# Excitation Functions for Nitrogen-Induced Nuclear Reactions in Carbon

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The excitation functions for the reactions $C^{12}(N^{14},2p)Na^{24}$, $C^{12}(N^{14},\alpha)Na^{22}$, and $C^{12}(N^{14},2\alpha)F^{18}$ were measured with the external 29-Mev nitrogen beam of the 63-inch cyclotron. Thick-target yields as a function of energy were differentiated to obtain absolute cross sections from 16 to 29 Mev. A similarity to the excitation functions for reactions produced by protons on $Mg^{25}$ is suggested.

A RECENT survey[1] of reactions produced by bombarding a number of light elements in the internal nitrogen beam of the 63-inch cyclotron at the Oak Ridge National Laboratory disclosed reactions such as $N^{14}(N^{14},N^{13})N^{15}$ in which only one nucleon is exchanged between participating nuclei. Another type of reaction, such as $C^{12}(N^{14},2p)Na^{24}$, was observed in which the major part of the nuclear matter fuses.

Since this survey was made the 63-inch cyclotron beam has been deflected and a program has been initiated to investigate the mechanism of heavy-particle reactions. At present, the reactions investigated are only those leading to radioactive nuclei. The nitrogen-induced reactions observed in carbon are $C^{12}(N^{14},\alpha)Na^{22}$, $C^{12}(N^{14},2p)Na^{24}$, and $C^{12}(N^{14},2\alpha)F^{18}$. The half-lives of the beta activities were used in identifying the nuclides. These reactions may be compared to proton-induced reactions on $Mg^{25}$ to see if the nitrogen-induced reactions proceed through the compound nucleus $Al^{26}$.

## EXPERIMENTAL METHOD

Bombardments were made in the following manner. Carbon buttons $\frac{1}{16}$-in. thick and $\frac{7}{8}$-in. in diameter were placed in a motor-driven 12-position target holder which was rotated rapidly through the deflected beam of nitrogen ions (Fig. 1). Nickel foils, increasing in thickness by 0.5-mg/cm$^2$ steps, were placed in front of these individual targets to reduce the effective energy of the beam. In this way a large part of the energy spectrum was covered in one run. The energy of the initial deflected beam was measured[2] by observing the energy of recoil protons from a gas target at zero degrees. From the initial energy and from the range-energy relations for nitrogen ions in nickel,[2] it was then possible to calculate the energy of nitrogen ions striking each carbon target.

The carbon targets, together with the absorbers in front of them, were placed in eleven positions of the target holder. One position was left open for monitoring; each time the wheel rotated a pulse of current passing through the open hole was collected in a Faraday cup placed above the wheel. The Faraday cup was in the 2000-oersted fringing magnetic field. A vibrating reed current integrator was used to record the total number of particles passing through the hole. The integrator was calibrated with a battery and vacuum resistor to about two percent. Electron loss for the triply charged nitrogen ions before collection in the Faraday cup was negligible at the pressure in the target assembly. When compared with the uncertainties due to absolute beta counting current measurement errors may thus be considered unimportant.

At the end of a run the targets were placed in an automatic sample changer and the beta particles were counted with an end-window Geiger counter. The Geiger counter was calibrated with $P^{32}$ and RaE sources of known intensity, obtained from the National Bureau of Standards. The RaE source had a thick backing of silver; the $P^{32}$ source was placed on a thin plastic backing. The saturation backscattering correction was measured for the $P^{32}$ sample with both silver and carbon backings. The value for silver agreed with that given by Burtt,[3] and the value obtained for carbon was 1.18. Burtt has shown that the saturation backscattering correction is essentially independent of the maximum beta-particle energy if it is above 0.5 Mev. The $P^{32}$ and RaE calibrations agreed to within 5 percent and gave a beta counting efficiency of 8.25 percent for the geometry used. Window and air-absorption corrections were applied by standard methods while self absorption in the targets was neglected because of the short range of nitrogen ions.

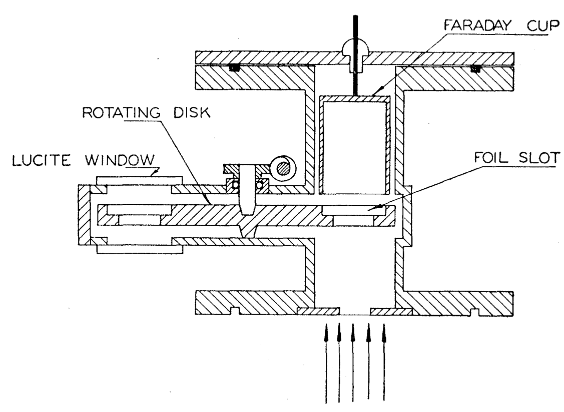


FIG. 1. Twelve-position rotating target holder. The beam emerges vertically from the cyclotron; the target holder rotates in the horizontal plane.

[1] Reynolds, Scott, and Zucker, Proc. Nat. Acad. Sci. **39**, 975 (1953).
[2] Reynolds, Scott, and Zucker, Phys. Rev. **95**, 671 (1954).
[3] B. P. Burtt, Nucleonics **5**, 28 (1949).

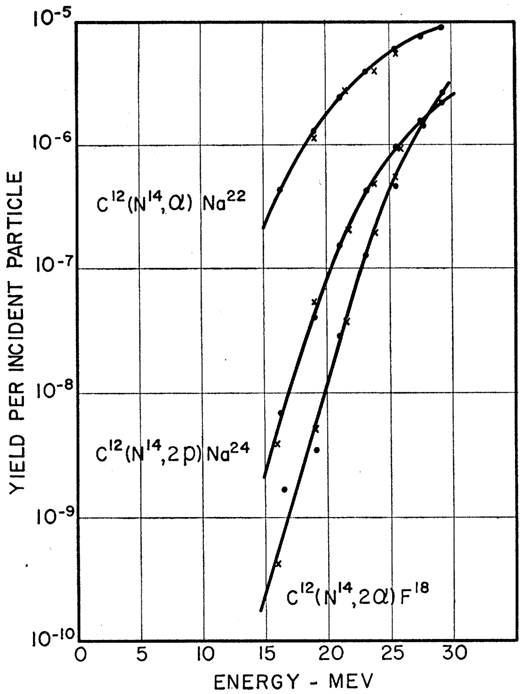


FIG. 2. Yield of nitrogen-induced reactions in carbon as a function of incident beam energy. The dots represent runs made with the rotating wheel; the crosses represent data obtained from direct bombardment in a Faraday cup.

A correction for the $K$-capture branching in $Na^{22}$ was applied.[4]

The activities observed in carbon were found to be due to $F^{18}$, $Na^{24}$, and $Na^{22}$, with half-lives of 112 minutes, 15 hours, and 2.6 years respectively. Chemical identification was not required since the few possible reaction products, after energy requirements were fulfilled, were widely separated in half-life. The decay curves were followed for several weeks until only the long-lived $Na^{22}$ remained; it was identified by observing the 1.28-Mev gamma ray. The decay curves were analyzed to determine the number of radioactive nuclei produced by a bombardment. Knowing the beam current, it was then possible to determine a yield for the reaction as a function of the incident beam energy. In order to check these runs, several individual targets were bombarded directly in a Faraday cup.

## RESULTS AND DISCUSSION

The absolute yield in reactions per incident particle is plotted as a function of energy, Fig. 2. The dots represent runs made with the rotating wheel; the crosses represent data obtained from direct bombardments in a Faraday cup. The agreement for the two types of bombardment is good. The probable errors are about 15 percent, chiefly due to the uncertainties involved in absolute beta counting. Relative yields are probably in error by less than 5 percent.

Smooth curves drawn through the points in Fig. 2 were differentiated to give the absolute cross sections

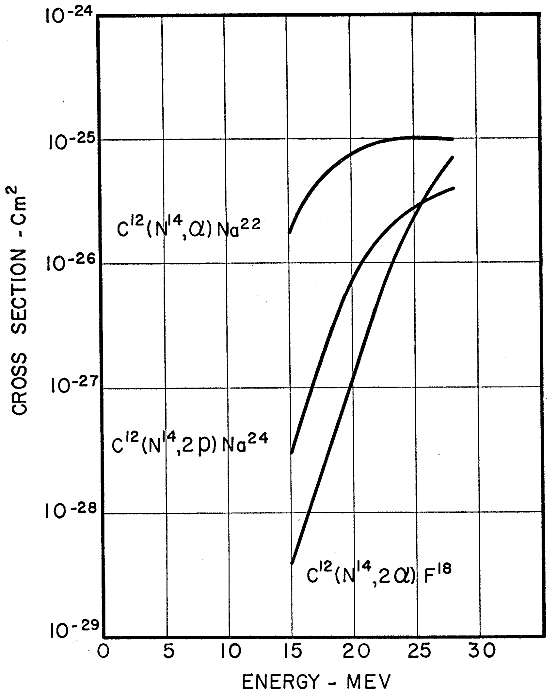


FIG. 3. Absolute cross sections for nitrogen-induced reactions in carbon as a function of nitrogen ion energy.

as a function of energy, Fig. 3. Errors in the yield become very important when the slope of the yield curve is small. In this region the errors in the cross section are greatest because differentiation involves subtracting large numbers to get small differences. Subtraction of experimentally determined yields proved less reproducible than the differentiation of smoothly drawn yield curves. For the differentiation it is necessary to know the range of nitrogen ions in carbon. The range of nitrogen ions in aluminum was measured and it was found that this range can be computed from the range of nitrogen ions in nickel, by using the relative stopping power for protons[5] of equal velocities. From the relative stopping power for protons in carbon and nickel, the range of nitrogen ions in carbon was calculated.

The relative yield of $F^{18}$ to $Na^{24}$ produced in the bombardment of carbon varies rapidly with the energy of the nitrogen beam; at 26 Mev the relative yield changes by 30 percent for a 4 percent change in energy. Thus, a simple relative yield determination provides a good beam energy measurement if the initial energy spread is not large.

The excitation functions, Fig. 3, have an exponential rise, suggesting a barrier penetration at low energies. They exhibit marked similarities to proton-induced reactions in $Mg^{25}$. A detailed comparison of excitation functions for reactions produced by protons on $Mg^{25}$ and nitrogen on carbon is made in the following paper.[6]

[4] R. H. Miller and R. Sherr, Phys. Rev. **93**, 1076 (1954).

[5] S. K. Allison and S. D. Warshaw, Revs. Modern Phys. **25**, 779 (1953).

[6] Cohen, Reynolds, and Zucker, following paper [Phys. Rev. **96**, 1617 (1954)].