Gamma Rays from Ne†*

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The decay scheme of the low-lying excited states of Ne^{22} has been investigated by means of a proton gamma-ray coincidence study of the $F^{19}(\alpha,p)Ne^{22}$ reaction using a NaI(Tl) gamma-ray scintillation spectrometer. The excitation energies of the second and third excited states were rechecked and found to be 3.3 and 4.9 Mev, respectively. The results cast considerable doubt on the existence of the previously reported level at 0.6 Mev. For the 1.28-Mev excited state a single transition to the ground state was identified. The second excited state was found to decay principally by a cascade transition through the first excited state, although a weaker crossover transition direct to the ground state was also observed. The third excited state was found to decay through transitions to both the first excited and ground states. A discussion of possible spin and parity assignments by means of the Weisskopf relations is presented.

I. INTRODUCTION

THE modes of decay of the lower excited states of Ne^{22} have been investigated by means of a proton gamma-ray coincidence study of the reaction $F^{19}(\alpha,p)Ne^{22}$ using a NaI(Tl) gamma-ray scintillation spectrometer. The experimental method is essentially the same as that used by Allen, May, and Rall[1] on the $Al^{27}(\alpha,p)Si^{30}$ reaction and by May and Foster[2] on the $Na^{23}(\alpha,p)Mg^{26}$ reaction.

II. EXCITED STATES OF Ne^{22}

The ground-state Q value of the $F^{19}(\alpha,p)Ne^{22}$ reaction can be deduced accurately from the work of Mileikowsky and Whaling[3] on the reactions $Ne^{21}(d,p)Ne^{22}$ and $Ne^{21}(d,\alpha)F^{19}$. The result is

$$Q = 1.705 \pm 0.015 \text{ Mev.}$$

The excitation energy of the first excited state of Ne^{22} is known accurately to be 1.277 ± 0.004 Mev from the work of Alburger[4] on the gamma ray following the β decay of Na^{22}. Other information on the low-lying excited states of Ne^{22} has been obtained by several authors[5,6] from the $F^{19}(\alpha,p)Ne^{22}$ reaction using natural α particles.

In the present work a $\frac{1}{4}$-mil "Teflon" (CF_2—1.4 mg/cm^2) foil was bombarded by the 7.6-Mev alpha-particle beam from the Yale cyclotron. Protons from the target were observed at 90° and their ranges measured by means of aluminum absorbers and a "peaked" proportional counter. Figure 1 shows the resulting proton group curve which is essentially that used in the coincidence study. Some resolution was sacrificed to get larger solid angle and higher counting rates.

Figure 2 shows the results of this paper along with those of May and Vaidyanathan and Hjalmar and Slätis. There is essential agreement within the limits of resolution for the levels at 1.28, 3.3, and 4.9 Mev, as Hjalmar and Slätis would not see the latter level because of the low energy of the polonium alpha particles used. Hjalmar and Slätis, however, report a level at 0.57 Mev,

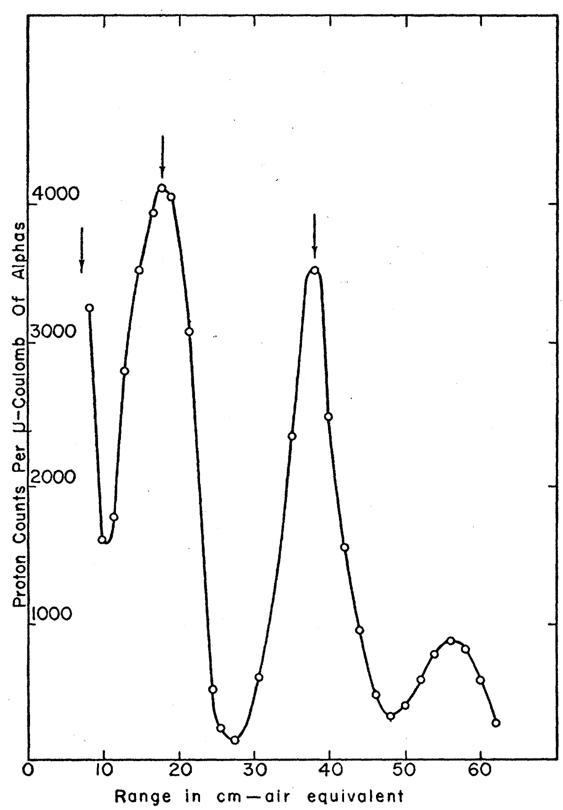

Fig. 1. Proton groups of $F^{19}(\alpha,p)Ne^{22}$ reaction for observation at 90°. Arrows indicate absorber used in coincidence studies.

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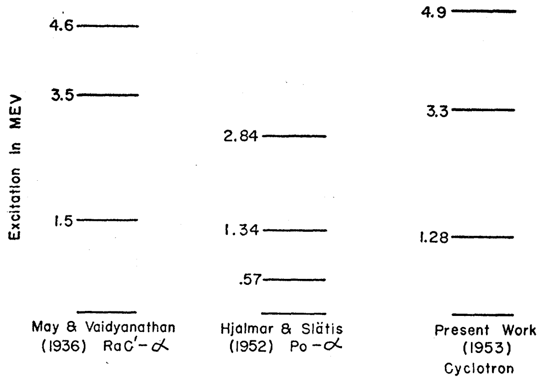

FIG. 2. Energy levels of Ne^{22} determined from present proton group results and those of previous workers.

which was earlier reported by Chadwick and Constable. Their experiment indicates that it is a state of very low yield. The present work, which has better resolution and statistics, gives no evidence for any level between the ground state and the 1.28-Mev excited state. This result, coupled with evidence from the β decay of Na^{22} makes the existence of any such state exceedingly unlikely.

III. COINCIDENCE TECHNIQUE

The detection geometry is shown in Figure 3. The spectrometer and electronic apparatus is essentially the same as that used in the work on Mg^{26}.[2] A block diagram of the electronic apparatus is shown in Fig. 4. With an amount of absorbing foil such that only protons corresponding to a desired excited state were counted, the gamma-ray pulses were selected for display on the synchroscope screen by triggering the sweep with a coincidence pulse. The absorber thicknesses used are shown by the arrows in Fig. 1. The pulse heights were photographed on continuously moving film and later analyzed to form a pulse height distribution. Natural sources of Cs^{137}, Na^{22}, and ThC″ were used for calibration.

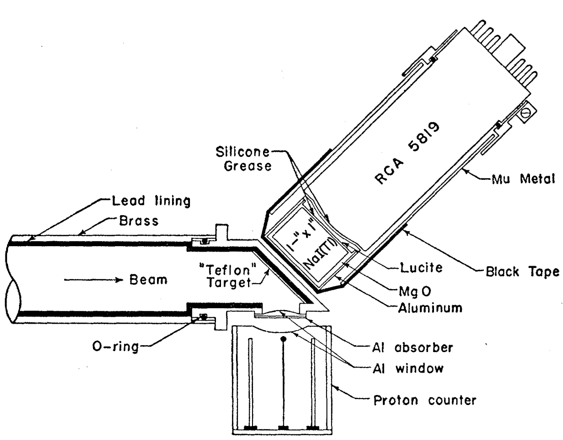

FIG. 3. Diagram of detection geometry.

IV. PULSE-HEIGHT DISTRIBUTION

A. First Excited State

The properties of the first excited state are well known from the β decay of Na^{22}. It was felt, therefore, that a run on this state would be a helpful check on the method and also give a direct quantitative measure of the accidental background above 1.5 Mev. The pulse-height distribution obtained for this state is shown in Fig. 5. The expected 1.28-Mev gamma ray is shown by both its photopeak and Compton edge at about 1.3 and 1.0 Mev, respectively. Spectrometer resolution during this run was 13 percent for the 1.28-Mev photopeak.

B. Second Excited State

Figure 6 shows the pulse-height distribution obtained for gamma rays in coincidence with protons from the second excited state. Two gamma rays are clearly indicated by the presence of their photopeaks at 1.3

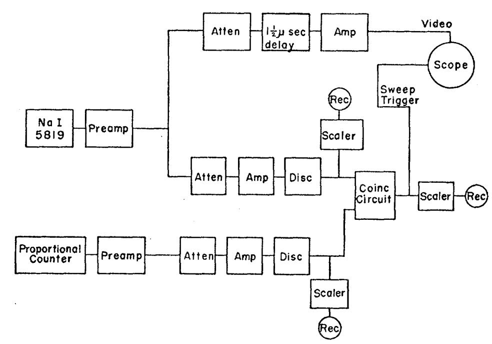

FIG. 4. Block diagram of counting circuits.

and 2.1 Mev, establishing the cascade transition through the first excited state. The Compton edge of the 1.28-Mev gamma ray is shown at 1 Mev, although the other peaks of the 2.1-Mev gamma ray are masked by the 1.28-Mev photopeak and by the rising accidental background. The number of counts above 2.3 Mev is well above the number to be expected from the sum of the background counts and those due to pile-up of the cascade gamma rays in the crystal. This establishes the presence of the 3.4-Mev crossover transition. Comparison of the areas under the curves indicates that the cascade transition is about three times stronger than the crossover. The data shown in Figs. 6 and 7 were taken with a spectrometer resolution of 11 percent for the 1.28-Mev gamma ray.

C. Third Excited State

The pulse-height distribution shown in Fig. 7 was taken for gamma rays in coincidence with protons of seven-cm range. The curve is the smoothest possible curve which can be drawn within the statistics of the points, therefore minimizing the peaks on the curve because of the poor statistics. The 1.28- and 2.1-Mev gamma rays are indicated by their photopeaks, and the 3.6-Mev transition from the third to the first excited states is shown by the three pair-peaks at about 2.6, 3.1, and 3.6 Mev. The peak at 3.4 Mev may be due to one of the pair-peaks of a weak 3.4-Mev gamma ray. The three higher-energy peaks in the curve may be assigned to the 4.9-Mev transition direct to ground. The pulse heights of these peaks do not fit exactly, but the energy calibration is not very precise in this higher energy region due to the lack of high-energy natural gamma-ray sources.

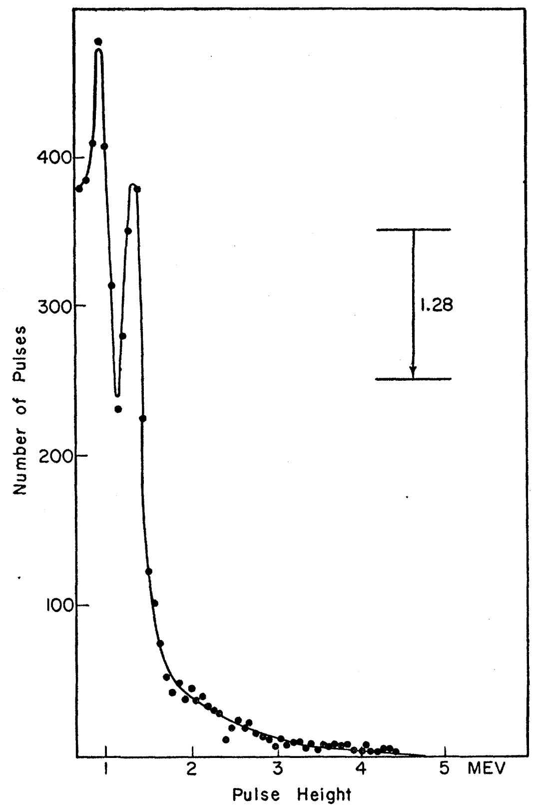

FIG. 5. Gamma rays from 1.28-Mev excited state of Ne^{22}.

In studying this state it was impossible to completely avoid counting some protons from the second excited state, since the absorber used was on the long-range side of the third excited state proton group. Using absorber thicknesses of less than 7-cm air equivalent was impractical because of the presence of elastically scattered alpha particles. Therefore, the pulse, height distribution shown in Fig. 7 comes from both the second and third excited states, and the detection of a gamma ray from the second excited state is not sufficient evidence to establish the presence of a cascade transition through the second excited state. In view of this we can definitely establish the transitions from the third excited state to the ground and first excited states by

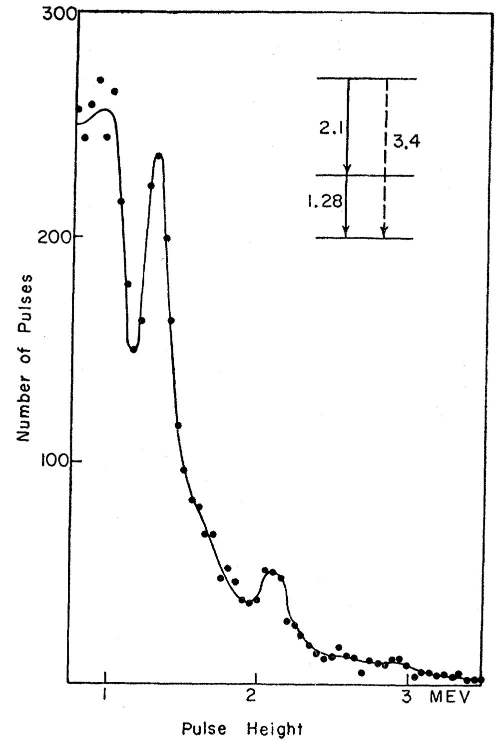

FIG. 6. Gamma rays from the second excited state of Ne^{22}.

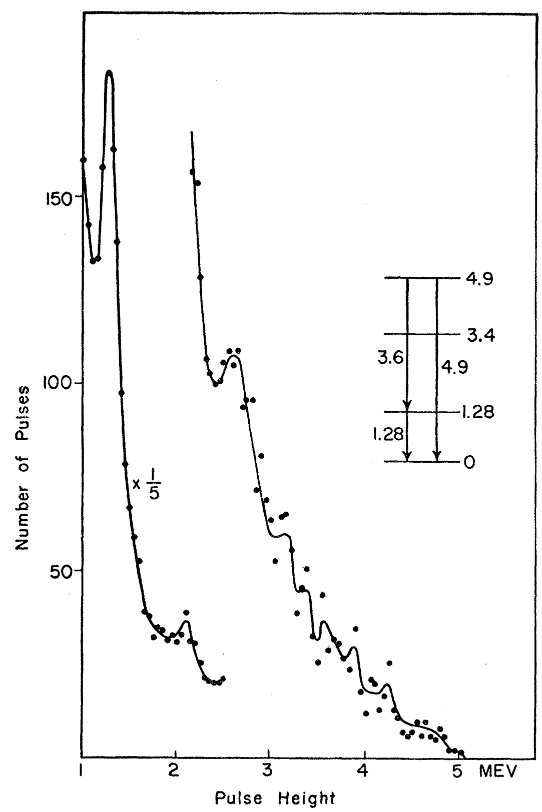

FIG. 7. Gamma rays from the third excited state of Ne^{22}.

the presence of the 4.9- and 3.6-Mev gamma rays, respectively, but cannot establish the cascade through the second excited state because of the absence of any evidence of the 1.5-Mev gamma ray between the second and third excited states. If the intensity of this transition were of the same order of magnitude as the other two transitions, one would definitely see a photopeak at 1.5 Mev. Comparison between the curves of Figs. 6 and 7 shows no evidence for such a peak.

V. DISCUSSION

In Sec. II it was shown that the existence of a level between the ground state and 1.28 Mev was extremely doubtful, and the remainder of the discussion will assume there is no such state.

Measurement of the internal conversion coefficient of the 1.28-Mev Na^{22} gamma ray shows that this transition is $E2$.[7] If we assume that the ground state of Ne^{22} has a spin and parity of 0^+ then the first excited state must be 2^+. Assuming these two spin and parity assignments, a comparison of the observed gamma-ray branching ratios with the Weisskopf transition probability relations[8] should give an indication of possible spin and parity assignments for the second and third excited states. Although the Weisskopf relations give answers which may be in error by as much as a factor of one hundred even such a rough indication can be of some value.

The decay of the second excited state was found to involve competition between a 2.1-Mev gamma ray to the first excited state and a 3.4-Mev transition direct to ground, with an intensity ratio of about three to one. The three possible spin and parity assignments which give order of magnitude agreement with this ratio are shown in Fig. 8(a) along with the calculated ratios. The next closest assignments are 2−, and 3+ or 4+ for the second excited state, and give ratios of 10^5 and 10^7, respectively, which can be definitely excluded.

On the basis of the rather limited data on the spins and parities of the second excited states of even-even nuclei, the assignment of 2+ to the second state appears the most likely.[9] Also, the limited amount of available experimental data shows that, while the Weisskopf relations give fairly accurate results for magnetic transitions, there is some evidence that the matrix elements for $E2$ transitions are exceptionally large, leading to transition probabilities which are larger than the calculated ones by factors of up to 50 or 100.[9–11] An increase in the $E2$ transition probability in the 2+ assignment would bring better agreement with the experimental results. This assignment would give complete agreement with the second excited state of Mg^{26}, which would be expected to have similar properties.[2] Therefore, although the experimental data do not definitely exclude the assignment of 1± to the second excited state, an assignment of 2+ seems most probable.

For the third excited state the transitions to the ground and first excited states were found to be about equally probably, while the transition to the second excited state is weaker by at least an order of magnitude. These results again lead to three possible spin and parity assignments, as shown in Fig. 8(b). Again making our assumption of increased probability for $E2$ transitions there is little to choose between the three possibilities. Arguments about nuclear systematics and the case of Mg^{26} again favor an assignment of 2+, although 1± is also compatible with the experimental results.

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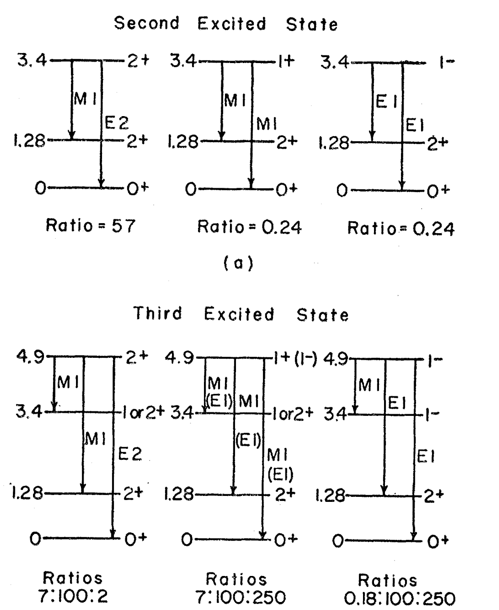

FIG. 8. Possible transitions, spins, and parities for the second and third excited states of Ne^{22}.

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