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Gamma-Ray Resonances in the Alpha-Particle Bombardment of Beryllium and Boron

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Be^9 and B^{10} have been bombarded with alpha-particles from our electrostatic generator at energies up to 3.0 Mev and the gamma-radiation yield observed with scintillation counters. The data indicate energy levels in C^{13} at 11.95 and 12.46 Mev and in N^{14} at 12.77, 12.87, 12.90, 13.01, and 13.24 Mev. A number of higher energy levels were indicated in N^{14} but were not satisfactorily resolved.

INTRODUCTION

We have examined energy levels of the compound nuclei C^{13} and N^{14} through the reactions: $Be^9(\alpha,n\gamma)C^{12}$ and $B^{10}(\alpha,p\gamma)C^{13}$, respectively, bombarding with singly ionized helium ions from the electrostatic generator. Reactions of this type have in the past largely been studied using natural alpha-emitters and cyclotrons. Comparatively little work has been done with electrostatic generators, mainly because of the poor helium ion current usually obtained from low voltage arc ion sources. The development of radio frequency ion sources has resulted in much larger singly ionized helium ion beams making this type of experiment more feasible.

Neutron yield curves such as Halpern's[1] indicate levels in C^{13} at 11.7 and 13.6 Mev. A number of energy levels in N^{14} have been indicated by previous work from resonances in the $B^{10}(\alpha,p\gamma)C^{13}$ reaction[2] using natural alpha-sources but these were not well resolved.

EXPERIMENTAL PROCEDURE

Thins targets were bombarded in the Department of Terrestrial Magnetism pressurized electrostatic generator with alpha-particles whose energies extended from about 1.0 Mev to 3.0 Mev. Both electrostatic generators in this laboratory have recently been equipped with radio frequency ion sources of the type developed at Oak Ridge National Laboratory.[3] Beams up to 10 microamperes were used, the limitation being the over heating of the target rather than the behavior of the ion source. The voltage scale of the generator was checked against the $Be^9(p,n)B^9$ threshold which was taken to be 2.059±0.002 Mev.[4]

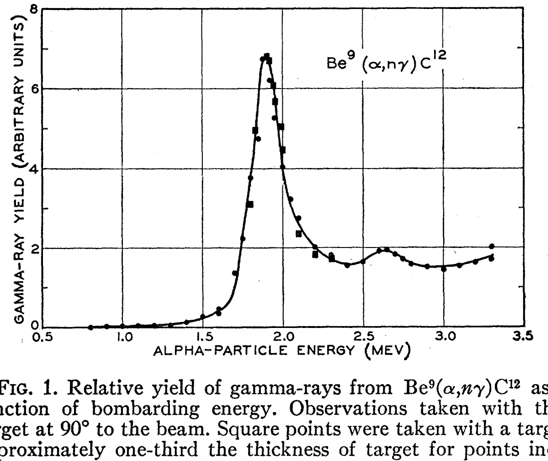

Fig. 1. Relative yield of gamma-rays from $Be^9(\alpha,n\gamma)C^{12}$ as a function of bombarding energy. Observations taken with thin target at 90° to the beam. Square points were taken with a target approximately one-third the thickness of target for points indicated by circles; curves normalized arbitrarily at 1.9 Mev.

Beryllium targets about 5 to 10 kev thick were obtained from S. S. Hanna at The Johns Hopkins University. We later prepared targets about one-quarter to one-third as thick by vacuum evaporation onto copper. Boron targets, both natural isotope percentage and enriched to 96 percent B^{10} (supplied by the Isotopes Division, U. S. Atomic Energy Commission, Oak Ridge, Tennessee), were also prepared by evaporation. The boron targets finally used had a stopping power of less than 10 kev for alpha-particles in the energy region investigated.

The gamma-radiation from both the beryllium alpha-neutron reaction and the boron alpha-proton reaction was examined at 90° to the incident beam. The final results reported in both cases were obtained with sodium iodide crystal scintillation counters. Two crystals were used, one being about an inch cube, the other one inch square and $1\frac{1}{2}$ inches long, the square face being in contact with an RCA 5819 photomultiplier tube. In the case of beryllium a neutron yield curve with a boron ionization chamber was also taken. This curve was very similar to the gamma-yield curve.

The gamma-yield curve for the $Be^9(\alpha,n\gamma)C^{12}$ reaction is shown in Fig. 1, the gamma-ray yield in arbitrary units being plotted against the bombarding energy in Mev. The use of a target approximately one-third as thick, as indicated by the total yield at the peak, showed no difference in the width of the peak. The gamma-yield obtained from bombarding boron with alpha-particles is shown in Fig. 2. All of the gamma-radiation seems to be due to the B^{10} as the only noticeable difference in the gamma-ray response curve on

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[1] I. Halpern, Phys. Rev. **76**, 248 (1949).

[2] Hornyak, Lauritsen, Morrison, and Fowler, Revs. Modern Phys. **22**, 291 (1950).

[3] Moak, Reese, and Good, Nucleonics **9**, 18 (Sept. 1951).

[4] Richards, Smith, and Browne, Phys. Rev. **80**, 524 (1950).

shifting from the natural to the enriched boron was an increase in the intensity of all peaks in about the ratio of the concentration of the B^{10}. The energy of the gamma-rays obtained from the boron bombardment was checked at several different bombardment energies with the $1\frac{1}{2}$ inch thick NaI crystal. The gamma-rays from Co^{60} and $F^{19}(p,\gamma)$ were used for calibration.[5] The energy was consistently 3.9 ± 0.1 Mev, indicating that the 3.89 Mev level in C^{13} is more strongly excited in this reaction than the 3.09 Mev level. Measurement of the energy of the $Be^9(\alpha,n\gamma)$ gamma-ray was made with the 1-inch thick NaI crystal and found to be 4.2 ± 0.2 Mev. This most likely corresponds to a predominant gamma transition from the well-known 4.47-Mev level in C^{12}.

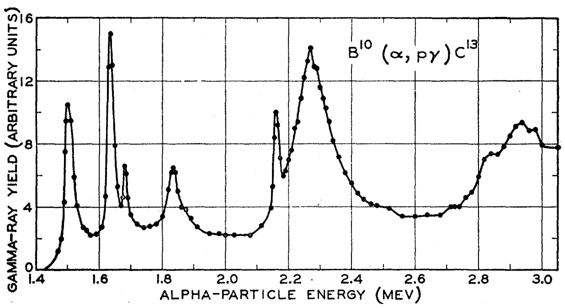

FIG. 2. Relative yield of gamma-rays from $B^{10}(\alpha,p\gamma)C^{13}$ as a function of bombarding energy. Observations taken with thin target at 90° to the beam.

DISCUSSION OF RESULTS

The beryllium curve has a strong first resonance peak at 1.90 Mev. The previous value was 1.5 Mev.[6] This would raise the level in C^{13} formerly set at 11.7 Mev to 11.95 Mev. A small but consistent peak appears at 2.65 Mev which would indicate a heretofore unreported level at 12.46 Mev.[7]

The boron yield curve shows fairly sharp maxima at 1.50, 1.63, 1.68, 1.83, and 2.16 Mev and somewhat broader peaks at 2.27 and 2.95 Mev. These values assign energy levels in N^{14} of 12.77, 12.87, 12.90, 13.01, and 13.24 Mev. The two broader peaks probably represent a number of unresolved energy levels lying very close together.

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[5] E. J. Woodbury and W. A. Fowler, Phys. Rev. **85**, 51 (1952).

[6] I. Halpern, Phys. Rev. **76**, 248 (1949).

[7] N. Nereson, Phys. Rev. **87**, 221 (1952), from total neutron cross-section measurements of C^{12}, has reported evidence of a level of 12.3 Mev.

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Electrical Conductivity of Single Crystals of Graphite

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The electrical conductivities along the principal directions of graphite crystals have been measured using a large number of well-developed single crystals obtained from Ceylon. The conductivity along a direction perpendicular to the hexagonal axis is about 10^4 times that along the axis. Rectification and other nonlinear effects are totally absent. Thickness plays an important part in the determination of the conductivity normal to the hexagonal axis and attempts have been made to avoid this difficulty. These measurements have been extended to temperatures between 80°K and 500°K. The conductivity perpendicular to the hexagonal axis falls roughly exponentially with rising temperature and that along the axis rises similarly with temperature. A magnetic field has been found to cause a decrease in both the conductivities—the effect on the conductivity normal to the hexagonal axis being more pronounced. This decrement falls roughly exponentially with rising temperature and has a tendency to attain a steady value at higher temperatures.

INTRODUCTION

GRAPHITE is a hexagonal layer-latticed crystal having a perfect basal cleavage and occurs in nature in the form of thin flakes. Investigations of its structure by Bernal[1] revealed that its carbon atoms are arranged in layers parallel to the basal plane, the atoms in each layer forming a regular hexagonal network. The distance of separation between the adjacent layers is 3.40A, which is much larger than the distance between the adjacent atoms in the same layer, namely, 1.42A; this shows that the binding between the adjacent layers is extremely loose, and is probably of the Van der Waals type. The diamagnetic properties of this crystal have been studied in details by Ganguli[2] and Krishnan and Ganguli.[3] The specific susceptibility (per gram) of the crystal perpendicular to the hexagonal axis $\chi_\perp$, is about -0.5×10^{-6}, which is nearly that of diamond. On the other hand, the susceptibility along the hexagonal axis, $\chi_{\parallel}$, is numerically very large, and is equal to -21.5×10^{-6}, i.e., about 40 times $\chi_\perp$. The above values refer to room temperature, and measurements have been

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[1] J. D. Bernal, Proc. Roy. Soc. (London) **A106**, 749 (1924).

[2] N. Ganguli, Phil. Mag. **21**, 355 (1936).

[3] K. S. Krishnan and N. Ganguli, Nature **139**, 155 (1937).