THE DECAY OF ^8He

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ABSTRACT

Delayed neutron and gamma emission following the beta decay of ^8He have been studied. The P_n value was determined to be $(16 \pm 1)\%$, indicating that $(84 \pm 1)\%$ of the beta decays feed the 981 keV first excited state in ^8Li . It was found that $(32 \pm 3)\%$ of the emitted neutrons populate the first excited state in ^7Li at 478 keV. The measured energy spectrum of delayed neutrons can be interpreted as mainly arising from the 3.21 MeV and 5.4 MeV states in ^8Li . Limits were set on charged particle emission. The half-life was determined to be (117.5 ± 1.5) ms.

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Radioactivity ^8He from U(p or ^3He ,X) chem. mass separation;
 measured βn - coin., $\beta\gamma$ - coin., n spec., $T_{1/2}$.
 deduced P_n , log ft. Natural targets.

1. INTRODUCTION

The heaviest isotope of the element helium ($Z=2$) has mass number 8 and is the nucleus with the highest neutron to proton ratio available. It was first definitely identified¹⁾ with a counter telescope technique as the third fragment in ^{252}Cf fission and the first study of its decay was made²⁾ in 1965. In the latter experiment the ^8He activity was produced by high-energy protons in a target of cotton fibres. The ^8He that diffused out of the target, was purified by gas phase chemistry and transported to a counting chamber. By means of neutron counting the half-life was determined to be (122 ± 2) ms. The state in ^8Li at 981 keV with $I = 1$ is the only state below the neutron separation energy that could be fed in allowed beta-decay (see fig. 1). The gamma emission from this state, observed with a NaI detector, established its parity as positive. The delayed neutron branch, P_n , was determined to be $(12 \pm 1)\%$ from the ratio of the neutron to gamma count rates. Later³⁾, 250 MeV bremsstrahlung was used for photoproduction of ^8He in natural boron which confirmed the half-life by multiscaling of the β -coincident 981 keV gamma rays. The first determination⁴⁾ of the ^8He mass was obtained from the four-neutron transfer reaction $^{26}\text{Mg}(\alpha, ^8\text{He})^{22}\text{Mg}$. Other aspects of the decay have been verified^{5,6)} but no new information has been contributed⁷⁾ to the original decay scheme²⁾.

In this paper we report on a new series of measurements on the ^8He decay. The half-life and the beta-delayed neutron branch have been remeasured and energy spectra of neutrons and gamma rays were recorded. A search for the possible beta-delayed charged-particle decay mode, involving the break-up of $^8\text{Li}^*$ into $\alpha+t+n$, has been made.

2. EXPERIMENTAL TECHNIQUE

The ^8He activity was produced at the ISOLDE facility through fragmentation reactions induced either by 600 MeV proton or 910 MeV ^3He beams from the CERN Synchro-Cyclotron. The production target⁸⁾ consisted of a 47.0 g/cm^2 uranium carbide matrix. A cooled transfer tube connecting the target to the plasma ion source assured chemical purity of the on-line mass separated ion beam. The absence of ^9Li at mass 9 showed that the suppression factor for this element⁸⁾ was more than 10^{10} .

The beam of $3 \cdot 10^4$ $^8\text{He}/\text{s}$ was directed to a low background counting area where the 60 keV ^8He ions were deposited in an aluminized mylar tape. A beta detector, consisting of a 1 mm thick $24 \times 16 \text{ mm}$ plastic scintillator (Nel02), mounted on a 30 mm diameter phototube, was placed behind the tape at the collection position. The tape was moved periodically in order to remove the daughter activity. The beta-detection efficiency was determined on-line to be $(40 \pm 3)\%$ in

a beta-gamma coincidence measurement on the nuclide ^{23}Ne ($T_{1/2} = 38$ s), which has a well-established decay scheme⁹⁾.

The gamma detector was placed close to the collection point and a fast coincidence technique was used for the beta-gamma coincidence measurements. A coaxial Ge(Li) crystal with 17% standard efficiency was used. The shape of the efficiency curve was determined to about 5% accuracy by means of calibrated sources and the ^{23}Ne measurement.

For the P_n -value measurements a 4π neutron counter, consisting of twelve ^8He proportional counters imbedded in paraffin-wax, was slid over the beta detector so that the collection position was in the centre of the counter. The neutron detection efficiency was determined to be $(20 \pm 1)\%$ with a 48 g sample of uranium. A possible source of systematic error is the energy dependence of the neutron detection efficiency which has not been determined experimentally. However, a Monte Carlo computation¹⁰⁾ revealed that the energy dependence is almost negligible in the interval 150 keV to 4 MeV, whereas it is pronounced below ~ 150 keV. Since the energy spectra of ^8He and the fission neutron spectrum of ^{238}U are similar, the systematic error is considered to be small. The beta-neutron coincidence method used for the determination of the P_n value involved the technique¹¹⁾ for measuring the time delay between the beta particle emission and the detection of a neutron.

The neutron energy spectrum was measured with a ^3He filled high resolution spectrometer. For the charged particle measurements the ^8He ions were collected in a 39 mg/cm^2 Ni foil in front of a $100 \mu\text{m}$ thick surface-barrier Si detector.

3. EXPERIMENTAL RESULTS

The half-life of ^8He was measured with the 4π neutron counter to be (117.5 ± 1.5) ms. If there were a diffusion loss of ^8He from the aluminized mylar tape the measured half-life would become too short. Such a source of systematic error could, however, be excluded since a measurement with the beta-detector, which due to its small size is much more sensitive to a loss of activity, gave the same half-life within the error limits. Combining this new value of the half-life with the one published earlier²⁾, we recommend a best value of (119 ± 1) ms.

The measurements of the P_n value were done both with a saturated ^8He source, and with periodic removal of the activity. When counting the beta activity in the saturation mode, one has to take into account the contribution from the 0.84 s ^8Li daughter which is in equilibrium with ^8He . If P_γ denotes the probability of beta decay to the 0.98 MeV state in ^8Li , then the beta count rate is proportional to $1 + P_\gamma$. This is equal to $2 - P_n$ since one can assume that $P_n + P_\gamma = 1$. In the short collection mode, where the activity was collected and counted during a 100 ms time interval followed by an interruption of 100 ms, when the tape was moved, the beta count rate was calculated to be proportional to $1 + 0.03 P_\gamma$.

The beta-neutron coincidence measurements gives a P_n value of $(15 \pm 1)\%$. This value is based on four measurements in saturation mode and one in the short collection mode. The error comes mainly from the uncertainty in the neutron detection efficiency. Nine sets of simultaneous beta and neutron singles measurements give a somewhat larger P_n value, $(18 \pm 2)\%$, where the larger error is due to the uncertainty in the beta detection efficiency. From the beta-gamma coincidence and the singles measurements a value of P_γ is obtained which gives an indirect determination of P_n . Although the result obtained in this way is consistent with the neutron measurements, the final error on the relatively smaller P_n becomes quite large since this is an inefficient way to determine P_n . Another method to obtain P_n is to use the ratio of neutron to gamma count rates, both normalized to their respective beta count rates. This method again gives $(18 \pm 2)\%$, even though the beta detection efficiency cancels out of the calculation. From all these measurements we adopt a value for P_n equal to $(16 \pm 1)\%$. This is somewhat larger than the earlier published value²⁾, but we believe that the present techniques, especially the β -n coincidence method, offer the best available determination of P_n .

The gamma energy spectrum (see inset fig. 2) shows, in addition to the 981 keV line, a broader peak at 478 keV from the deexcitation of the first excited state in ${}^7\text{Li}$ populated after neutron emission. The larger FWHM of the 478 keV peak is presumably a doppler broadening caused by the neutron emission recoil. The ratio of the probability of emission of the 478 keV gamma to P_γ was found to be 0.060 ± 0.003 . Using our adopted value of P_n , this shows that the fraction of neutrons emitted to this state amounts to $(32 \pm 3)\%$.

The neutron energy spectrum is shown in fig. 2. No significant structure is observed in the spectrum as expected since the known neutron emitting states in ${}^8\text{Li}$ are broad. The spectral shapes measured with and without lead around the source position were the same which shows that high energy beta particles do not contribute to the spectrum.

The Q_β value of ${}^8\text{He}$ is 10.649 MeV and the thresholds for the break up of ${}^8\text{Li}$ into $\alpha + t + n$ and ${}^5\text{He} + t$ are at 4.499 and 5.39 MeV, respectively⁷⁾. It was therefore considered possible to detect beta feedings to states above these energies from the observation of beta-delayed triton emission. The measured charged particle spectrum was, however, severely interfered with both alpha particles from the ${}^8\text{Li}$ daughters and beta particles from ${}^8\text{He}$ itself. As a result only upper limits can be set at 10% per decay for charged particles with an energy below 1 MeV and 1% per decay with an energy above 1 MeV. These are not very useful limits as one expects mainly low-energy alphas and tritons from the possible ${}^8\text{He}$ delayed charged particle decay mode. A tighter limit may be obtained from the neutron energy spectrum which in an indirect way may show the delayed triton branch. This is discussed below.

4. DISCUSSION

The ground state of ^8Li has $I^\pi = 2^+$ and its first excited state at 981 keV, $I^\pi = 1^+$. The beta feeding to the 1^+ state is 84% which gives a log ft value of 4.20. This is in good agreement with the results from shell model calculations of 4.26 by Cohen and Kurath¹²⁾ and 4.01 by Hauge and Maripuu¹³⁾. The lowest excited state above the neutron separation energy at 2.255 MeV has $I^\pi = 3^+$ and beta feeding to this state cannot be expected.

It has earlier been assumed^{2,7)} that the main part of the emitted neutrons originates in the 3.21 MeV state. In order to try to detect neutron emission from higher excited states in ^8Li we have calculated the shape of the neutron energy spectrum and compared it with our measured spectrum. The calculation of the spectrum was made in two steps :

- (i) Calculation of the energy distribution of the recoiling beta-decay daughter $^8\text{Li}^*$.
- (ii) Calculation of the neutron energy distribution taking the recoil broadening as well as the width of the neutron emitting state into account.

The first part of the calculation, which will be discussed¹⁴⁾ for the 680 keV neutron line in ^9Li , is in this case of comparatively small importance but has been incorporated for completeness. The broad states fed in the beta decay are populated asymmetrically due to the phase space distribution. A schematic illustration of this effect is shown in fig. 3. The results from our calculations are illustrated in fig. 4 where the contributions from the 3.21 MeV and 5.4 MeV states are shown. The calculated spectrum follows the main trend of the experimental spectrum but there is some additional intensity in the experimental spectrum at the lowest energy and at about 1.8 MeV which cannot be explained from neutron emission from any known state in ^8Li . It is interesting to speculate whether part of the intensity at the lowest energy could be due to $\alpha+t+n$ break-up. Assuming that all the additional intensity up to 1 MeV arises from this decay mode we get an upper limit for this decay branch of 2%.

The calculated feeding to the first excited $\frac{1}{2}^-$ state at 478 keV in ^8Li is 32.4%, in excellent agreement with the measured value. Taking into account the widths of the broad levels, the calculated log ft value are 4.6 for the 3.21 MeV state and 5.0 for the 5.4 MeV state. From this we suggest that the 3.21 MeV state, which has spin equal to 1, has positive parity and that the 5.4 MeV state could be either 0^+ or 1^+ .

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FIGURE CAPTIONS

- Fig. 1 : The decay scheme of ^8He from ref. 7 and this work.
- Fig. 2 : Energy spectrum of beta-delayed neutrons from ^8He . The spectrum was measured with a ^3He filled proportional counter. The inset shows the gamma spectrum. The peak at 478 keV shows that there is a 32% feeding of the first excited state in the neutron daughter ^7Li .
- Fig. 3 : Delayed-neutron emission from the 3.21 MeV state in ^8Li . The dashed curve shows the shape of the 1 MeV broad state and the hatched area is the relative feeding of the state which is slightly asymmetric due to the influence of the phase space distribution.
- Fig. 4 : Experimental and calculated energy spectrum of beta delayed neutrons from ^8He . The experimental spectrum (open circles) is obtained from fig. 1 after correction for detection efficiency and subtraction of the thermal peak. The curve peaking at 700 keV is from the 1 MeV broad 3.21 MeV state (dot-dash curve) and the one with its maximum at 2.7 MeV (dashed curve) is from the 5.4 MeV state ($\Gamma = 0.65$ MeV). The arrows indicate the normalization points. The inset shows the difference between the experimental and calculated spectra.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

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