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The γ activity from 11Li beta decay

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Résumé. — Les énergies et les intensités absolues des raies γ consécutives à la désintégration β de 11Li ont été mesurées. La transition β vers le niveau fondamental du 11Be n’est pas observée. Le pourcentage de désintégration β ne conduisant pas à l’émission de particules retardées n’est que de (5,2 ± 1,4) %. On observe de nouvelles voies de neutrons retardés vers des états excités de 10Be et on en déduit la probabilité totale d’émission de neutrons retardés.

Abstract. — The energies and absolute intensities of the γ-rays from the β-decay of 11Li are measured. There is no sizable β branch to the 11Be ground state. Only (5.2 ± 1.4) % of the β-decay strength does not lead to β-delayed particle emission. New β-delayed neutron branches to excited states of 10Be are observed and the total delayed neutron emission probability is deduced.

Since its first observation [1], the 11Li isotope has been actively studied. A 8.5 ± 0.2 ms half-life [2] and a 40.94 ± 0.08 MeV mass excess [3] have been measured. Its β-delayed total neutron emission probability [$P_n = (60.8 ± 7.2) %$] has been observed [2]. More recently, the neutron energy spectrum has been measured [4] which led to the first observation of β-delayed multiple neutron emission reported with a probability of $P_{2n} = (9 ± 3) %$ value [4]. A sizable probability of β-delayed light charged particle emission is observed in a study currently in progress in our group [5].

In view of this wealth of information, it is somewhat paradoxical that the γ-activity of 11Li had never been observed previously. This work was thus undertaken to measure the energy and absolute intensity of the various γ-rays emitted from the β-decay of 11Li. From the present measurements, a new value for the β-delayed neutron emission probability is deduced which resolves the discrepancy between the earlier $P_n$ measurement [2] and a recent theoretical estimate [6].

The experimental method is the same as described in our report on γ-activities from neutron-rich Na isotopes [7]. To summarize it, a pulsed beam of 24 GeV protons from the CERN synchrotron (1), induces nuclear fragmentation in a target of a heavy element, in the present case Ir. The recoiling nuclear fragments are thermalized in heated graphite, out of which the alkali elements selectively diffuse. The selectivity is enhanced by a surface ionization mechanism. At last, alkali ions are extracted and analysed by a mass spectrometer. This insures a complete selectivity in Z and A for the collected ions. The resulting γ-activity measured with a Ge(Li) detector is observed in coincidence with the beta activity detected by a plastic scintillator.

As an improvement over our previous work [7], three pieces of information are stored on tape for each β-γ coincidental event : the γ energy ($E$), the time ($T$) elapsed between the proton beam burst and the detection of the β-γ coincidence, and the time between the β and γ signals. Off line analysis of the data allows the constitution of $E$ spectra according to the $T$ parameter in order to discriminate between activities of different half-lives.

Figure 1 shows a γ energy spectrum with no restriction on $T$. As a result, γ-rays from the 8.5 ms 11Li coexist with the 2 125 keV γ-ray from its 14 s 11Be daughter.

One major aim of this work was to measure the absolute intensity $I_γ$ of the observed γ-rays. The abso-
The efficiency of the Ge(Li) detector was determined from calibrated sources of $^{56}$Co, $^{85}$Sr and $^{203}$Hg with an estimated uncertainty of 12%. The measurement of the number of decaying $^{11}$Li ions collected was more difficult. It was determined in two ways: i) before and after each data accumulating run, direct measurements were made of the number of ions collected from the mass spectrometer per beam burst, i.e. for a certain number of incident protons; ii) the $\beta$-activity was multiscaled to identify the $\beta$-particles due to the short-lived $^{11}$Li from those due to background or long-lived descendants. From the efficiency of the $\beta$ detector, the corresponding number of collected $^{11}$Li ions was deduced.

Although the results from these two methods were found to agree within 10%, a more realistic estimate of 20% was retained for the uncertainty on the number of $^{11}$Li ions collected.

Table I lists the $\gamma$-activities observed and their absolute intensities. Three conclusions can be readily drawn from these results:

1) The intensity of the 2125 keV $\gamma$-ray due to the $\beta$-decay of the daughter $^{11}$Be nucleus, with a known $^{[8]} I_\gamma = (33 \pm 3)\%$, is fully accounted for by the measured intensity of the 320 keV $\gamma$-ray activity from the $^{11}$Li decay of the first excited state of $^{11}$Be which is the only bound excited state against particle emission $^{[8]}$. Therefore, no sizable $\beta$ branch to the $^{11}$Be ground state is observed within the experimental uncertainties, as expected for a $1/2^- \rightarrow 1/2^+$ $\beta$ transition.

2) Only $(5.2 \pm 1.4)\%$ of the $\beta$-decays strength of $^{11}$Li, which feeds the 320 keV level of $^{11}$Be, does not give rise to $\beta$-delayed particle emission. All the remainder, which populates the other excited states of $^{11}$Be, must then lead to one or several channels of particle emission, $^{10}$Be + n, $\alpha + ^6$He + n, $^9$Be + 2n, 2$\alpha$ + 3n, $^8$Li + t.

As a result, the total particle emission probability is thus deduced to be

$$P_{1n} + P_{2n} + P_{3n} + P_t = 94.8 \pm 1.4\%.$$ 

Our current study of $\beta$-delayed light charged particle emission indicates a probability of the order of 5\% for the emission of 2$\alpha$ or $\alpha + ^6$He and a negligible one for $^8$Li + t. This leads to a total delayed neutron intensity per beta disintegration of $^{11}$Li,

$$(P_n = P_{1n} + 2P_{2n} + 3P_{3n})$$

varying from 95 to 105\%, depending on whether the emission of $\alpha$ or $^6$He-particles is associated with In or 3n emission.

This value is in strong disagreement with the only earlier measurement $^{[2]}$ which determined $P_n$ as the ratio of the measured numbers of detected neutrons to $\beta$-particles. Whether a systematic error was introduced by an incorrect $P_n(^{11}$Li) normalizing value, by an inaccurate estimate of the efficiency for high energy neutrons, as suggested by Barker and Hickey $^{[6]}$, or by an improper determination of the fraction of $\beta$ counting due to $^{11}$Li as opposed to the background remains unclear. However it is felt that the new value, which is in qualitative agreement with a theoretical estimate $^{[6]}$ should be free of systematic errors for the following reasons: i) the number of decaying $^{11}$Li has been measured consistently by two independent methods described above, ii) the neutron branching to the $2^+$ state of $^{10}$Be of $(14 \pm 5)\%$ (see Fig. 2) is in good agreement with the independent measurement of Jonson and his coworkers $^{[9]}$ who give a value of 11\% with an estimated uncertainty of half of that value.

The observed $\gamma$-rays from $^{11}$Li decay give evidence for the population by $\beta$-delayed neutron emission of at least some of four states of $^{10}$Be lying around 6 MeV excitation energy. Only an upper limit can be set for the feeding of the 6 263 keV level but the two $\gamma$-rays associated with the decay of the 6 179 keV level are observed. The $\gamma$-rays from the doublet of levels at 5.96 MeV, only 1.6 keV apart, cannot be resolved but a transition between this doublet and the 3 368 keV 2$^+$ level is observed. The $\beta$-delayed neutron feeding of a

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\[ ^{11}\text{Be} \] level is defined as the difference between the \( \gamma \) intensities from and to this level.

Figure 2 summarizes the \( \gamma \) transitions observed and shows the \( \beta \) and \( \beta \)-delayed neutron intensities measured. It is clear that the major part of the \( \beta \)-decays, which goes unobserved in the present experiment, feeds the \( ^{10}\text{Be} \) ground state through neutron emission.

Even if \( ^{11}\text{Li} \) is an extreme case due to the low energy thresholds of many particle emission channels, the present results are in agreement with more general trends described elsewhere for Na isotopes [10]. More specifically, for odd-\( Z \) elements, \( P_{1n} \) tends towards 100 \% for odd-\( A \) isotopes as observed here, while for even-\( A \) isotopes, \( P_{2n} \) tends towards \( P_{1n} \) as observed for \( ^{32}\text{Na} \) [11].

In any case, the high probability of \( \beta \)-delayed neutron emission is clearly the dominant aspect of \( \beta \)-decay of very neutron-rich isotopes.

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**References**