cates that the electron capture takes place to the 421-kev level exclusively. From this, it follows that the mass difference between Cr^{48} and V^{48} lies between 1.25 and 1.65 Mev, compatible with the predictions of beta decay energy systematics in this region.[7] The various decay properties of Cr^{48} are listed in Table I.

The conversion coefficients limit the multipolarity of γ_1 to fairly pure $M1$ and that of γ_2 to $E2$. The order of emission of γ_1 and γ_2 is not known, but in either case rather severe restrictions can be placed on the possible spin values of the various states.

The total angular momentum carried away by the allowed electron capture process and by the gamma cascade is $J \leq 4$. This fixes the ground state spin of V^{48} as 4 and the spin of the 421-kev level as 1; spins 2 or 3 can be chosen respectively for the intermediate level for case A or case B (see Fig. 2). The branching ratio of the two posssible γ transitions from the 421-kev level can be calculated using the nomogram published by Montalbetti[8] which is based on the formulas of Blatt and Weisskopf. For scheme A, the upper limit on the intensity of the cross over relative to the 116-kev transition is $\sim 1\times 10^{-8}$, for scheme B its upper limit relative to the 305-kev transition is $\sim 1\times 10^{-6}$. Neither of the two excited states is expected to have a half life of over 10^{-7} sec; thus the decay of Cr^{48} does not seem to lead to a metastable state of V^{48}.

From our data for the various gamma-ray intensities, it follows that for a 380-Mev proton bombardment of Ni the cross section for the production of 27-day Cr^{51} is 18 ± 2 times the cross section for the production of 23-hour Cr^{48} (assuming 10% K capture to the 0.32-Mev level in V^{51}).

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Excitation Function for the Reaction $Be^9(N^{14},\alpha n)F^{18}$

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The cross section for the production of F^{18} by nitrogen bombardment of beryllium was measured as a function of energy. The cross section varies from 100 to 200 millibarns at energies from 15 to 30 Mev. Below the barrier, the cross section falls off with decreasing energy in a manner which indicates a barrier penetration by the entire nucleus.

A SURVEY of nitrogen-induced nuclear reactions produced in light elements by 26-Mev nitrogen ions from the Oak Ridge National Laboratory 63-Inch Cyclotron was made by Reynolds, Scott, and Zucker.[1] The excitation functions of three nitrogen-induced reactions in carbon which result in radioactive residual nuclei were reported previously.[2] In this paper the excitation function of the reaction $Be^9(N^{14},\alpha n)F^{18}$ is reported for energies from 6 to 29 Mev.

The experimental method is similar to that described previously.[2] Thick targets of beryllium metal were bombarded in the deflected nitrogen beam at various maximum nitrogen energies. The energy of the incident beam was varied by placing nickel foils in front of the targets. Bombardments were made in two ways. In the first method, a disk with twelve holes on the periphery, eleven of which contained beryllium and appropriate absorbers, was rotated through the beam at approximately 5 rpm. A Faraday cup was placed beyond the disk so that for each rotation of the disk the current passing through the empty hole was measured and integrated, thus determining the number of particles striking each target. Fluctuations in beam intensity were averaged out since bombardments lasted for 30 minutes or longer. After bombardment the targets were removed and the amount of 112-minute F^{18} activity was measured with shielded Geiger counters which were calibrated by standard procedures.[2]

In the second method, targets were bombarded individually inside the Faraday cup. The energy absorbers were placed inside the cup to avoid making corrections for electron charge exchange in the foils. The results from the two methods are in good agreement, as shown by the yield curve in Fig. 1. The points indicated by dots were obtained with the rotating disk while the crosses represent data obtained from the direct bombardments in the Faraday cup. The probable error in

[1] Reynolds, Scott, and Zucker, Proc. Natl. Acad. Sci. **39**, 975 (1953).
[2] H. L. Reynolds and A. Zucker, Phys. Rev. **96**, 1615 (1954).

the absolute yield is about 20%, mainly due to inaccuracies in Geiger-counter calibration. At energies below 10 Mev the errors are probably larger due to energy straggling, the 600-kev spread in the beam energy, and poorer statistics at low counting rates. The energy of the incident nitrogen ions was determined by passing the nitrogen beam into hydrogen gas and measuring the range of elastically scattered protons at zero degrees to the incident beam.[3]

The smooth curve drawn through the yields was differentiated to obtain the cross section as a function of energy, as shown in Fig. 2. The range of nitrogen in Be^9 was obtained by using the known range of nitrogen

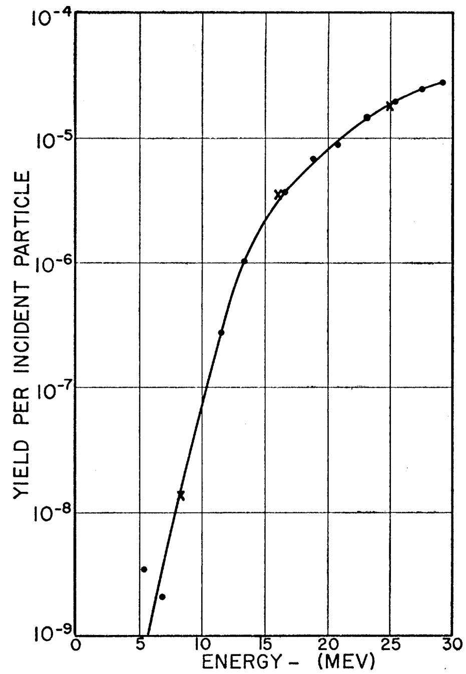

FIG. 1. Yield of the reaction $Be^9(N^{14},\alpha n)F^{18}$ as a function of energy. The dots represent runs made with the rotating disk; the crosses represent data obtained from direct bombardment in a Faraday cup.

in nickel[3] and the relative stopping power in nickel and beryllium for protons of equal velocity.

Since this reaction is detected by the F^{18} activity, it is not known if the other reaction products are He^5, or He^4 and a neutron, or both. No other reactions leading to radioactive products have been observed from the nitrogen bombardment of Be^9. This is to be expected because of the low Q-values for other reactions of this type. Of course, there are other competing reactions in

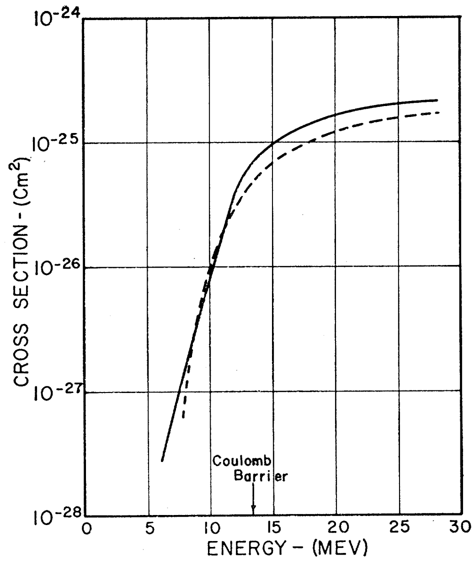

FIG. 2. Absolute cross section for the reaction $Be^9(N^{14},\alpha n)F^{18}$ as a function of the nitrogen ion energy. Solid line: experimental; dashed line: calculated.

beryllium, but they lead to stable residual nuclei which are not observed in this type of experiment.

It can be seen, from Fig. 2, that the cross section rises exponentially as the energy increases until the Coulomb barrier is reached. The shape of the curve suggests a barrier penetration phenomenon. The total cross section for the formation of the compound nucleus Na^{23} was computed from the relation

$$\sigma_T = \pi \lambda\!\!\!^{-2} \sum_l (2l+1) P_l \xi_l.$$

The penetrabilities P_l for charged-particle reactions were taken from Feshbach *et al.*[4] The sticking probability ξ_l is assumed to be unity. At maximum energy, l values as high as 13 enter into the cross section. The values for nuclear radii, 3.8×10^{-13} cm for Be^9 and 3.9×10^{-13} for N^{14}, used in this calculation were obtained from the fast neutron scattering data of Coon *et al.*[5] The dashed line in Fig. 2 represents the computed total cross section, divided by seven for purposes of normalization so that a visual comparison with the data can be made. The similarity between the data and the total cross section calculation indicates that the reaction rate is determined primarily by the entrance barrier penetration of the nuclei. The fact that the ratio of this reaction cross section to the total cross section remains nearly constant over this large an energy region is unexpected since there are many competing reactions possible.

[3] Reynolds, Scott, and Zucker, Phys. Rev. **95**, 671 (1954).

[4] Feshbach, Shapiro, and Weisskopf, U. S. Atomic Energy Commission Report NYO-3077, 1953 (unpublished).

[5] Coon, Graves, and Barschall, Phys. Rev. **88**, 562 (1952).