Evidence for the Instability of He^5

Recently Kempton, Browne and Maasdorp[1] have made a search for homogeneous groups of particles from the proposed reaction

$$_3Li^7 + {_1H^2} \rightarrow {_2He^5} + {_2He^4}. \quad (1)$$

If He^5 were stable the He^4 group would have a greater energy than the continuous energy distribution of α-particles from

$$_3Li^7 + {_1H^2} \rightarrow {_2He^4} + {_2He^4} + {_0n^1}, \quad (2)$$

which has been investigated by Oliphant, Kempton and Rutherford.[2] The former authors' interpretation of their experimental results was that if (1) occurs at all it must be less than one percent of (2).

With the 275 kv transformer-kenetron apparatus previously described[3] we have made a study of the numbers *vs.* range distribution of α-particles resulting from (2). Deuterons magnetically separated from the constant energy ion beam impinged on targets of LiOH or LiCl fused on steel disks. These targets were rotated to present a fresh surface after each reading of approximately two minutes duration. The disintegration products were observed at $90 \pm 5°$ to the direction of the ion beam with a modified Dunning[4] ionization chamber and linear amplifier after passing through an adjustable pressure absorption tube. The residual range of the mica windows and ionization chamber was calibrated with α-particles from a Th C+C′ source replacing the Li target.

Curves of numbers of particles *vs.* absorbing material in cm of air at 15°C are shown in Fig. 1. The scale of numbers is the ratio of numbers observed at a given amount of absorbing material to the number at minimum absorbing material. Numbers at the minimum absorption were repeated every third reading and served to check the constancy of our deuterium concentration, target condition and amplifier gain. This procedure served to minimize the "capricious fluctuations" reported by others and observed by us in less controlled experiments.

The curves show the existence of a homogeneous group superimposed on the background of (2). The yield in this group is small compared to the yield from (2) and only becomes detectable with increasing differentiality of the ionization chamber and amplifier. The number of particles detected for minimum absorption per arbitrary unit of deuterium charge is a rough measure of the inverse of the differentiality. When the detecting apparatus is "semi-differential," curve (*B*), the results compare favorably with those of Oliphant, Kempton and Rutherford[2] who selected oscillograph kicks greater than one cm, curve (*A*).

The ionizing power of the particles in the homogeneous group compared to those at 3.5 cm range was tested by continuing to increase the negative bias of our counter until no particles were recorded. No significant difference was found in the ratio of the counts at the peak to counts at the control range. We conclude that the homogeneous group is due to α-particles.

Assuming the peak of 7.10 cm mean range to be α-

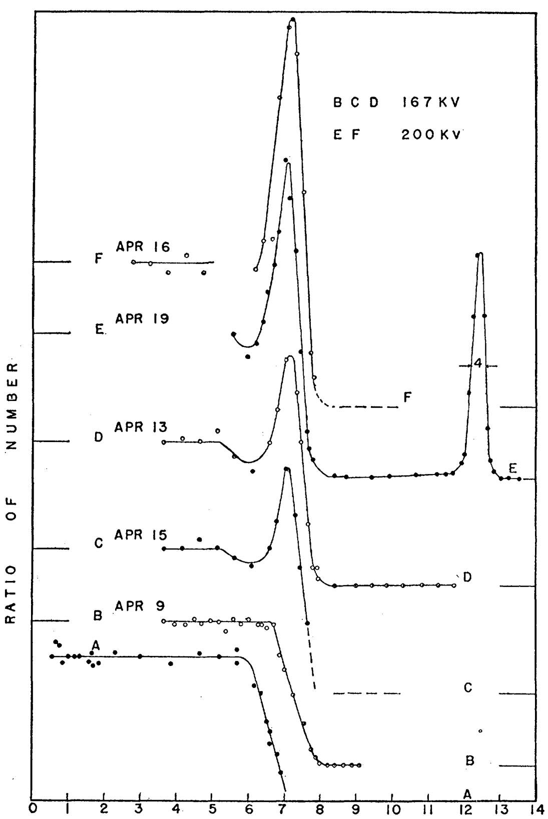

Fig. 1. Ratio of number of particles detected at a given absorption to the number at the minimum absorption. The lettered scale marks on the left are unity and the corresponding marks on the right are zero. Curve *A* is from Oliphant, Kempton and Rutherford. Increasing peak height at a given voltage is evidence of increasing differentiality of detecting apparatus.

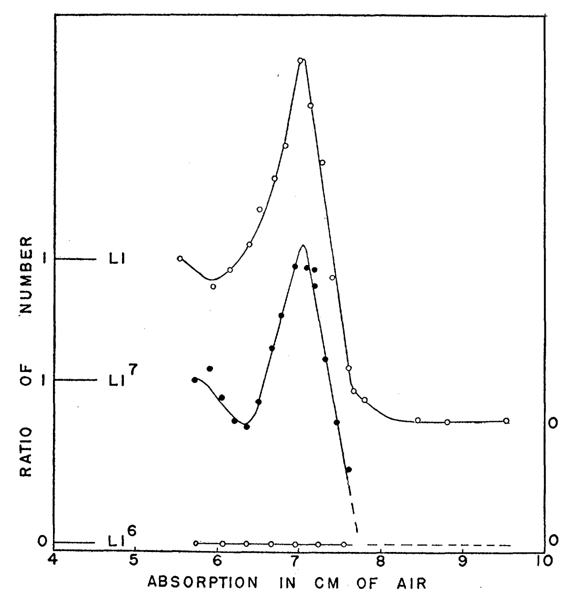

Fig. 2. Ratio of number of particles detected at a given absorption to the number at the minimum absorption for targets of natural Li in LiOH and separated isotopes of Li^7 and Li^6.

particles from (1), the expected range of He^5 is 4.35 cm on reasonable assumptions for the range-energy distribution for He^5 as compared to He^4. The mass of He^5 is then 5.0140 which is unstable by 0.93 Mev. There is no evidence for such a homogeneous group from our results shown in Fig. 1.

The other alternative is to assume the homogeneous group is He^5 from (1) which leads to the prediction of an α-particle group of equal intensity at 11.68 cm. There is no evidence for this group on the low energy side of the homogeneous group of α-particles from

$$_3Li^6+{}_1H^2\rightarrow{}_2He^4+{}_2He^4, \quad (3)$$

which have a range of 12.70 ± 0.05 cm at a bombarding potential of 190 kv.[2]

If the homogeneous group observed at 7.10 cm is due to α-particles from (1) a possible interpretation is that He^5 exists only long enough to give He^4 a definite energy before it disintegrates into He^4 and a neutron. A somewhat equivalent interpretation is that the observed group is a preferential mode of disintegration (2). The former interpretation leads to a continuous energy distribution of α-particles and neutrons, the α-particle continuum extending from 1.85 cm to 6.26 cm range.

The origin of the observed group was established by observations on targets of the separated isotopes of Li kindly supplied by Dr. L. H. Rumbaugh of the Bartol Research Foundation. The definite indications of Fig. 2 also eliminate any possibility of the group originating from a contamination of the target. A further measurement showed that the yield of the group increased regularly relative to the yield from (2) in the range 140 to 210 kv.

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April 20, 1937.

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Neutron-Proton Interactions

Measurements of Harkins[1] and co-workers on the scattering of Po-Be neutrons by protons have shown that there is a marked anisotropy in the system where the center of gravity is at rest. These results have recently been augmented by investigations of the scattering of D-D neutrons by protons, (1) by Lampson, Mueller, and Barton[2] using a photographic emulsion method of detection, and (2) by Kruger, Shoupp, and Stallman[3] with a cloud chamber. The general forms of the scattering curves agree, so that we have evidence for a preferred backward scattering of neutrons already at about 2 Mev.

The writer has attempted to fit the experimental curves by assuming that a single rectangular potential well[4] is effective. This would necessitate a radius of about 5.5×10^{-13} cm, provided that the depth be adjusted to give the observed mass defect of the deuteron, whereas the radius of a Gaussian well necessary to fit the observed binding energies of H^3, He^3, and He^4 is 2.25×10^{-13} cm, so that the disagreement is considerable. Furthermore, the theoretical scattering curve deviates rather badly from the observed one at large proton recoil angles (110°–130°).

Current theories provide for four types of interaction between neutron and proton, one being an ordinary force, and the other three of an exchange nature. As a consequence, the states of the deuteron may be classified as symmetric or antisymmetric in the spins, and as even or odd, so that there will be four force laws between a proton and a neutron.[5] Let us denote them generically by ^1S, ^3S, ^1P, and ^3P. In a discussion with the writer, Dr. Feenberg[6] pointed out that it is only the ^1S and ^3S interactions which are used for calculations of the binding energies of H^3, He^3, and He^4, and that one is still free to choose the ^1P and ^3P interactions.

For a preliminary investigation, it seems to be sufficiently accurate not to distinguish between singlets and triplets, and to regard the incident wave function as a sum of two parts, one with even l and the other with odd l. The even part is to be matched with wave functions of the "S" well, and the odd part with wave functions of the "P" well. Phase shifts for $l>1$ will be supposed negligible, as is usually so. Only two phases, δ_0 and δ_1 will enter the problem, and there is now no connection between them because each has its own potential well. Therefore, one needs only to fit the experimental scattering curve (e.g. system) by a quadratic expression in $\cos\theta$ where θ=angle of neutron scattering, and to determine δ_0 and δ_1 from the relations between the coefficients. This was done for the data of Kruger, Shoupp, and Stallman, and the resulting phases were $\delta_0=133°\ 40'$ and $\delta_1=16°\ 10'$. (These are not to be regarded as very accurate, owing to the statistical fluctuations. However, the only result which we use is δ_0, which will not become appreciably smaller by fitting differently.) If now, we use this value of δ_0, together with the binding energy of the deuteron, we find 1.7×10^{-13} as the radius of the rectangular potential well, so that the scattering results seem to be in good agreement with the theoretical expectations. From the value of δ_1, we may determine the radius of the "P" well as a function of its depth, which, however, is not known. Measurements for neutrons of other velocities, if made accurately, should yield this knowledge.

I wish to thank Dr. Feenberg for the discussion above mentioned, and Messrs. Shoupp and Lampson for informing me of their results before publication.

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April 17, 1937.

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[5] Cf. Cassen and Condon, Phys. Rev. 50, 846 (1936).
[6] See also Feenberg, Phys. Rev. 51, 775 (1937).