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Gamma-Rays from Beryllium and Nitrogen Bombarded with Deuterons

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Measurements have been made on the Compton electrons ejected from a thin lamina of carbon by the gamma-rays from Be+D and N+D. Lines at 3.45 and 1.0 Mev were found in the case of Be+D and lines at 8.2, 6.6, and 5.1 Mev were found in the case of N+D, with a slight indication of two other lines at 4.1 and 2.5 Mev. Possible ways in which these lines may be correlated with the energies of the heavy particles emitted is discussed.

INVESTIGATIONS of the gamma-rays emitted when beryllium[1–4] and nitrogen[5] are bombarded with deuterons have previously been made, and it is already clear that both of these spectra are complex. We have obtained a new set of data on each of these gamma-ray spectra and we believe that sufficient improvement in technique has been accomplished so that more reliable estimates of the energies of the lines can be given that those which were possible in the earlier work. The scale of energy was calibrated directly against the 2.6-Mev line of thorium C″, and was also checked against the calibration obtained by measuring the magnetic field with a flip-coil. Targets of beryllium metal granules (Eimer and Amend) and of ammonium chloride were bombarded with a beam of deuterons of approximately 0.6 Mev energy, from the high voltage accelerating tube.[6] The resulting radiation was allowed to pass into a cloud chamber through a thin aluminum window in the glass wall. Lead blocks were used to prevent the radiation striking any part of the chamber except the window. A lamina of graphite weighing 0.24 g/cm^2 was placed across the center of the cloud chamber perpendicular to the direction of the radiation, to act as a source of secondary electrons. From the known absorption coefficients in the range of energies studied it was expected that the secondaries would be mainly Compton electrons. A magnetic field was applied by means of a pair of air core coils. Nonstereoscopic photographs were taken by a Sept camera located directly above the chamber. Only those tracks which were due to negative electrons originating in the graphite and having initial directions within 15 degrees of the direction of the gamma-radiation were measured and included in the data. In order to obtain data on thorium C″ a sample of mesothorium and its products of about 1 millicurie strength was placed in the position otherwise occupied by the beryllium or ammonium chloride target, and a block of lead 3 cm thick was interposed to filter out the soft gamma-ray components.

BERYLLIUM

Figure 1 shows the energy distribution of the tracks found. Referring to the 1300-gauss curve (open circles), the very steep front ending at about 3.2 Mev indicates a strong gamma-ray of 3.45±0.2 Mev. A few tracks of higher energy appear, extending up to 6.4 Mev, but it does not seem probable that these arise from Be±D. In the first place, the energy available from the reaction is not great enough to make it possible. They may be the result of some protons[2] in the ion beam, or they may be due to gamma-rays resulting from the capture of neutrons in the material near the chamber. The latter explanation seems the more plausible. No attempt was made to explore the range below 1.5 Mev with the 1300-gauss field, but for this purpose a field of 500 gauss was used. The lower field has the advantage of increasing the resolving power at low energy, but at the same time makes it impossible to measure the lines at the high end of the spectrum. The distribution obtained at

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[1] H. R. Crane and C. C. Lauritsen, Phys. Rev. **45**, 226 (1934).

[2] H. R. Crane, L. A. Delsasso, W. A. Fowler and C. C. Lauritsen, Phys. Rev. **47**, 782 (1935).

[3] P. G. Kruger and G. K. Green, Phys. Rev. **52**, 773 (1937).

[4] P. G. Kruger, F. W. Stallmann and W. E. Schoupp, Phys. Rev. **56**, 297 (1939).

[5] H. R. Crane, L. A. Delsasso, W. A. Fowler and C. C. Lauritsen, Phys. Rev. **48**, 100 (1935).

[6] H. R. Crane, Phys. Rev. **52**, 11 (1937).

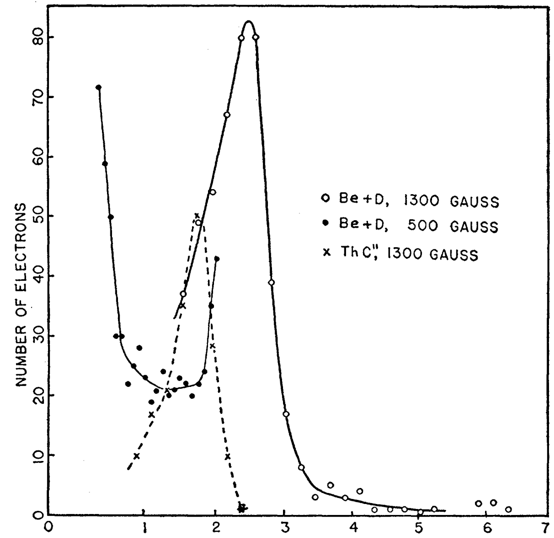

FIG. 1.

500 gauss shows that there is strong radiation of low energy. The steep front ending at 0.8 Mev indicates that there is a line at about 1 Mev, but we cannot say whether or not lines of still lower energy exist. The interpretation of this end of the spectrum is made difficult also by the presence of radiation which comes from inelastic collisions of the neutrons with the nuclei of the material surrounding the chamber, such as the copper coils.

Bonner and Brubaker[7] have found neutron groups having Q values (energies corrected for the bombarding energy and the recoil of the nucleus) of 4.25, 3.7, 2.1 and 0.8 Mev. Staub and Stephens[8] have published a neutron spectrum which is in agreement with that of Bonner and Brubaker. The simplest level scheme based upon these neutron energies would predict gamma-ray lines at 3.45, 2.15 and 0.55 Mev. Our gamma-ray spectrum gives a line in good agreement with the 3.45-Mev line which is predicted, and the strong radiation which we found at low energy could easily include the predicted 0.55-Mev line. The neutron data indicate that the product nucleus (B^{10}) is formed also on level 2.15 Mev above ground. The absence of a 2.15-Mev gamma-ray in our data indicates that this level does not combine with the ground state, and the presence of the radiation of about 1 Mev in our data would be consistent with the view that the transition occurs in two nearly equal jumps. It is premature, however, to attempt to construct an actual level diagram.

Kruger, Stallmann and Schoupp[4] have recently reported 31 gamma-ray lines from beryllium bombarded with 0.96-Mev deuterons. Although we cannot claim great enough resolving power to detect lines so close together, we find little similarity between our curves and theirs, even as to the general distribution of intensity.

NITROGEN

The energy distribution of electrons found when nitrogen was bombarded with deuterons is shown in Fig. 2. We can be quite certain of the existence of three gamma-ray lines, of 8.2±0.5, 6.6±0.3 and 5.1±0.3 Mev. There is a slight indication of a line at about 4.1 Mev, and a somewhat better indication of a line at about 2.5 Mev. It is not possible to say anything regarding the possibility of lines below 2.5 Mev, except to say that there is none of very large intensity. Holloway and Moore[9] have recently measured the ranges of the particles emitted in the reactions $N^{14}(d\alpha)C^{12}$ and $N^{14}(dp)N^{15}$. Their results indicate that the C^{12} nucleus is formed on an excited level of 4.35 Mev and that the N^{15} nucleus is formed on two levels, 5.31 and 1.53 Mev. Previous work by others[10, 11] is in fair agreement with this. Our

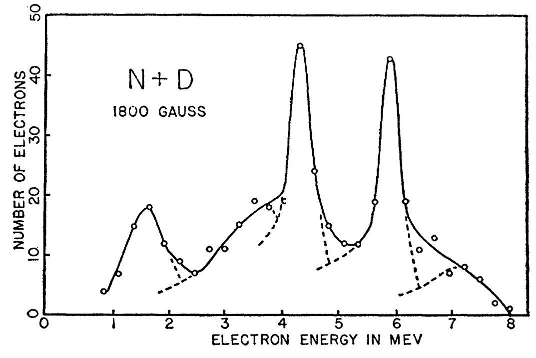

FIG. 2.

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[9] M. G. Holloway and B. L. Moore, Phys. Rev. **56**, 706 (1939).

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4.1- and 5.1-Mev gamma-ray lines can probably be identified with the above 4.35- and 5.31-Mev nuclear levels. We cannot attempt to correlate the intensities of the gamma-ray lines with the intensities of the particle groups until the complete energy level scheme is known, because there may be alternative or competing ways in which an excited nucleus may make the transition to the ground state. As to our 6.6-Mev gamma-ray line, the particle ranges show that neither C^{12} nor N^{15} is formed on a level of that energy; therefore the line must arise as part of a complex transition from a higher level. The particle ranges also show that C^{12} is not formed on a level of 8 Mev, corresponding to our 8-Mev gamma-ray line, but do not preclude the possibility that the N^{15} is formed on that level. The protons in the latter case would have only 0.5 Mev, and would escape detection. One prediction can be made on the basis of the above argument: If the 8-Mev gamma-ray (and possibly others also) arises from an 8-Mev level in N^{15}, the intensities of these lines should be sensitive to the energy of the deuteron beam. This is because of the low energy of the ejected proton.

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Zeeman Effects in Complex Spectra at Fields up to 100,000 Gauss

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A newly constructed electromagnet of the Bitter type has been arranged to give fields up to 100,000 gauss, uniform to 1 percent over a volume of 25 cc. A special type of horizontal arc, with electrodes of salts compressed in silver powder, is operated at 4 amp. and furnishes light transversely to the field to three grating spectrographs, which can be used to cover the range 2000 to 8000A in a single exposure. Plane-polarized components of the light are separated with a 2-inch quartz Rochon prism, and exposures of 5 to 30 minutes give dense spectrograms at resolutions of 100,000 and greater. Plates in the ultraviolet region have been obtained for cerium, columbium, erbium, europium, gadolinium, iron, neodymium, praseodymium, rhodium, ruthenium, thorium, tungsten, and ytterbium. On most of the plates lines of the second and third spectra are more in evidence than those of the first, and air lines are prominent. Typical portions of a rhodium plate at 90,500 and 70,000 gauss are shown, and data are given for a number of cerium, rhodium, and ruthenium lines.

THOUGH the study of Zeeman effects affords one of the most powerful aids to the classification of spectra, it has been limited in great degree by the relatively weak magnetic fields which could be maintained over appreciable periods, by the small volume and lack of uniformity of these fields, and by the low intensities of light sources operated in magnetic fields. Kapitza[1] and his co-workers have produced fields up to 320,000 gauss in electromagnets, but these fields remained constant for only about 0.01 second, and were used to photograph Zeeman effects of very strong lines in simple spectra only. Jacquinot[2] and various colleagues have used the large Bellevue electromagnet for Zeeman effect studies, but the strongest fields used were apparently not over 65,800 gauss, 50,000 gauss being the usual value. Most of the Zeeman effect studies reported in the literature have involved fields of 43,000 gauss or less, obtainable with commercial iron-core magnets of the Weiss type.

The new type of electromagnet which one of us has designed[3] has been used successfully to resolve Zeeman patterns of complex spectra at fields up to 99,830 gauss, accommodating a bright electric arc with which 5- to 30-minute exposures suffice to give dense spectrograms with gratings of resolving power 100,000 and over. We have thus been able to resolve very complex

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