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Proton Groups from the $F^{19}(\alpha,p)Ne^{22}$ Reaction and the $Ca^{40}(\alpha,p)Sc^{43}$ Reaction*

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A CaF_2 target was bombarded with 21.9-Mev alpha particles and the energies of the outgoing protons were measured with a magnetic spectrometer. Proton groups leading to energy levels in Ne^{22} at excitation energies of 0, 1.28, 3.37, 4.52, 5.18, 5.67, 6.41, 6.88, and 7.49 Mev were seen. The ground state Q value for the $Ca^{40}(\alpha,p)Sc^{43}$ reaction was found to be -3.47 ± 0.030 Mev. Some information about absolute cross sections and angular distributions for the fluorine and calcium reactions is also presented.

NEON-22 is probably the only stable light nucleus that has not had its energy level spectrum investigated throughout the first 10-Mev excitation energy region. The ground and first excited states have been studied in the Na^{22} β^+ decay, but most of the information about higher excited states has been given by the $F^{19}(\alpha,p)Ne^{22}$ and the $O^{18}(\alpha,n)Ne^{21}$ reactions.[1,2] The (α,p) reaction, with Ne^{22} as a final state, examined the energy level spectrum at low excitation energies; the (α,n) reaction, with Ne^{22} as the compound nucleus, examined the spectrum at high excitation energies. There is a gap between excitation energies of 5 Mev and 11 Mev that has not been reached by either reaction. The work reported here extends the excitation

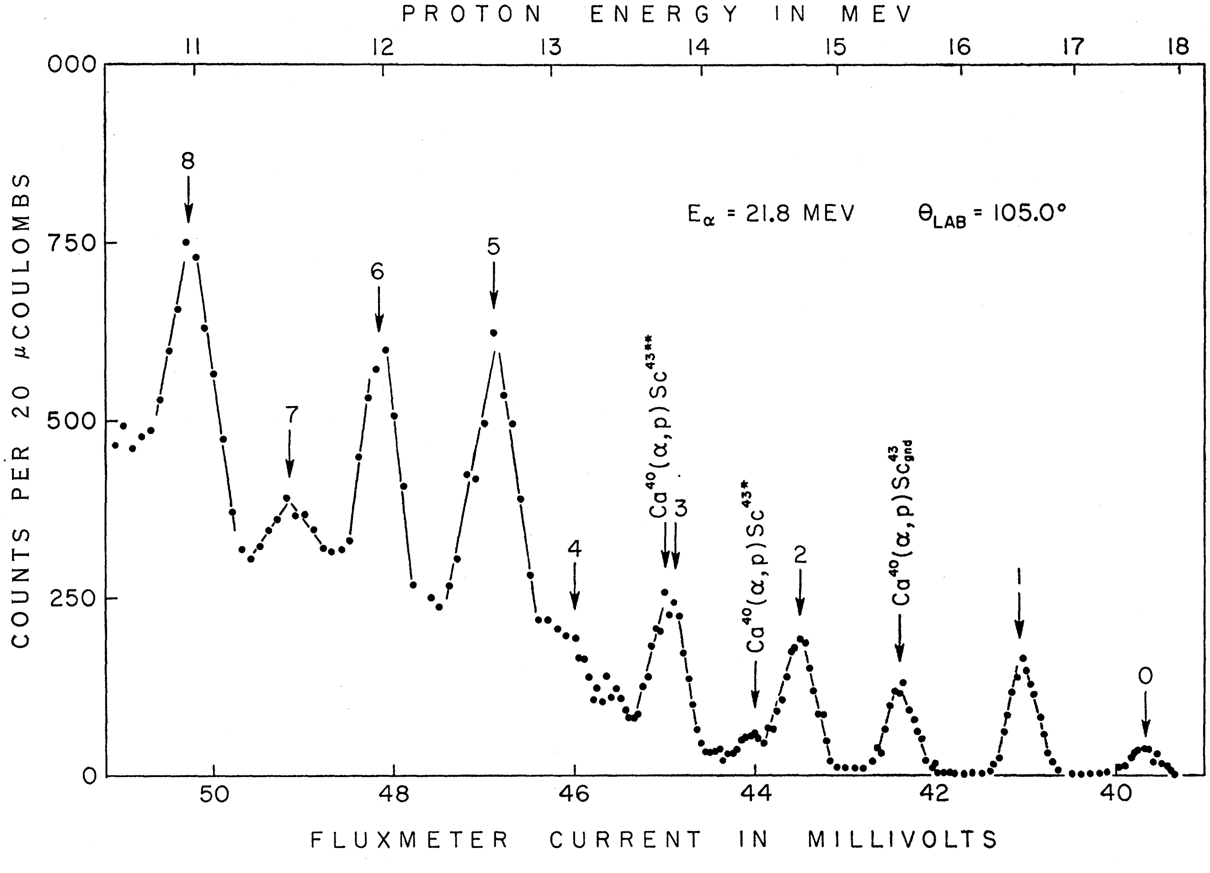

FIG. 1. A typical proton momentum spectrum for 21.9-Mev alpha particles bombarding a CaF_2 target. The numbered peaks are the proton groups excited in the $F^{19}(\alpha,p)Ne^{22}$ reaction. The $Ca^{40}(\alpha,p)Sc^{43}$ proton groups move through the fluorine proton groups at different angles.

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[1] F. Ajzenberg-Selove and T. Lauritsen, Nuclear Phys. **11**, 1 (1959).

[2] J. R. Priest, D. J. Tendam, and E. Bleuler, Phys. Rev. **119**, 1301 (1960).

region studied by the (α,p) reaction and partially closes the gap. Corollary information about absolute cross sections and angular distributions is also presented.

The 21.0-Mev alpha-particle beam from the Indiana University cyclotron was used to bombard a CaF_2 target (0.84 mg/cm^2) evaporated onto a Au backing (0.48 mg/cm^2). A ThC$''$ alpha-particle source was used to determine the thickness of the target and of the backing. The energy loss of the 8.78-Mev alpha particles in passing through the target was measured and the number of target atoms was calculated by using stopping powers given by Whaling.[3] The magnetic spectrometer used to measure the proton momenta and the rest of the experimental arrangement have been described in earlier papers.[4,5] A typical proton momentum spectrum is shown in Fig. 1.

Absolute Q-value measurements were not made in this work. Relative Q-value measurements were carried out instead, by using adjacent final states in the reaction. The difference in the Q values of two nearby states can be well determined even if the absolute value of the incident beam is uncertain by 1% (provided the beam energy remains constant throughout the measurement). This difference in Q values is, of course, the energy difference between the two states of Ne^{22} that have been excited, so that the excitation energy of a Ne^{22} state represents the sum of all the differences from this ground state. Consequently, any shift of the excitation energy of one level will shift all the levels at higher excitation energies by an equal amount.

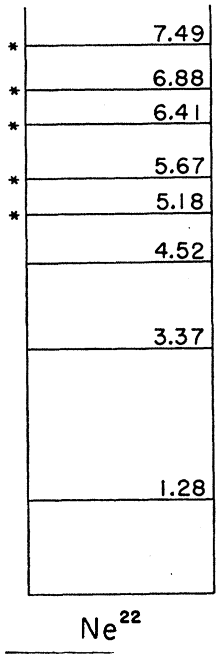

FIG. 2. The energy levels of Ne^{22} excited by the $F^{19}(\alpha,p)Ne^{22}$ reaction. Asterisks indicate the new levels that were found in the present work.

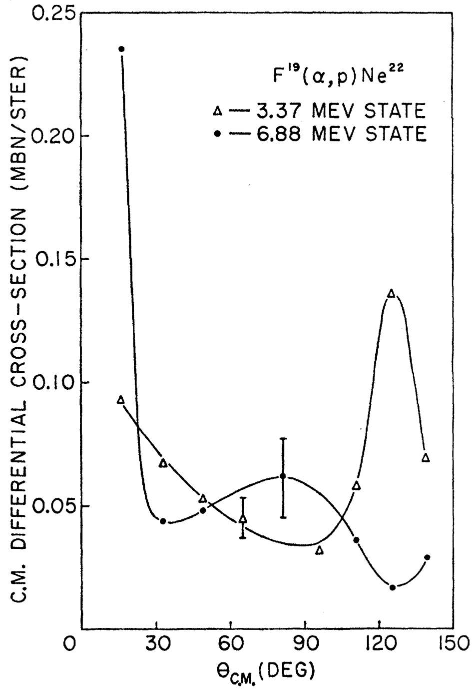

FIG. 3. The angular distributions for the proton groups leading to the 3.37-Mev and the 6.88-Mev states of Ne^{22}. Protons from the calcium in the target were troublesome at many angles and limited the information that could be obtained.

$F^{19}(\alpha,p)Ne^{22}$

Figure 2 shows the energy levels of Ne^{22} that were found in this work. The excitation energies are within ±30 kev except for the state at 5.18 Mev, for which the error is ±50 kev. The 5.18-Mev state and the 6.88-Mev state were quite weak and were not used in setting up the energy scale, thus variations in their energies do not affect the higher levels. The excitation energies of the first and second excited states are consistent with the values given in reference 1, but the energy found for the third excited state disagrees with the accepted value of 4.9 Mev. The excitation energy of 4.5 Mev that is given here does agree with the 4.4-Mev measurement by Ophel and Wright[6] using the $Na^{23}(\gamma,p)Ne^{22}$ reaction. These authors also discuss the earlier 4.9-Mev measurement. Ophel and Wright's experiment is the only previous work to penetrate the gap between 5-Mev and 11-Mev excitation energy. They found possible levels at 5.4-Mev and 5.7-Mev excitation energy. The five states found in the present work between 5-Mev excitation and 7.5-Mev excitation overlap Ophel and Wright's work and extend into the energy region that was not previously studied.

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[3] W. Whaling, Handbuch der Physik, edited by S. Flügge (Springer-Verlag, Berlin, 1958), Vol. 34, p. 193.

[4] V. K. Rasmussen, D. W. Miller, and M. B. Sampson, Phys. Rev. **100**, 181 (1955).

[5] M. T. McEllistrem, H. J. Martin, D. W. Miller, and M. B. Sampson, Phys. Rev. **111**, 1636 (1958).

[6] T. R. Ophel and I. F. Wright, Proc. Phys. Soc. (London) **A71**, 389 (1958).

Angular distributions for some of the more intense proton groups are shown in Figs. 3 and 4. Absolute cross-section errors are ±40%. The range of the magnetic spectrometer was not sufficient to measure the two highest energy proton groups at forward angles so that only partial angular distributions were obtained for these. These partial distributions are not shown, but they are in agreement with the work by Priest, Tendam, and Bleuler[2] using 18.9-Mev alpha particles. The cross sections for the 3.37-Mev state presented in Fig. 3 are smaller than Priest's results. Angular distributions are not shown for the 4.52-Mev, the 5.18-Mev, and the 5.67-Mev states. These states are either weak or they are obscured by calcium peaks at a large number of angles. Protons from calcium were quite troublesome, in general, and they strongly limited the amount of angular distribution information that could be obtained. This was particularly true for the low-energy proton groups.

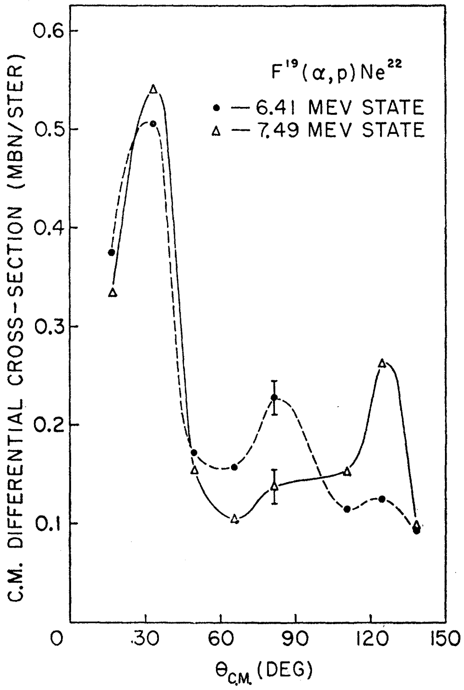

FIG. 4. The proton angular distributions for excitation of the 6.41-Mev and the 7.49-Mev states of Ne^{22}.

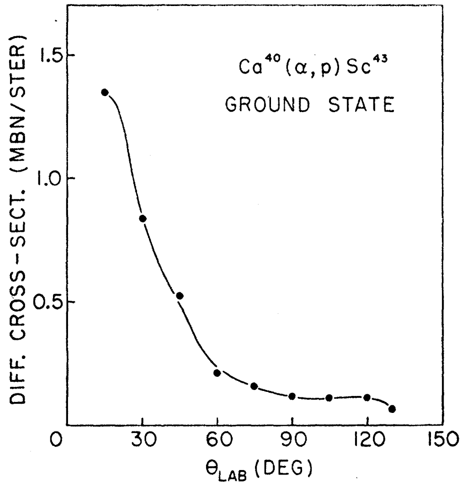

FIG. 5. The angular distribution of the proton group leading to the ground state of Sc^{43} in the $Ca^{40}(\alpha,p)Sc^{43}$ reaction.

$Ca^{40}(\alpha,p)Sc^{43}$

Three of the proton groups in the momentum spectrum varied with angle in such a way as to identify them with the $Ca^{40}(\alpha,p)Sc^{43}$ reaction. The angular distribution for the ground-state group is shown in Fig. 5.

An absolute Q-value measurement for these groups was made at back angles by using the $F^{19}(\alpha,p)Ne^{22}$ ground-state group to determine the beam energy. The Q value for the highest energy protons from fluorine is well known.[1] The highest energy protons from calcium were found to have a Q of -3.47 ± 0.030 Mev while the lowest energy group had a Q of -4.67 ± 0.030 Mev. The intermediate group was very weak and its Q could not be measured. The only previous measurement of the $Ca^{40}(\alpha,p)Sc^{43}$ ground state Q value was in 1937 and was -4.3 ± 0.2 Mev.[7] Mass defects, given by Endt *et al.*,[8] give a Q of -3.45 ± 0.04 Mev, in good agreement with the present work.

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[7] D. M. Van Patter and W. Whaling, Revs. Modern Phys. **26**, 402 (1954).

[8] P. M. Endt, W. W. Buechner, C. M. Braams, C. H. Paris, and A. Sperduto, Phys. Rev. **105**, 1002 (1957).