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Letters to the Editor

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Half-Life of Li^8

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MANY determinations have been made of the half-life of Li^8. Those using the $Li(d, p)$ reaction as a source of Li^8 have so far not been so accurate as the more recent experiments using $Li(n, \gamma)$ or $Be(\gamma, p)$ reactions, the most recent published figures for the half-lives being, respectively,[1,2,3] 0.88 ± 0.1 sec, $0.89+0.02$, and 0.88 ± 0.03 sec for the three methods of formation. Preparatory to a search for a β-ray from H^4 described below[4] the half-life of Li^8 produced by the (d, p) reaction on Li was measured.

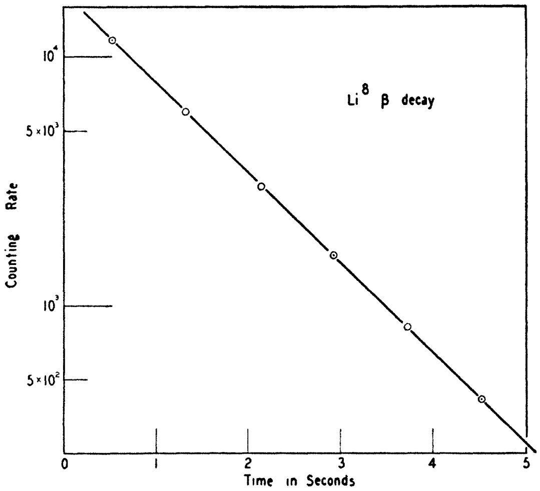

FIG. 1. Decay curve of $Li^8\rightarrow Be^8$ β-decay; the observed half-life is 0.825 ± 0.02 sec.

A 0.5-μa beam of 4-Mev cyclotron deuterons was used. This was first focused on a gold leaf covered shutter which could be swung away out of the beam by a remotely controlled solenoid arrangement, allowing the beam to fall on the Li. After three seconds irradiation of the Li, the beam was instantaneously cut off by breaking the rf power supplies to the cyclotron. A NaI(Tl) crystal and photomultiplier were used to detect the beta-rays, which passed through 2.5 g/cm^2 of brass before entering the crystal. The pulses from the photomultiplier were fed through conventional circuits to two scalers. The circuit constants were so adjusted that there was no detectable background before the beam was switched on. The pulses from the scalers could be fed to the Y plates of a self-triggered CRO adjusted to have a sweep speed of 100 μsec. The data displayed on the CRO were recorded by means of a shutterless movie camera, the film in which was driven at a speed of 40 cm/sec by a motor switched on simultaneously with the cutting of the beam. One scaler, which ran continuously, was set to record every 128th count, while the output of the other, which recorded every 32nd count, was switched in 2 sec after the beam interruption. This avoided saturating the CRO at the beginning of the run, while extending the number of half-lives measured. Timing pips were displayed every 8/60 sec from a scaler actuated by the 60-cps line voltage. Runs usually lasted 5 sec. In all, 17 acceptable runs were taken and analyzed.

After development of the film, it was possible to obtain from the data the counting rate over a period of six half-lives. Figure 1 is a plot of the experimental data. The value of the half-life obtained is 0.825 ± 0.02 sec. This is somewhat lower and outside the error of the most closely specified result of 0.89 sec reported by Hughes *et al.*[2] Hughes[5] points out that their analysis may contain over-corrections for the dead time of the G-M counter used, since the He^6 half-life of 0.89 sec[6] obtained using the same corrections has been remeasured to be 0.82 sec.[7,8]

To check that it was in fact the high energy Li^8 beta-rays that were being counted, the crystal and photomultiplier were roughly calibrated using the 1.28-Mev gamma-rays from Na^{22}. Since the maximum pulses from the Li were approximately a factor of 10 larger than the photoelectron pulses from the 1.28-Mev gamma-rays, it was estimated that 12-Mev betas were being detected in the main experiment, in agreement with the known maximum energy of the betas.

It is considered that this method of measuring half-lives is useful in the range 0.01 to 1.0 sec, usually regarded as being somewhat difficult.

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The Possibility of the Reaction $H^3(d, p)H^4$

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EXPERIMENTS have been conducted to investigate the possibility of the reaction $H^3(d, p)H^4$. The stability of H^4 is doubtful, and it was considered that an investigation into its possible formation was desirable.

The research falls into two parts. In the first, an air-cooled target of H^3 on zirconium, supplied by the Oak Ridge National Laboratory was bombarded by cyclotron deuterons of energies between 0.5 and 3.8 Mev. A search was made for the protons which would arise from the (d, p) reaction if it existed. A "peaked" proportional counter was used to detect protons at the end of their range. Difficulty was experienced due to the presence of oxygen, nitrogen, and carbon impurities on the target, all of which yielded (d, p) protons. These could be distinguished from $H^3(d, p)H^4$ protons by their shift in range with altered deuteron energy. The impurities, however, gave a background which prevented a search for low yield $H^3(d, p)H^4$ protons of small range. The following limits can be put on the reaction: either the reaction's Q value is less than 4.4 Mev, which implies that the mass value of H^4 is greater than 4.019 mass units, or the probability of the reaction is at least 1500 times as small as that of the $H^3(d, n)He^4$ reaction. This latter conclusion was reached after measurement of the neutron flux from the target using the $Ag^{107}(n, 2n)$ and $C^{63}(n, 2n)$ reactions and measuring the activity of the Ag^{106} and Cu^{62}.

The experiments do not exclude the possibility of Q being less than 4.4 Mev, since protons would not have been detected for such Q. Part of the corresponding mass range of H^4 could correspond perhaps to sufficient stability against mechanical disintegration to make β-emission possible. The β-emission $\mathrm{H}^4 \rightarrow \mathrm{He}^4 + \beta^-$ would give rise to high energy (~15 Mev) β-rays with a likelihood of short half-life. A search for these was made using a NaI (Tl) scintillation detector.

To study the region of half-lives of about 1 second, the same technique was used in the Li^8 half-life determination described in the previous letter.[1] The discriminator in the circuit was set so that only high energy electrons would be counted. The observation of Li^8 produced by the $\mathrm{Li}^7(d, p)\mathrm{Li}^8$ reaction was used as an indicator of the sensitivity of the apparatus and made it possible to relate the expected ratio of β-intensities from H^4 and Li^8 to the ratio of cross sections of the reactions $\mathrm{H}^3(d, p)\mathrm{H}^4$ and $\mathrm{Li}^7(d, p)\mathrm{Li}^8$. For a bombarding energy of 3.82 Mev there were 2000 counts observed from Li^8 after bombardment for 3 seconds. There were no counts attributable to H^4 after bombardment of the H^3 target with the same current and energy in the interval extending from 0.006 to 3 seconds after shutting off the cyclotron beam. This experiment was repeated 8 times, and not a single H^4 β-ray was observed.

For half-life investigations in the region of 100 seconds, H^3 was irradiated for 3 minutes and counts were simply looked for on the scaler after cutting the beam. Again, no counts were recorded, though as before, while the beam was on, neutrons from the $\mathrm{H}^3(d, n)\mathrm{He}^4$ reaction gave many counts.

The β-ray experiments were repeated with 4.1-Mev deuterons and 1/20 of the current of the first set of runs, and again no β-rays were detected. The combined evidence of absence of protons for Q values which would make their detection feasible, together with the absence of β-rays, decreases the probability of the existence of a stable H^4, as is more fully discussed in the following note.[2]

We wish to thank Professor Breit for many helpful discussions and Professor Pollard for his continued interest in the problem.

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† Assisted by the joint program of the ONR and AEC.

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Evidence Regarding Instability of H^4

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McNeill and Rall's attempts[1] to find protons or β-rays from $\mathrm{H}^3(d, p)\mathrm{H}^4$ failed to detect these particles, decreasing the probability of there being a stable H^4. The mass of a mechanically stable H^4 must be greater than 4.0211, for otherwise $\mathrm{Li}^8 \rightarrow \mathrm{He}^4 + \mathrm{H}^4$ would compete with β-decay of Li^8. It must be less than 4.0259, for otherwise $\mathrm{H}^4 \rightarrow \mathrm{H}^3 + n$ could take place. The lower limit agrees with the value 4.019 obtained experimentally;[1] E_β for $\mathrm{H}^4 \rightarrow \mathrm{He}^4 + \beta^-$ is accordingly between 22.0 and 17.3 mMU, and the corresponding values of Q for $\mathrm{H}^3(d, p)\mathrm{He}^3$ are -2.23 and $+2.23$ Mev. The first of these is directly $\mathrm{H}^2 - \mathrm{H}^1 - n^1$. Calculations give half-lives as in Table I.

Under "Notes," *N.C.* is a normalization correction for a p neutron taking account of overlap probability with a He^4 proton. The notation is as in the paper by Konopinski.[5] The "forbid." factors give lengthening of the half-life. Uncertainties in Table I are: (a) the *N.C.* may be different for ${}^1D$; (b) just below dissociation into $\mathrm{H}^3 + n$ the *N.C.* (${}^1S$) is large and $t_{\frac{1}{2}}$ unobservably long; (c) an uncertainty of a factor of 2 is possible on account of variability of ft values, (d) vector coupling effects in the ${}^3P$ states are neglected. A trace of Fermi interaction would seriously shorten $t_{\frac{1}{2}}$ for ${}^1S_0$.

From data on β-counts, estimates have been made regarding the lower limit of Y_H/Y_L, where Y_H and Y_L are yields of (, $p)H^4$ and of (, $p)\mathrm{Li}^8$. Factors considered are: (1) ratios of barrier penetrations for first stage as in OBJ,[6] (2) ratio of velocities for second stage, (3) ratio of geometric cross sections. Effects of Zr in target and of stopping powers are as in the following note.[7] Curve A in Fig. 1 is derived from data.[1] Absence of counts forbids the region below A. Probable regions of t are marked for states of H^4; w, Q are shown at end points of regions. Curves marked $a, \cdots, d'$ show yield ratios *versus* Q. Primed letters refer to lower E_d. Unprimed letters deal with $E_d = 4.1$ Mev. The graphs for these have been displaced up by $\log_{10}20$ to allow for the smaller current. The 4.1-Mev experiment gives less information but provides more certainty regarding errors in energy scales, because for $Q = -2.23$ Mev the 3.82-Mev experiment would barely make the reaction possible. The ${}^1D_2$, ${}^1S_0$ states are probably[8] unstable to n emission. The ${}^3P_2$ state appears likely to have lowest energy from shell structure spin-orbit coupling theory.[9] The more likely possibility is made improbable by the experiments[1] within the reservations mentioned together with uncertainties in yields of reactions. The writers are grateful to Drs. McNeill and Rall for a helpful discussion of data.

TABLE I. Expected half-lives of H^4.

State of H^4	Type of transition	Limits on $t_{\frac{1}{2}}$ (sec)	Notes
${}^3P_2$ odd	$\Delta I = 2$ (yes)	$4.5 < t < 16$ $w = 41.2$ to 32.5	($w = 41.2$, $N.C. = 3$) ($w = 32.5$, $N.C. = 2$) Theory as in references 2, 3, and 4.
${}^3P_{1,0}$ odd	$\Delta I = 0, \pm 1$ (yes)	$0.03 < t < 0.12$ $w = 41.2$ to 32.5	
${}^1P_1$ odd (pure)	$\Delta I = 0, \pm 1$ (yes)		
${}^1P_1 + 0.001\ {}^3P_1$	$\Delta I = 0, \pm 1$ (yes)	$30 < t < 120$	
${}^1D_2$, ${}^1S_0$ even		$0.4 < t < 3$ $w = 41.2$ to 32.5	15, 25 = forbid. factor for $w = 41.2$, 32.5

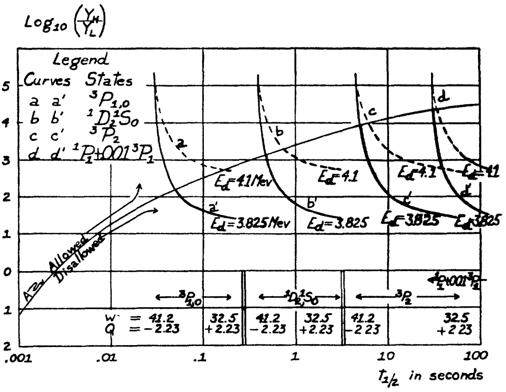

FIG. 1. Allowed and excluded regions. For each state of H^4, parts of curves $a, \cdots d'$ below curve A are excluded.

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