LETTERS TO THE EDITORS

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Properties of a Hypothetical di-Neutron

THE question of the possibility of obtaining experimental evidence for the existence of a neutral particle of mass 2 has recently been raised by Kundu and Pool[1]. These authors suggest that certain features of nuclear transformations produced by bombardment by tritium (^3H) ions favour the conclusion that a di-neutron having at least transient existence may be captured as a single entity in a nuclear process of an Oppenheimer–Phillips type.

It is the object of this note to point out that the β-active species ^6He, though stable against the spontaneous emission of neutrons of normal mass (stable, that is, against the process $^6He \rightarrow {}^5He + {}^1n$), is unstable against the emission of a di-neutron which has more than a relatively small energy of binding, so that the presumption that a di-neutron is not, in fact, emitted by ^6He (based on the evidence of its 'long' life-time) sets an upper limit to the binding energy of this hypothetical particle. In deducing this limiting energy, we may consider the reactions :

$$^9Be\ (+ h\nu) \rightarrow {}^8Be + {}^1n + Q_1$$

$$^8Be \rightarrow 2\,{}^4He + Q_2$$

$$^9Be + {}^1n \rightarrow {}^6He + {}^4He + Q_3.$$

Obviously we have

$$^6He \rightarrow {}^4He + 2\,{}^1n + Q_1 + Q_2 - Q_3\,;$$

and inserting experimental values, $Q_1 = -1{\cdot}63$ MeV.[2], $Q_2 = 0{\cdot}12$ MeV.[3], $Q_3 = -0{\cdot}8$ MeV.[4], we obtain

$$^6He \rightarrow {}^4He + 2\,{}^1n - 0{\cdot}7 \text{ MeV.}$$

This last figure ($0{\cdot}7 \pm 0{\cdot}2$ MeV.) is the upper limit to the binding energy in question—a very much smaller binding energy than that of the deuteron ($2{\cdot}17$ MeV.).

In terms of these last two binding energies, we can proceed to set limits to the energy available for the β-disintegration of a quasi-stable di-neutron (^2_0n). Clearly we have

$$^2n - {}^2H + Q_4 = {}^1n - {}^1H + 2{\cdot}17 \text{ MeV.}\,;$$

where ${}^1n - {}^1H = 0{\cdot}76$ MeV. and, as above obtained, $0 < Q_4 < (0{\cdot}7 \pm 0{\cdot}2)$ MeV. Thus $(2{\cdot}2 \pm 0{\cdot}2) < ({}^2n - {}^2H) < 2{\cdot}93$ MeV. This estimate allows us to predict the life-time (τ) of the di-neutron on the reasonable assumption that the transition

$$^2n \xrightarrow{\beta} {}^2H$$

is super-allowed[5]. In this way we obtain $1 < \tau < 5$ sec.

From the fact that ^6He is sufficiently long-lived to exhibit β-activity, we have thus deduced quite narrow limits for the radioactive constants of the hypothetical di-neutron. It might be added that, if such a particle should exist, it would be expected to be produced in (^1n, ^2n) reactions over a small range of neutron bombarding energy, in each case just below the absolute threshold energy for the corresponding (n, $2n$) reaction—and even at energies somewhat above these absolute thresholds, because of the requirement that the first neutron emitted in an (n, $2n$) process shall be emitted with finite energy. But, above all, search for the di-neutron might most conveniently begin with beryllium under neutron bombardment, not only because the (n, $2n$) threshold is lowest with this element (which makes possible the use of a D—D neutron source, which is free from γ-radiation), but also because the possibility of producing ^6He in an excited state in this case opens the further possibility (see above) that the di-neutron may be obtained as a secondary disintegration particle following upon the reaction ^9Be (^1n, ^4He) $^6He^*$. This possibility is unique just because the mass number 5 is the only mass number for which a neutron-stable species does not exist ; thus the excitation necessary to render ^6He unstable against the successive emission of two neutrons of normal mass is correspondingly increased.

As regards possible methods of detecting a di-neutron, it is perhaps out of place in this note to offer detailed suggestions. But apart from its spontaneous radioactivity (the half-value period of which is reasonably short) a quasi-stable di-neutron might be expected to produce nuclear transformations which in certain cases might be sufficiently characteristic to be used for its identification. Thus activities might be induced in effectively simple elements (such as ^6He in helium, ^{25}Na in sodium, ^{105}Rh in rhodium, ^{211}AcC in bismuth, for example) for some of which large capture cross-sections might apply. It might even be possible, investigating suitable substances under deuteron or α-particle bombardment at energies in the neighbourhood of the (d, $2n$) or (α, $2n$) thresholds, to work under conditions in which the flux of di-neutrons was comparable with the normal neutron flux. In such circumstances comparison of the pulse-size distributions due to the recoil particles in hydrogen- and deuterium-filled ionization chambers might be used to effect a clear-cut identification.

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[1] Kundu and Pool, *Phys. Rev.*, **73**, 22 (1948).
[2] Myers and Van Atta, *Phys. Rev.*, **61**, 19 (1942). Wiedenbeck and Marhoefer, *Phys. Rev.*, **67**, 54 (1945).
[3] Hemmendinger, *Phys. Rev.*, **73**, 806 (1948).
[4] Allen, Burcham and Wilkinson, *Proc. Roy. Soc.*, A, **192**, 114 (1947).
[5] Feather and Richardson, *Proc. Phys. Soc.*, in the course of publication.

Propagation of Pulses of Second Sound in Liquid Helium II

PRELIMINARY measurements of the velocity of second sound in this Laboratory using a resonator of fixed length and signals of a variable frequency have given results in good agreement with the resonance measurements of Peshkov[1] and of Lane, Fairbank and Fairbank[2]. In the course of these experiments it became apparent that if measurements were to be extended below 1° K., some method would be necessary which used a smaller mean power input. It can be shown, too, that the amplitude of temperature oscillation obtained in a resonance experiment is governed entirely by damping, and provides little information about the propagation of travelling waves in the medium.

With these considerations in view, a technique has been developed for transmitting and receiving pulses of second sound. The signals are generated by applying a direct current pulse of 0·1–1 millisecond duration to a fine wire heater. The second sound pulse travels down an ebonite tube about 5 cm. long filled with liquid helium II, and is received by a phosphor bronze resistance thermometer which carries