Gamma-Rays from the Disintegration of Beryllium by Deuterons and Protons

Beryllium Bombarded with Deuterons

It was found in this laboratory that beryllium bombarded by deuterons gives a large yield of neutrons,[1] and, later, that the neutrons were accompanied by gamma-rays in about equal numbers, having an absorption coefficient corresponding to about 0.7 MEV quantum energy.[2] More recently we have investigated the same gamma-radiation by means of a cloud chamber and verified the existence of a very strong component of about 0.7 MEV, and have found additional, but weaker, lines up to 4 MEV. Bonner and Brubaker[3] have investigated the energy spectrum of the neutrons emitted under the same conditions, and have made some attempt at correlating the differences in energy of neutron groups with the observed gamma-rays.

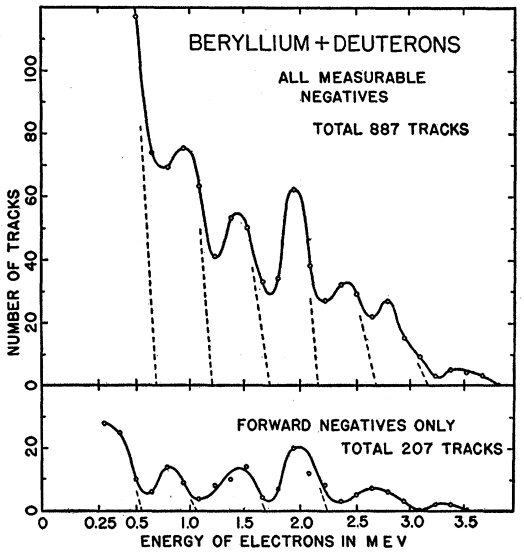

FIG. 1. Energy spectra of negative electrons ejected from the glass wall of the cloud chamber by the gamma-radiation from beryllium bombarded with deuterons.

Fig. 1 shows the energy spectra of electrons obtained by measuring the curvature of tracks in a 1000 gauss magnetic field, from 1200 cloud-chamber photographs. The source of the recoil electrons was the glass wall of the cloud chamber, which has a thickness corresponding to roughly 2 MEV stopping power for electrons in this region of energy. The radiation was obtained from beryllium metal bombarded with about 80 microamperes of deuterons at 700 kv. The upper curve in Fig. 1 includes all measurable tracks, without regard to direction. However, to meet the specification of measurability a track must lie approximately in the plane of the chamber: for example, if it is visible for 2/3 the diameter of the chamber it necessarily makes an angle less than 7.5° with the horizontal. The lower curve in Fig. 1 is composed only of tracks which make angles less than 7.5° with the direction of the incident quantum, in both the horizontal and the vertical planes. This, as is to be expected, gives fewer tracks, but greater resolution, and gives a more accurate determination of the gamma-ray energies, especially at the lower end of the scale. The two curves are in agreement as to the essential features of the spectrum, and indicate gamma-ray lines at about 0.8, 1.3, 2.0, 2.5, 2.9, 3.3, and 4.0 MEV. In accordance with the theory of Compton collisions we have added 0.2 to 0.25 MEV to the values of the intercepts in the electron spectra to obtain the corresponding gamma-ray energies. It is not certain, on the basis of intensity, that the 4.0 MEV line is not due to protons, since protons cannot be eliminated entirely from the beam.

The gamma-ray lines we have found correspond to the strongest lines indicated by differences in energy of neutron groups found by Bonner and Brubaker, but they have found indications of a number of additional lines. The natural explanation of this is that the resolving power of our method is sufficient to reveal only the strong lines. The agreement, both as to energy groups and total numbers, of neutrons and gamma-rays suggests that they arise from the same reaction, namely, $Be^9+H^2\rightarrow B^{10}+n^1+\gamma$.

Beryllium Bombarded with Protons

Fig. 2 shows similar energy spectra of recoil electrons due to the radiation from beryllium bombarded with protons.

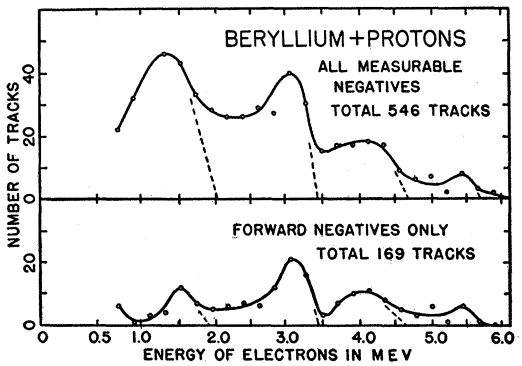

FIG. 2. Energy spectra of negative electron ejected from the glass wall of the cloud chamber by the gamma-radiation from beryllium bombarded with protons.

Here are represented 3400 photographs, taken at 900 kv, 80 microamperes proton current, and 1500 gauss magnetic field. The lines indicated are 2.2, 3.7, 4.8 and 6.0 MEV. Although the total intensity of this gamma-radiation is much smaller than that due to deuteron bombardment, the difference in the character of the spectra eliminates any suspicion of deuteron contamination.

The upper energy limit of the gamma-radiation is so high that it seems possible to account for it only on the basis of a radiative capture process, namely, $Be^9+H^1\rightarrow B^{10}+\gamma$, provided we assume a stable mass for Be^9. The emission of an alpha-particle, for example, would lead to a much lower estimate for the maximum gamma-ray energy available. Although the upper limit of energy is not very definite, because of the small number of tracks, it can be used to obtain a lower limit for the mass of Be^9 referred to $B^{10}=10.0135$, with $H^1=1.0078$. It gives $Be^9>9.0117$, assuming that the proton energy corresponding to maxi-

mum probability of capture is 500 kv. Using Bethe's values[4] for B^{10} and H^1 we obtain $Be^9 > 9.0124$.

Voltage Excitation Curve

We have determined the yield of gamma-rays as a function of proton bombarding voltage in the range 200 to 800 kv, by means of an ionization chamber. Because of the low intensity of the effect, it was necessary to use a thick target. The effect began rather abruptly at 450 kv and continued to increase to 800 kv. This may mean, if the reaction postulated above is correct, that the first maximum in the probability for proton capture occurs when the proton energy is in the neighborhood of 0.5 MEV.

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April 30, 1935.

[1] Crane, Lauritsen and Soltan, Phys. Rev. **44**, 692 (1933).
[2] Crane and Lauritsen, Phys. Rev. **45**, 226 (1934); (see correction in Phys. Rev. **45**, 493 (1934)).
[3] Bonner and Brubaker, Phys. Rev., June 1, 1935 (in press).
[4] Bethe, Phys. Rev. **47**, 633 (1935).

Alternating Intensities in the Spectrum of P_2

The nuclear spin quantum number I for phosphorus was found to be 1/2 by Miss Ashley,[1] who studied the alternating intensities in the $^1\Sigma$, $^1\Sigma$ bands of P_2. Although her work proved definitely that an alternation ratio of 2 ($I=1$) or lower was out of the question, it seemed desirable to have a direct measurement of this ratio to see if any discrepancy occurs similar to that observed by Aars[2] for fluorine. Aars found a ratio varying between 3.4 and 5.5 in different bands, although the highest value predicted theoretically is 3.0, for $I=\frac{1}{2}$.

The phosphorus bands were excited in a sealed-off quartz tube containing pure phosphorus and helium at 20 mm pressure. Power was supplied through external electrodes connected to a 5 kw power-oscillator giving a wavelength of 45 m. The spectrum was photographed in the second order of the 21-ft. grating, with a step-weakener directly in front of the plate so that the band lines themselves constituted the calibration marks. The weakener had seven steps of different thicknesses of platinum sputtered on a quartz plate, and the transmissions of the steps were determined as a function of wavelength by a monochromator and quartz vacuum phoelectric cell connected to a Wynn-Williams bridge amplifier. The peak intensities of the lines were measured, and the continuous background subtracted in each case. On plotting these intensities on a logarithmic scale, two parallel curves were obtained, and the displacement required to make the curve for the weaker lines (even K) coincide with that for the stronger gave the ratio of alternating intensities. The results of measurements on five different bands are summarized in Table I, data from two different plates being given for the 5,21 and 6,22 bands.

Table I.

Bands	Lines used	g_s/g_a
5,21	$P(56)+R(68)$ to $P(66)+R(78)$	3.5 ± 0.2
	$P(47)+R(59)$ to $P(66)+R(78)$	3.4 ± 0.2
6,22	$P(5)+R(17)$ to $P(47)+R(59)$	3.0 ± 0.2
	$P(21)+R(33)$ to $P(56)+R(68)$	3.0 ± 0.1
9,28	$P(47)$ to $P(65)$	3.0 ± 0.1
	$R(61)$ to $R(77)$	3.0 ± 0.6
9,29	$P(47)$ to $P(65)$	2.9 ± 0.2
	$R(61)$ to $R(79)$	2.8 ± 0.4
10,31	$P(41)$ to $P(59)$	2.9 ± 0.1

The deviation of g_s/g_a from the expected value of 3.0 in the 5,21 band may be due to the presence of lines from a faint underlying band, or it may result from the fact that this band shows much stronger perturbations than the others which were studied. It seems hardly possible to invoke the quenching mechanism proposed by Aars to explain his results, since in the present case the fairly high pressure of helium would serve to maintain a normal distribution of molecules among the rotational states.[3] This may account for the better agreement with theory shown by the above results.

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April 17, 1935.

[1] Muriel Ashley, Phys. Rev. **44**, 919 (1933).
[2] J. Aars, Zeits. f. Physik **79**, 122 (1932).
[3] O. Oldenberg, Phys. Rev. **46**, 210 (1934).

Arcs in Inert Gases—III

Several previous reports[1] have shown that a stable arc discharge of low amperage (5 to 10 amperes) between metal electrodes of high purity cannot be maintained under ordinary conditions in argon gas and in some of the other inert gases, provided the gases are first highly purified. In discussion of these earlier results, several arc authorities have suggested that the phenomenon might be one which occurs only in low current arcs and would probably disappear when higher currents flowed upon short circuiting of the electrodes. In a current investigation[2] of the metallurgical properties of pure iron welds made in argon, it is found on the contrary that a stable arc discharge cannot be maintained even across a gap one millimeter long, with open circuit voltages up to 60 volts and with short circuit amperages up to 120 amperes. If the open circuit voltage is increased to 62 to 64 volts or if the short circuit current is increased to 150 amperes, an arc discharge can be maintained for several seconds. If the open circuit voltage is increased to 65 to 70 volts or the short circuit amperage increased to 170 amperes, a stable arc discharge can be maintained indefinitely. These tests were carried out in argon gas of 99.5 percent purity. The electrode wires were of carefully cleaned pure iron in one case and of carefully cleaned steel wire in the other. The wires were one-eighth inch in diameter. In each case a plate of the same material was used as the opposite electrode.