gamma$ and $\Gamma_p\Gamma_{p'}/\Gamma = \Gamma_{p'} = 0.1$ kev.

E_p, Mev	E_{exc}, Mev	Γ, Kev	σ_{res} mb	J^π	$\Gamma_p\Gamma_{p'}/\Gamma$, kev	$\gamma_{p'}^2$, kev	$\gamma_{p'}^2 \cdot 2mR^2/3\hbar^2$	A_2 for the γ ray: experiment	theory
2.15	4.50	17	13±3	$3/2^+$	0.10±0.03	50	0.02	0.47±0.03	0.5
2.72	5.05	36	800±100	$3/2^+$	10±2	100	0.04	0.49±0.01	0.5

For the 5.05 Mev level the value $\Gamma_p \Gamma_{p'}/\Gamma = 10$ kev with a total width $\Gamma = 36$ kev can be obtained under the condition that $\Gamma_p = \Gamma_{p'}$. This means that in this case $\Gamma_{p'} = 18$ kev.

Using these values we calculated the reduced widths for inelastic scattering $\gamma_{p'}^2 = \Gamma_{p'} A_{l'}^2/2\rho$. The barrier penetrability $A_{l'}^2/2\rho$ was determined from the graphs given in reference 5. The values of $\gamma_{p'}^2$ and their ratio to the quantity $3\hbar^2/2mR^2$ are given in the table.

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[1] W. Haeberli, Phys. Rev. **99**, 640 (A), 1955.

[2] A. K. Val'ter et al., Izv. Akad. Nauk S.S.S.R. Ser. Fiz. **24**, 884, 1960.

[3] A. K. Val'ter et al., Izv. Akad. Nauk S.S.S.R. Ser. Fiz. **23**, 839, 1959; Columbia Tech. Transl, p. 833.

[4] A. A. Kraus, Jr. et al., Phys. Rev. **104**, 1667, 1956.

[5] Nuclear Reactions, ed. P. M. Endt and M. Demeur, **1**, Amsterdam 1959.

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214