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Properties of the 7.03-MeV Excited State of N^{14}†

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The 7.03-MeV state in N^{14} has been excited by resonance scattering of the Doppler-broadened 7.115-MeV radiation from the $F^{19}(p,\alpha\gamma)O^{16}$ reaction. The measurement of the resonance effect as a function of the angle between the proton beam and the γ rays incident on the scatterer gives a cutoff angle which corresponds to a level energy of 7.029 ± 0.006 MeV. The angular distribution of the scattered radiation is consistent with a spin of 2, a fit being obtained for a quadrupole-dipole amplitude ratio of -0.60 ± 0.15. Assuming all the decays of this level are to the ground state, the mean life of this level becomes $(5.4\pm0.5)\times10^{-15}$ sec.

I. INTRODUCTION

THE 7.03-MeV level of N^{14} is presumably one of the levels arising out of the ground-state configuration of N^{14}. Originally a level somewhere near this energy with $(J^\pi,T)=(2^+,0)$ was predicted by intermediate shell-model calculations.[1] Warburton and Pinkston[2] using three different coupling schemes, i.e., *j-j* coupling, the wave functions derived from the work of Elliott,[3] and the wave functions of Visscher and Ferrell,[4] calculated the energy-independent $M1$ and $E2$ transition strengths for the first five levels in N^{14}, arising from the $s^4p^{10\,2}$ configuration, one of these being a $(J^\pi,T)=(2^+,0)$ state. Subsequently, the spin[5–7] and parity[8] and the isotopic spin[9] of the 7.03-MeV level were established to be 2^+ and 0, respectively. Other measurements were also made to determine the quadrupole-dipole amplitude ratio,[5–7,10] the branching ratios,[10] and the $E2$ transition strength.[8] Warburton *et al.*[10] then observed that the experimentally determined properties of this level agreed rather well with the predictions calculated by Warburton and Pinkston.[2] However, these evaluations depended on the mixing parameter as determined by one group of workers[6] and the $E2$ transition rate as determined by another group.[8] It therefore seemed important to make an independent measurement which might give both the ground-state transition probability and the mixing ratio. This is a report on such a study using the resonance-fluorescence technique.

Assuming the nominal value of 7.03 MeV to be the correct energy, it should be possible to resonantly excite this level with the Doppler-broadened 7.115-MeV radiation from the $F^{19}(p,\alpha\gamma)O^{16}$ reaction. Initial measurements made with a point scatterer located at 135° to the proton beam and for a proton energy of 2.65 MeV indicated a reasonable resonance effect. Similar measurements for a proton energy of 2.2 MeV gave essentially no effect. From the kinematics of the $F^{19}(p,\alpha\gamma)O^{16}$ reaction it could be seen, therefore, that the energy of the level must be within about 6 keV of the 7.030-MeV value. Following these measurements it was decided to modify the experimental arrangement to improve the signal-to-noise ratio and to carry out detailed measurements.

II. EXPERIMENTAL PROCEDURE

Figure 1 shows a typical geometry used in these measurements. The large lead shield around the detector was added to reduce the effect of resonance scattering from the air and materials of the room in general. A window was cut in this shield to allow the γ rays from the scatterer to reach the 3×3 in. NaI detector.

The fact that the NaI detector was exposed to the beam tube during these measurements also required some modifications. Fluorine contamination on the beam-defining apertures gave rise to a variable γ-ray

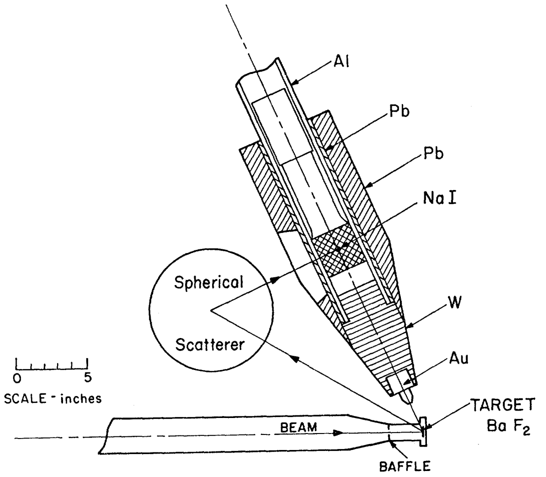

FIG. 1. Scattering geometry. For the angular distribution measurements, the different scattering angles were obtained by moving the NaI crystal axially.

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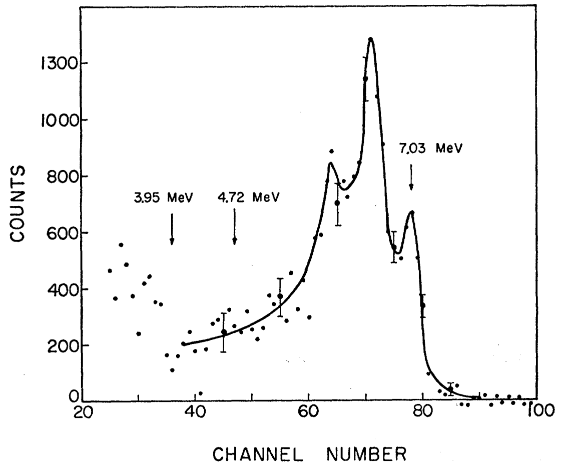

FIG. 2. Pulse-height distribution of the resonantly scattered radiation obtained as the difference between the nitrogen and benzene scatterers. The solid curve gives the best estimate of the distribution expected for a 7.03-MeV γ ray. Shown also are the expected positions of the full energy peaks for γ rays that would result if branching took place to the 2.31- and 3.95-MeV levels. The rise below channel 35 is the result of a mismatch in the scatterers for multiple Compton scattering.

background depending on the amount of stray beam hitting the apertures. The first of these apertures, about 5 ft from the detector, was shielded by several inches of Mallory metal. The second baffle, shown in Fig. 1, was placed close to the target so that it was shielded by the main attenuator of the detector assembly.

Two 4-liter glass Dewars served as the scatterer containers. Liquid nitrogen and benzene were used as the principal and comparative scattering materials, respectively. Since glass contains oxygen and silicon, both of which give rise to resonance scattering, the Dewar which contained nitrogen originally was used to contain benzene and vice versa during some of the runs to cancel out the possibility of different amounts of glass in the two Dewars.

BaF_2 targets approximately 200 keV thick for 2.65-MeV protons were prepared by vacuum evaporation onto 10-mil Ta backings. These targets were contained in the water-cooled assembly described previously.[11] A bombarding energy of 2.65 MeV was selected since the resonance effect seemed to be pronounced at this energy, whereas it was significantly lower at 2.2 MeV. All the runs were monitored by a 5×4 in. NaI detector placed approximately 8 ft from the target. Several times during the runs the 3×3 in. NaI detector was calibrated against the monitor. This was done by placing the 3×3 in. NaI detector directly in the γ-ray beam at the same angle to the proton beam as seen by the scatterer.

Initial measurements verified the importance of the lead shield added around the detector. The addition of this shield increased the ratio of the resonance effect from the nitrogen scatterer to the background effect with the benzene scatterer from 0.11 to 0.55.

Spectral Shape and Branching Ratio

Figure 2 shows the pulse-height distribution obtained as the difference between the nitrogen and benzene scatterers and represents some 100 h of data. The rise below channel 35 was caused by the mismatching of the scatterers for the effect of multiple Compton scattering. However, it is still possible to give an estimate on the limit of the branching to the 2.31-MeV level although little can be said concerning the branching to the 3.95-MeV level since this level in turn only decays 4% of the time to the ground state. The value for the branching to the 2.31 MeV is estimated to be less than 5%.

Level Energy

The energy of this level in N^{14} was determined by measuring the resonance effect as a function of the angle β between the γ rays incident on the scatterer and the proton beam. Throughout these measurements the scatterer-detector geometry was kept fixed, thus eliminating the effect of the angular distribution of the scattered radiation. Figure 3 gives the results. It is apparent that no levels are excited in the region from the maximum Doppler-shifted energy, i.e., the most forward direction, to the energy at which the resonance effect appears. If 6.916 and 7.115 MeV[12] are taken as the energies of the O^{16} levels responsible for the exciting radiations and 2.65 MeV for the proton energy, these maximum energies become 7.006 and 7.208 MeV, respectively. It is further seen that the data for 117° 45′ show no resonance effect whereas that at 130° 14′ are definitely up. These angles must be increased by one-half the angle subtended by the scatterer which then gives 130° 45′ as the lower limit and 143° 14′ as the upper limit. For a mean proton energy of 2.55 MeV and assuming that the radiation from the 7.115-MeV

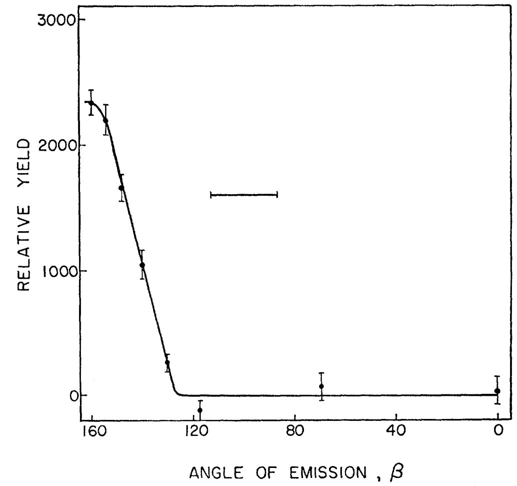

FIG. 3. Resonance effect as a function of the angle β between the proton beam and the γ rays incident on the scatterer. The horizontal bar represents the angle subtended by the scatterer.

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level is responsible for the resonance effect, these angles are equivalent to energies of 7.032 and 7.026 MeV, respectively. This includes a 3.5-keV reduction resulting from the recoil losses in the emission and absorption processes. Taking into account the quoted error of 3 keV[12] on the energy of the O^{16} level, the energy of the N^{14} level becomes (7.029 ± 0.006) MeV. If the radiation resulting from the 6.916-MeV state of O^{16} were responsible for the resonance effect, the energy of the N^{14} level would be 6.84 MeV which is not consistent with the limit set by others.[13]

Quadrupole-Dipole Amplitude Ratio

In the measurement of the angular distribution of the scattered radiation the position of the scatterer and the axis of the NaI detector system were kept fixed. The angle was changed by moving the NaI detector along its axis. Keeping the position of the scatterer fixed was essential because of the variation in the resonance effect with the change in the angle β as shown in Fig. 3. The angular distribution results are shown in Fig. 4. The least-squares fit to this data gives $W(\theta)=1+(1.25\pm0.16)P_2+(0.29\pm0.26)P_4$. This is consistent with a spin of 2 and a quadrupole-dipole amplitude ratio of $\delta=-0.60\pm0.15$. In determining δ we have used the convention of Biedenharn and Rose.[14] A spin of 1 cannot be ruled out since the errors on the P_4 coefficient are so large as to make the necessity of this term questionable. For a spin of 3, however, a reasonable fit cannot be made.

It has been assumed in the analysis of the angular distribution results that the incident γ rays were unpolarized. This is justified for two reasons. First, a rather large solid angle was subtended by the scatterer. Second, since the target was about 200 keV thick a fair number of states in the compound nucleus were probably involved.

Level Width

Since the resonance effect in absolute counting rate was quite small and since the absorption to be expected for a reasonable thickness absorber would also be small, a self-absorption experiment was considered to be impractical. Therefore, it was necessary to know the absolute scattering cross section in order to determine the mean life of this state in N^{14}. This resonance-fluorescence scattering cross section is proportional to $N(E_R)g\Gamma_0^2/\Gamma$ [15] where $N(E_R)$ is the number of γ rays per unit energy interval at the resonance energy, $g=(2J_1+1)/(2J+1)$, J_1 and J being the spins of the excited state and the ground state, respectively, and Γ_0 and Γ are the ground-state width and the total width, respectively. The determination of $N(E_R)$ involved several steps. First, the intensity of the incident radiation per monitor count was measured by placing the 3×3 in. NaI detector used in the resonance scattering measurements directly in the γ-ray beam at the same angle to the proton beam as the scatterer, i.e., $\beta=160°\ 23'$. Second, the shape of the Doppler-broadened γ-ray line was examined with a small Ge (Li) detector which has a resolution of 3 keV for the 661-keV γ ray from Cs^{137}. The spectra so obtained for $\beta=90°$ and $\beta=160°\ 23'$ are shown in Fig. 5. Next, a comparison was made between the spectrum for $\beta=160°\ 23'$ and the shape of the curve given in Fig. 3. From this it could be seen that the incident γ rays for the $\beta=160°\ 23'$ point of Fig. 3 came from the peak of the 7.115-MeV broadened spectrum of Fig. 5, the spread because of the finite size of the scatterer being about 6 keV. This information was then used to analyze the "direct beam" spectrum and thereby obtain $N(E_R)$. In this analysis the region of the "direct-beam" spectrum was selected so as to exclude the pulses resulting from the 6.14-MeV radiation. Applying the known spin of 2 for this level of N^{14} and using the angular distribution data of Fig. 4 we calculate $\Gamma_0^2/\Gamma=(0.122+0.004)$ eV. If we further assume that all the decays are to the ground state, the mean life of this level becomes $\tau=(5.40\pm0.18)\times10^{15}$ sec. However, because of the uncertainties involved in the evaluation of $N(E_R)$ and in the geometrical corrections this error has been increased by a factor of 3, giving $\tau=(5.4\pm0.5)\times10^{-15}$ sec. Of course, if there is any branching to states other than the ground state this value must be decreased by that amount.

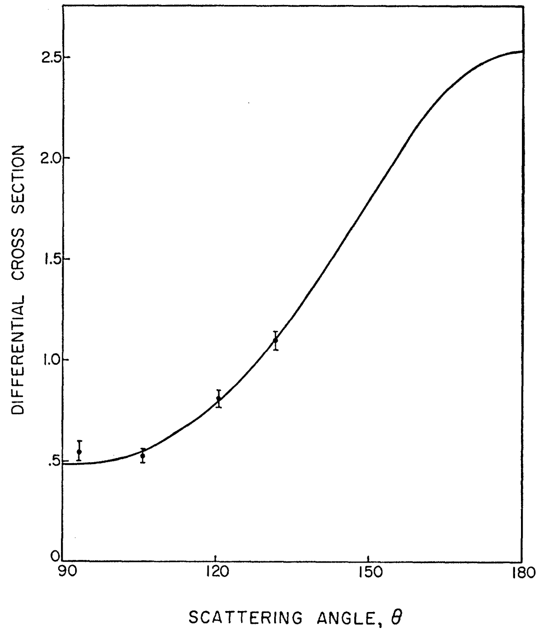

FIG. 4. Angular distribution of the resonantly scattered radiation. The solid curve gives the least-square fit, i.e., $W(\theta)=1+(1.25\pm0.16)P_2+(0.29\pm0.26)P_4$.

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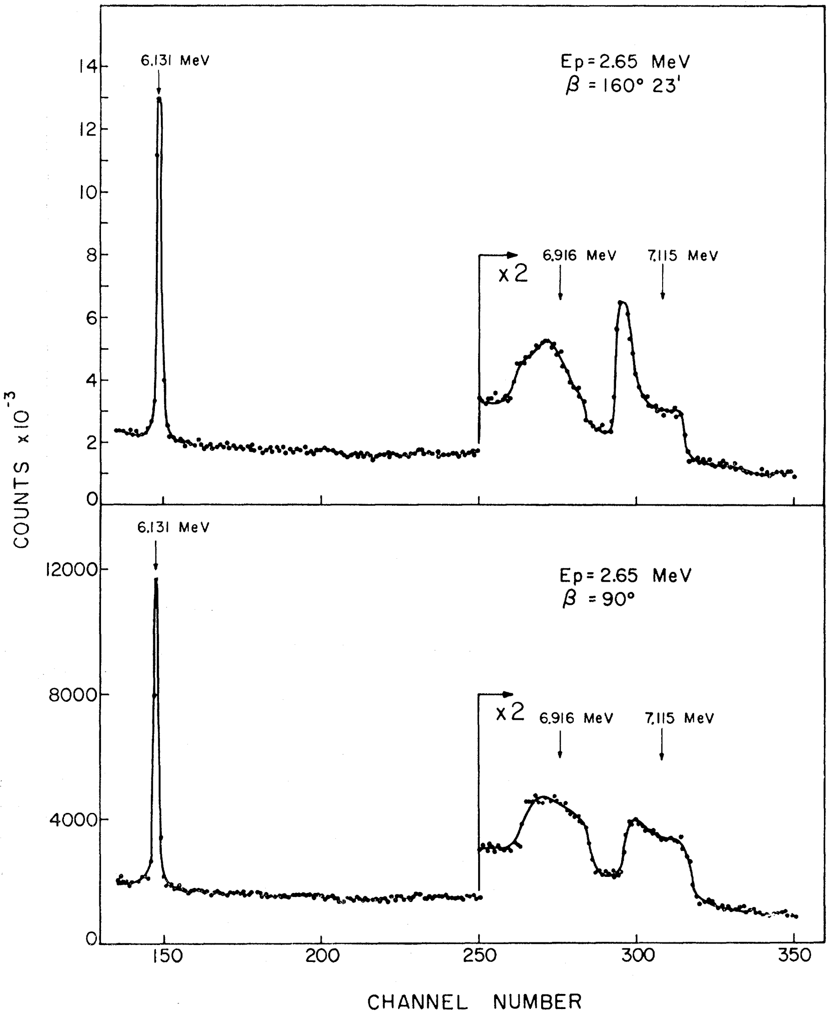

FIG. 5. Microspectrum of the radiation from the $F^{19}(p,\alpha\gamma)O^{16}$ reaction as observed in a Ge(Li) detector. β is the angle between the proton beam and the γ rays incident on the detector. Only the two escape peaks are apparent. The arrows locate the energies of the O^{16} levels.

III. CONCLUSION

The energy of the state observed in N^{14} was measured to be (7.029±0.006) MeV which is well within the limits previously set of (7.032±0.010) MeV.[13] The angular distribution of the scattered radiation is consistent with the known spin of 2,[5–7] and assuming this spin the quadrupole-dipole amplitude ratio becomes $\delta=-0.60\pm0.15$. This again agrees well with other work, the one with the least error being $\delta=-0.60\pm0.10$.[6] The branching from the 7.03-MeV state to the 2.31-MeV state was estimated to be less than 5% whereas little could be said about the branching to the 3.95-MeV state. Warburton *et al.*[10] give less than 5% and (9±5)%, respectively, for these two branchings. Young[16] however, finds a limit of less than 1% for decays to states other than the ground state. If we assume no branching to other than the ground state, the mean life of the 7.03-MeV level in N^{14} becomes $(5.4\pm0.5)\times10^{-15}$ sec. From inelastic electron scattering studies a positive parity is strongly preferred for this level.[8] This same work then gives for the $E2$ transition strength to the ground state $\tau(E2)=(1.02\pm0.07)\times10^{-14}$ sec. From this and the total lifetime given above we calculate the quadrupole-dipole amplitude ratio to be $|\delta|=0.76\pm0.17$. This value for δ is also in agreement with the values given above.

Since all the experimental results for this 7.03-MeV level are in basic agreement it appears rather conclusively that this level has $(J^\pi,T)=(2^+,0)$. Furthermore, since there is general agreement between the theoretical predictions and the experimental results,[10] this is very likely the $(2^+,0)$ level arising out of the s^4p^{10} configuration.

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[16] F. C. Young (private communication).