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Search for a Super-Allowed β^--Decay of H^4

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With 1 Figure in the Text

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If a β-decaying H^4 exists a super-allowed transition to the excited analogue state of He^4 is possible. Such a decay mode was not considered in previous experiments. The reaction $Li^6(\gamma, 2p)\,H^4$ was used to produce H^4. No super-allowed β^--decay of H^4 could be observed and upper limits for the production cross section are given.

1. Introduction

Several experiments have been performed[1–4] to find out whether the ground state of H^4 is unstable with regard to the spontaneous disintegration into H^3+n or undergoes a β^--decay to He^4. All experiments so far have indicated that nuclear disintegration takes place, but they do not prove it conclusively. In view of this situation it was still thought worthwhile to consider another β-decay mode of H^4 which has not been studied and searched for before.

2. General Considerations

The ground state of H^4 has an isobaric spin of $T=1$ (isobaric spin $T=2$ is extremely unlikely). Consequently, the mass of H^4 is closely related to the energetic position of the lowest excited state with $T=1$ in He^4. If one arbitrarily assumes an excitation energy for this state of 22.5 MeV (dotted line) it becomes clear from Fig. 1 that H^4 is highly unstable with regard to the spontaneous emission of a neutron. However, the ground state of H^4 can be stable with regard to disintegration into H^3+n if the known O^+ state in He^4 at 19.94 ± 0.02 MeV* excitation energy[5–8] has

* This value is given in ref. 8c while a value of 19.99 ± 0.02 MeV is given in ref. 8b

1 SPICER, B. M.: Phys. Letters 6, 88 (1963).

2 NEFKENS, B. M. K., and G. MOSCATI. Phys. Rev. **133**, B 17 (1964)

3 POPIĆ, R. V., B. Z. STEPANČIĆ, and N. R. ALEKSIĆ: Phys. Letters **10**, 79 (1964)

4 IMHOFF, W. L., F. J. VAUGHN, L. F. CHASE, and H. A. GRENCH: Nuclear Phys. **59**, 81 (1964).

5 LEFEVRE, H. W., R. R. BORCHERS, and C. H. POPPE: Phys. Rev. **128**, 1328 (1962). — POPPE, C. H., C. H. HOLBROW, and R. R. BORCHERS: Phys. Rev. **129**, 733 (1963).

6 JARMIE, N., M. G. SILBERT, D. B. SMITH, and J. L. LOOS: Phys. Rev. **130**, 1987 (1963).

7 YOUNG, P. G., and G. G. OHLSEN: Phys. Letters **8**, 124 (1963).

8 MOLLENAUER, J. F., P. F. DONOVAN, and J. V. KANE: Bull Am. Phys. Soc. **9**, 389 (1964). — DONOVAN, P. F., J. V. KANE, J. F. MOLLENAUER, and P. D. PARKER: Internat. Conference on Nuclear Physics, Paris 1964, Vol. II, p. 236. — DONOVAN, P. F.: Conference on Correlations of Particles Emitted in Nuclear Reactions, Gatlinburg 1964

isobaric spin $T=1$ as originally suggested by WERNTZ and BRENNAN[9]. H^4 must then β-decay to He^4 and a T-forbidden $0^+ \to 0^+$-transition to the ground state of He^4 with $E_\beta \approx 20$ MeV should take place[9]. The negative results[1-4] in the search for such a transition strongly indicate that the state at 19.94 MeV in He^4 has $T=0$ and not $T=1$. However, there is a chance[10] that the negative results might instead be due to a suppression of the T-forbidden $0^+ \to 0^+$ transition to the ground state of

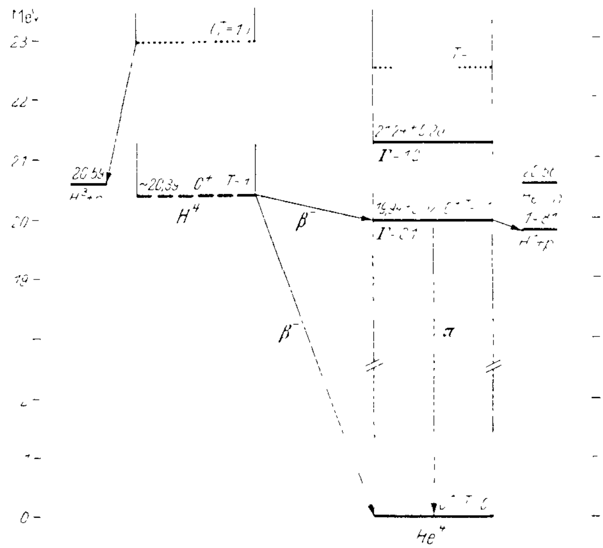

Fig. 1. Level and decay scheme for He^4 (see ref. 8) and H^4. If the state at 19.94 ± 0.02 MeV excitation energy in He^4 has isobaric spin $T=1$, the nucleus H^4 can β-decay to He^4 with *two* components. If the lowest state with $T=1$ has a higher excitation energy (dotted line, drawn arbitrarily), the nucleus H^4 is unstable with regard to the spontaneous emission of a neutron

He^4 in favour of the superallowed $0^+ \to 0^+$ transition to the analogous $T=1$ state in He^4. The latter transition must take place (if the state at 19.94 MeV in He^4 has $T=1$ and if a β-decaying H^4 exists; both related assumptions will be maintained in the following paragraphs until stated otherwise) and its ft-value can be predicted very accurately from the other known $0^+ \to 0^+$ transitions (O^{14}, Al^{26m}, Cl^{34} etc.).

The ft-value of the T-forbidden $0^+ \to 0^+$ transition on the other hand depends very sensitively on the isobaric spin impurities α of the ground state of He^4 according to

$$(f\,t)_{T\text{-forbidden}} = (f\,t)_{O^{14}} \frac{2}{\alpha^2 \left[T(T+1) - T_Z^{(i)}\, T_Z^{(f)}\right]} \tag{1}$$

[9] WERNTZ, C., and J. G. BRENNAN: Phys. Letters 6, 113 (1963).
[10] JANECKE, J.: Kernforschungszentrum Karlsruhe report KFK-185 (1963), p. 33.

or for our special case with $T=1$

$$(f\,t)_{T\text{-forbidden}} = \frac{(f\,t)_{O^{14}}}{\alpha^2}\,. \tag{2}$$

The situation for this T-forbidden transition is very similar to the known β-decays of Ge^{66} and Ga^{66} as discussed by ALFORD and FRENCH[11]. WERNTZ and BRENNAN[9] estimated the $T=1$ admixtures to the ground state of He^4 and obtained from the ft-value with $E_\beta \approx 20$ MeV a partial half-life of $T_{\frac{1}{2}} \approx 1$ h.

The ft-value of the superallowed $O^+ \to O^+$ β^--transition is $ft=3100$ sec. From an estimate of the Coulomb energy difference[9,12] and the Thomas shift[9,13] one obtains for the maximum β-energy $E_{\beta^-} \approx 0.45$ MeV. The maximum permissible value is $E_{\beta^-} = 0.65$ MeV. Otherwise, H^4 can disintegrate into $H^3 + n$ despite the assumptions made (see Fig. 1). For E_{β^-} in the range 0.65 MeV − 0.45 MeV − 0.25 MeV the partial half-life becomes[14] 1 h − 4 h − 1.5 d.

Thus, one has a branching between the ground state transition and the transition to the excited state in He^4 of >0.5. Consequently, the conclusions of NEFKENS and MOSCATI[2] (a β-decaying H^4 seems not to exist) hold, except that the upper limit for the production cross section of the $Li^6(\gamma, 2p)\,H^4$ reaction must be slightly increased. The situation remains essentially unchanged if the isobaric spin impurities α of the ground state of He^4 are bigger than estimated by WERNTZ and BRENNAN[9]. If, however, the isobaric spin impurities of the ground state of He^4 are much smaller than estimated, the ground state transition is suppressed accordingly and H^4 decays through the super-allowed channel. It would then have escaped all β-experiments undertaken so far which discriminated against high energy β-rays (and γ-rays). This is because the super-allowed $O^+ \to O^+$ β^--transition has a low maximum β-energy and is followed by the delayed emission of protons, i.e. by a spontaneous breakup into $t+p$. Subsequent emission of γ-rays is not possible, and the emission of internal electron pairs is supressed by many orders of magnitude[6].

3. Experimental Procedure

As in other investigations[1,2] the $Li^6(\gamma, 2p)\,H^4$ reaction was used to produce H^4. Li-loaded scintillation glasses (Thorn Electronics, type KG 1 and KG 2) were bombarded with γ-radiation. Two glasses (diameter 38 mm, thickness 6.3 mm, Li contents 8.8%) were used, one with

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[12] JANECKE, J.: Z. Physik 160, 171 (1961).

[13] LANE, A. M., and R. G. THOMAS: Rev. Mod. Phys. 30, 329 (1958).

[14] DŽELEPOV, B. S., and L. N. ZYRYANOVA: Influence of Atomic Electric Fields on Beta Decay [in Russian]. Moscva: Izd. Akad. Nauk SSSR 1950.

Li of natural isotopic abundance, the other with Li enriched in Li^6 by 96%. Both glasses were irradiated several times with 31 MeV maximum energy bremsstrahlung from the Karlsruhe betatron and with 51 MeV maximum energy bremsstrahlung from the Darmstadt electron linear accelerator. If a β-decaying H^4 exists, the γ-threshold must be $\lesssim 23.5$ MeV. Carbon disks were activated simultaneously and the well known $C^{12}(\gamma, n)\,C^{11}$ reaction[15] was used for reference. The glasses were irradiated for periods of up to three hours and then mounted on a RCA 6810 A photomultiplier. The pulse height spectrum from the induced activities was recorded repeatedly in 16 successive time intervals with 300 sec to 10,000 sec each. An Intertechnique 4096-channel analyzer was used in the 16×256 channel mode. The decay of the activities was observed for periods of up to 14 days. The gain of the photomultiplier and electronic system including the multi-channel analyzer was stabilized.

As the activated nuclei are dispersed in the detector there is no absorption for the emitted β-rays. Also, the discrimination threshold for the hypothetical H^4 spectrum can be set for an energy of practically zero. A constant energy of about 100 keV is added to every single β-ray pulse because the β-rays from H^4 and the proton and tritium from the subsequent breakup are detected simultaneously. The detection efficiency is 100%. At first sight it appears as a disadvantage that interfering activities can be produced from the other chemical compounds, above all from oxygen and silicon. However, there are only very few reactions (with low cross sections) resulting in activities with half-lives in the region of interest.

4. Results and Conclusions

Detailed half-life analyses were carried out for various parts of the measured decay spectra. It turned out that C^{11} with $T_{\frac{1}{2}} = 20.5$ min (shorter half-lives were not considered) from the $O^{16}(\gamma, \alpha n)\,C^{11}$ reaction[16] with $\sigma_{\mathrm{prod}} \approx 5$ μb at 31 MeV and $\sigma_{\mathrm{prod}} \approx 45$ μb at 51 MeV was the strongest component. The C^{11} counting rates were used as additional convenient reference values for the calculation of absolute cross sections. In addition, three weak components were observed with half-lives up to 10–20 d. The activities are probably due to $Si^{30}(\gamma, 2p)\,Mg^{28}$ and photo-reactions on Ce^{142}. No effort was made for definite assignments because the production cross sections for the reactions on the glasses with natural Li and with Li^6 were equal and are therefore not due to a reaction on Li^6. From the 51 MeV bombardment of the natural Li glass an additional component with $T_{\frac{1}{2}} \approx 35$ min was obtained which did not

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[16] HOLTZMAN, R. B., and N. SUGARMAN: Phys. Rev. **87**, 633 (1952). — SCHMOUKER, J., P. ERDOS, P. JORDAN et P. STOLL: J. phys. radium **16**, 169 (1955). — BISHOP, G. R., B. GROSSETETE et J. C. RISSET: J. phys. radium **23**, 31 (1962).

show up in the 51 MeV bombardment of the Li^6 glass. Since this activity cannot be due to Li^7 it is concluded that impurities, possibly Cl, were contained in the natural Li glass.

From the half-life analysis and from the comparison of the decay curves for the two γ-activated Li-loaded scintillation glasses it must be concluded that no super-allowed β^--decay of H^4 could be observed with half-lives between 0.8 h and 5 d. If H^4 with such a decay mode exists, the upper limit for the production cross section at 51 MeV of the $Li^6(\gamma, 2p)\ H^4$ reaction is $\sigma_{prod} \approx 2.4\ \mu b$ (for half-lives from 0.8 h to 5 d) and $\sigma_{prod} \approx 1.2\ \mu b$ (for half-lives from 2 h to 1.5 d), respectively.

The result of this work is in agreement with all previous investigations[1-4, 17]. They already strongly indicated that a β-decaying H^4 does not exist but did not completely rule out the possibility of a super-allowed $0^+ \to 0^+\ \beta^-$-transition to the state at 19.94 MeV excitation energy in He^4. Direct proof of an unbound H^4 must come from reaction studies like low energy $n+t$ elastic scattering with a phase shift analysis or from a study of final state interaction in the reaction $d+t \to p+n+t$.

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