discrete energies, rather than with a continuous distribution. The values of the maximum range for these groups are given in Table I and are indicated in Fig. 1. The velocity and energy corresponding to these ranges are given in succeeding columns of this table.

TABLE I.

Proton Emission from Fluorine (Chadwick and Constable)				*Neutron Emission from Fluorine*				
Rp (cm)	$Ep/10^6$ e.v.	ΔEp	$R\alpha$ (cm)	Rn (cm)	$Vn/10^9$ cm/sec.	$En/10^6$ e.v.	ΔEn	$R\alpha$ (cm)
56	6.55		3.9	10.5	2.20	2.54		3.9 (assumed)
		0.42					0.43	
47	6.13		3.9	7.8	2.01	2.11		3.9 (assumed)
		0.55					0.52	
40	5.58		2.7	4.9	1.74	1.59		2.7 (assumed)
		0.51					0.49	
33.5	5.07		2.2	2.8	1.45	1.10		2.3
		0.30						
30.5	4.77		2.7	—	—	—	—	—
		0.51						
25	4.26		2.2	—	—	—	—	—

Rp = Range of disintegration protons
Ep = Energy of protons.
ΔEp = Energy difference between proton groups.
$R\alpha$ = Range of α-particles producing disintegration.
Rn = Maximum range of recoil protons.
Vn = Neutron velocity.
En = Neutron energy.
ΔEn = Energy difference between neutron groups.

Since the α-particles producing the disintegrations have a continuous range of energy from their maximum to zero (because a thick target was used) it seems probable that the discrete energy groups in the neutron emission are produced by the penetration of the α-particle into the nucleus through resonance levels. Such a resonance phenomenon has been observed in the other type of disintegration of fluorine where a proton is emitted. The latest work on this subject is that of Chadwick and Constable.[4] Since both types of disintegration depend on the entrance of the α-particle into the fluorine nucleus, it was expected that the resonance levels should be the same in both cases. Accordingly, we have looked for a correlation between the proton groups and the neutron groups. It cannot be expected that the actual energies of the groups shall be the same in both cases since the disintegration reactions are entirely different. However, the energy differences between successive groups should be the same if the same resonance levels are involved. The energy differences for both cases are given in Table I. The corresponding differences for the two cases are seen to agree as well as could be expected. It will be noted that the two groups of lowest energy for the neutron disintegration are missing. It is probable that they exist but have not been found because of poor resolving power at the shorter ranges. Further evidence that the same resonance levels are effective comes from the fact that the emission of neutrons from fluorine begins when the α-particle has a range of 2.3 cm.[5] This value agrees with the range of 2.2 cm corresponding to the lowest resonance level which Chadwick and Constable observed in the proton disintegration.

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[4] J. Chadwick and J. E. R. Constable, Proc. Roy. Soc. **A135**, 48 (1932).
[5] T. W. Bonner, Phys. Rev. **45**, 425 (1934).

Disintegration of Li^6 by Protons and Deutons

In a recent letter to *Nature*, Oliphant, Shire and Crowther[1] reported the results of the disintegration of the separate isotopes of lithium by protons and deutons. The results for Li^7 are well understood, the nuclear reactions being:

$$Li_3^7+H_1^1\rightarrow 2\ He_2^4 \quad (1)$$

$$Li_3^7+H_1^2\rightarrow 2\ He_2^4+n_0^1 \quad (2)$$

as shown by Cockroft, Walton,[2] Oliphant, Kinsey and Rutherford.[3] In case (1) the α-particles have a sharp range of 8.4 cm, in case (2) all ranges up to 8 cm are observed.

On bombarding ordinary Li with protons two other groups of α-particles in addition to the 8.4 cm group were observed,[3] having ranges of 6.5 mm and 11.5 mm. The experiments of Oliphant, Shire and Crowther show that the 11.5 mm group is due to Li_3^6. The group of 6.5 mm could not be observed because the screen had a stopping power of about 6 mm. Perhaps it may also be ascribed to Li_3^6. If this is the case one can try to explain these two groups by assuming the reaction:

$$Li_3^6+H_1^1\rightarrow He_2^4+He_2^3 \quad (3)$$

as already suggested by Oliphant, Kinsey and Rutherford.[3] We must assume then further that the 11.5 mm group is really He_2^3. Neglecting the impulse of the proton, the velocity of He_2^4 would then be three-fourths the velocity of He_2^3. Taking tentatively[4] the range of two equally charged particles as proportional to mv^3 one obtains for the range of He_2^4 $(\frac{3}{4})^2\times 11.5=6.47$ mm, in agreement with the observed value. The kinetic energy of an α-particle of 6.5 mm range is 1.6×10^6 e.v. and hence the kinetic energy of the He_2^3 would be 2.1×10^6 e.v. If we use for the values of the nuclear masses $Li_3^6=6.0129$, $H_1^1=1.0072$, $He_2^4=4.0011$ and take for the kinetic energy of the protons 0.0002 M.U., the mass of He_2^3 comes out to be 3.0152. With the value 1.0065 for the mass of the neutron the binding energy of He_2^3 would be 0.0057 or about 5×10^6 e.v. This is a quite

[1] Oliphant, Shire and Crowther, Nature **133**, 377 (1934).
[2] Cockroft and Walton, Proc. Roy. Soc. **A137**, 229 (1932).
[3] Oliphant, Kinsey and Rutherford, Proc. Roy. Soc. **A141**, 722 (1933).
[4] Comp. Blackett, Proc. Roy. Soc. **A135**, 132 (1932); Duncanson, Proc. Camb. Phil. Soc. **30**, 102 (1934).

reasonable value. Assuming with Heisenberg that the main interaction is between protons and neutrons, one must expect that the mass defect of He_2^3 lies between 2×10^6 e.v. (=twice the mass defect of H_1^2) and 12×10^6 e.v. (=one-half the mass defect of He_2^4). Considering also the interaction in triples[5] one gets as a next approximation:

$$[He_2^4]=2[He_2^3]+2[H_1^3]-4[H_1^2], \quad (4)$$

when the brackets denote the mass defect. This is always still with only proton-neutron interaction. Then also $[He_2^3]\cong[H_1^3]$ and we get for the mass defect of He_2^3 and H_1^3 about 7×10^6 e.v. Finally one can try to estimate the mass defect of He_2^3 more precisely by assuming with Wigner and Chadwick[6] for the interaction between proton and neutron a very narrow and deep potential hole (width $\cong10^{-13}$ cm, depth $\cong90\times10^6$ e.v.). As these authors have shown, one can then understand the large mass defect of He_2^4, and the experimental results on the scattering of neutrons by protons. With this model one obtains for the mass defect of He_2^3 again values between 3×10^6 e.v. and 7×10^6 e.v.[7]

On bombarding Li_3^6 with deutons, α-particles of 13.2 cm range are observed and in addition protons of 30 cm range. The former are explained by the reaction:[8]

$$Li_3^6+H_1^2\rightarrow2\ He_2^4. \quad (5)$$

The protons can be explained by assuming:

$$Li_3^6+H_1^2\rightarrow Li_3^7+H_1^1. \quad (6)$$

Taking for the kinetic energy of the deutons again 0.0002 and substituting for the masses of $Li_3^7=7.0130$, $H_1^2=2.0131$, the kinetic energy of the Li_3^7 and H_1^1 comes out to be 0.0060 M.U. or 5.63×10^6 e.v. Because of the conservation of momentum 7/8 of this or 4.92×10^6 e.v. is taken up by the proton. This corresponds to a velocity of 3.04×10^9 cm/sec., and a range[4] of about 31 cm, in good agreement with the observed value. The reaction (6) is analogous to the capture process of deutons by carbon as proposed recently by Lauritsen and Crane.[9]

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[5] Comp. a forthcoming paper in the Phys. Rev. by Goudsmit and Bacher.

[6] Wigner, Phys. Rev. **43**, 252 (1933); Chadwick, Proc. Roy. Soc. **A142**, 1 (1933).

[7] During the writing of this Letter, the March 17 issue of Nature arrived here, in which Oliphant, Harteck and Rutherford communicate the results of their experiments on the transformation effects observed with heavy hydrogen. In here they also mention that (3) would lead to the mass 3.0165 for He_2^3, which is the same as our value plus two electrons. They further make very probable the existence of H_1^3, for which mass they obtain the value 3.0151. This gives a mass defect of 0.0056 M.U. (mass units) or again about 5×10^6 e.v.! The equality of the mass defects of H_1^3 and He_2^3 seems to us a very strong argument in favor of the Heisenberg hypothesis that the main interaction is between protons and neutrons.

[8] Lewis, Livingstone and Lawrence, Phys. Rev. **44**, 55 (1933). Comp. also reference 3.

[9] Lauritsen and Crane, Phys. Rev. **45**, 345 (1934). With our interpretation of the two short range groups the γ-radiation observed by these authors (Phys. Rev. **45**, 63 (1934)) has become difficult to understand.

The Energy Distribution of Neutrons from Boron

In a previous letter,[1] we have presented energy measurements of the neutrons from a polonium-fluorine source. These measurements were carried out by observing the tracks of the recoil protons produced in a cloud chamber containing hydrogen at high pressure. By means of this method of measurement we were able to show that in the case of this element there were several neutron groups of different energy. In fact this method seemed particularly suitable for detecting neutron groups when they exist. Accordingly, experiments using this same method have been carried out for the neutrons emitted from boron when bombarded by α-particles from polonium.

4000 pairs of photographs have been taken with this source of neutrons. 2000 of these photographs were taken with hydrogen in the chamber at a pressure of 12.9 atmospheres, the remainder with methane (CH_4) at the same pressure. In both cases only tracks of recoil protons were used; those due to the carbon atoms in the methane at this pressure were too short to be measurable or to be confused with the proton tracks. It was convenient to use the two gases because with hydrogen a large number of the faster protons collided with the walls of the chamber and thus could not be measured, while with methane the proton tracks of lower energy were too short to be measured with sufficient accuracy. With hydrogen, 162 tracks were measured; with methane, 210. The observed ranges were converted to their equivalent length in air by using, in the case of hydrogen, the stopping-power data from Gurney,[2] and for methane, the data given by Van der Merwe.[3] The value of the relative stopping-power which was used in this conversion depends somewhat on the range of the proton. The value adopted at our longest range for the stopping-power of hydrogen at one atmosphere relative to air is 0.211. The corresponding stopping-power for methane was taken to be 0.83. The curves of Fig. 1 show the distribution-in-range of the observed recoil protons. As in the case of fluorine, the curves show distinct maxima and minima which we believe cannot be caused entirely by statistical fluctuations but must principally be due to the

[1] T. W. Bonner and L. M. Mott-Smith, Phys. Rev. **45**, 552 (1934).

[2] R. W. Gurney, Proc. Roy. Soc. **A135**, 48 (1925).

[3] C. W. Van der Merwe, Phil. Mag. **45**, 379 (1923).