Investigations of the Deuteron-Deuteron Reaction

Last year we reported some results on the yield of neutrons produced by bombarding different targets containing deuterium, beryllium or lithium with ion beams of deuterium, which were accelerated by a 400 kv transformer rectifier outfit.[1]

In continuation of these investigations we have studied in more detail the neutrons and the protons produced by bombarding different deuterium targets with fast deuterons ("D-D" reaction). This case is especially interesting on account of the apparently very high yield[2] (about 10^{-6}) and because these neutrons have all the same energy[2, 3] (about 2×10^6 volts).

The accelerating voltage is measured both with an improved generating voltmeter and with a high resistance and microammeter.[4] The current carried by the magnetically analyzed ions is recorded by a current integrator. In some experiments the molecular ions (mass 4) from a low voltage arc are used. Voltages applied between the Faraday cage containing the target and adjacent diaphragms and an auxiliary small magnetic field prevent any effects from secondary electrons. The protons produced in the D-D reaction penetrate thin aluminum windows and are counted by means of an ionization chamber, linear amplifier and a scale-of-eight thyratron counter.[5] The neutrons are recorded with the same apparatus, by the use of a paraffin-lined chamber for the fast neutrons, a boron-lined chamber for slow neutrons, or a simple air chamber (for calculating absolute values). The yield of the neutrons was compared with that of neutrons from a 15 mg radium-beryllium source replacing the target. A comparison of the radium source with a radon beryllium source of the same gamma-ray activity showed the neutron activity to be the same within 10 percent.[6]

As solid targets of D-compounds did not last long under bombardment, we used liquid D_3PO_4 for longer series of measurements, which proved to be very satisfactory.

The results obtained so far are the following:

1. The excitation function of the "thick" targets between 40 and 100 kv is the same for protons and neutrons as found before by Alexopoulos[2] and agrees approximately with that given by Oliphant, Harteck and Rutherford. The relative yield is 1 : 4.4 : 8 for 100, 200 and 300 kv. No resonance has been found between 40 and 100 kv although measurements were made every 5 kv.

2. The increase of slow neutrons absorbable by 0.6 mm of cadmium with increasing thicknesses of paraffin cylinders surrounding the source and the ionization chamber has been measured, both for the D-D neutrons and the Ra-Be neutrons. The two such curves coincide above 5 cm of paraffin. For smaller thicknesses relatively more slow neutrons are observed from the Ra-Be. This effect is probably due to the large number of relatively slow neutrons originating from the Ra-Be source.

3. The yield of Cd neutrons produced in 7.5 cm of paraffin from a D_3PO_4 target bombarded by 1μA D-ions at 100 kv is the same as that of our 15 mC Ra-Be source; but a slight change of the geometry of the neutron source inside the paraffin has an appreciable effect. The yield of fast neutrons for 1μA D-ions at 100 kv is the same as that of 44 mC Ra-Be. The main reason for this difference is the higher initial proportion of relatively slow neutrons from Ra-Be which give no measurable recoil protons in the paraffin-lined chamber.

4. The total number of protons produced in D_3PO_4, measured at 90° from the direction of the ion beam, is 7.10^4/sec. at 100 kv and 1μA on the assumption of isotropic emission in all directions. Actually appreciably more neutrons were found *in* the direction of the beam than at 90°, in accordance with recent reports from the Cavendish laboratory.[9] Multiplying the yield by 50/3, the ratio of the number of electrons in D_3PO_4 and the number of D-atoms, one gets as yield for the D-D reaction 1 proton for 6.10^6 impinging deuterons. Solid targets—$(ND_4)_2SO_4$, ND_4Cl, KOD—give within 20 percent the same yield after correcting for the stopping power in the same way as for the D_3PO_4 target. Oliphant, Harteck and Rutherford estimate the yield to be of the order of magnitude of 1 in 10 at 100 kv.

5. When using the simple air chamber for counting fast neutrons and taking the cross section of 1.8×10^{-24} cm^2 given by Dunning[7] for the scattering of neutrons from Rn-Be, we find about half as many neutrons as we found protons before,—under the assumption that every recoil O or N atom from scattered neutrons produces a count in our ionization chamber.[8] So it is safe to say that the two reactions produced by the D-D collision give approximately the same yield.

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[1] Ladenburg, Roberts and Sampson, Phys. Rev. **48**, 467 (1935).

[2] See Oliphant, Harteck and Lord Rutherford, Proc. Roy. Soc. **144**, 612 (1934); Alexopoulos, Helv. Acta **8**, 513 and 601 (1935).

[3] Dee, Proc. Roy. Soc. **A148**, 623 (1935); Bonner and Brubaker, Phys. Rev. **49**, 19 (1936).

[4] Hafstad, Heydenburg and Tuve, Phys. Rev. **50**, 504 (1936).

[5] This device was constructed for these experiments by J. Giarratana who developed a special Wynn-Williams circuit, adapted for RCA thyratrons.

[6] Our method for mixing Ra and Be is described by Erbacher and Philipp, Zeits. f. physik. Chemie **A176**, 175 (1936) who used a similar method.

[7] Dunning, Phys. Rev. **45**, 586 (1934).

[8] Alexopoulos estimates (reference 2, p. 513) the number of neutrons produced by 1μA and 100 kv to be 4.10^6 per second, i.e., about 50 times as big as we find, and without correcting for the stopping power of his target he gives as yield 1 neutron per 1.6×10^6 deuterons of 100 kv. The yield given by Kikuchi, Aoki and Husimi (Proc. Phys. Math. Soc. Japan **18**, 122, 299 (1936)) does approximately agree with our value, but the percentage of D-ions in their beam is only estimated and not measured by magnetic analysis.

[9] Kempton, Brown and Maasdorp, Proc. Roy. Soc. **157**, 372 (1936).