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# THE $\gamma$ ACTIVITY FROM $^{11}Li$ BETA DECAY


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$\gamma$ activity of $^{11}Li$
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# The $\gamma$ activity from $^{11}Li$ beta decay

## Rayonnement $\gamma$ associé à la désintégration $\beta$ de $^{11}Li$

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Résumé : Les énergies et les intensités absolues des raies $\gamma$ consécutives à la désintégration $\beta$ de $^{11}Li$ ont été mesurées. La transition $\beta$ vers le niveau fondamental du $^{11}Be$ n'est pas observée. Le pourcentage de désintégration $\beta$ ne conduisant pas à l'émission de particules retardées n'est que de $(5.2 \pm 1.4)$ % . On observe de nouvelles voies de neutrons retardés vers des états excités de $^{10}Be$ et on en déduit la probabilité totale d'émission de neutrons retardés.

Abstract : The energies and absolute intensities of the $\gamma$-rays from the $\beta$.decay of $^{11}Li$ are measured. There is no sizable $\beta$ branch to the $^{11}Be$ ground state. Only $(5.2 \pm 1.4)$ % of the $\beta$-decay strength does not lead to $\beta$-delayed particle emission. New $\beta$-delayed neutron branches to excited states of $^{10}Be$ are observed and the total delayed neutron emission probability is deduced.

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Since its first observation[1], the $^{11}Li$ isotope has been actively studied. A 8.5 $\pm$ 0.2 ms half life[2] and a 40.94 $\pm$ 0.08 MeV mass excess[3] have been measured. Its $\beta$-delayed total neutron emission probability [Pn = (60.8 $\pm$ 7.2) %] has been observed[2]. More recently, the neutron energy spectrum has been measured[4] which led to the first observation of $\beta$-delayed multiple neutron emission reported with a probability of $P_{2n}$ = (9 $\pm$ 3) % value[4]. A sizable probability of $\beta$-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 $\gamma$ activity of $^{11}Li$ had never been observed previously. This work was thus undertaken to measure the energy and absolute intensity of the various $\gamma$ rays emitted from the $\beta$-decay of $^{11}Li$. From the present measurements, a new value for the $\beta$-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 $\gamma$ activities from neutron-rich Na isotopes[7]. To summarize it, a pulsed beam of 24 GeV protons from the CERN synchrotron,(*) 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 $\gamma$ activity measured with a Ge(Li) detector is observed in coïncidence with the beta activity detected by a plastic scintillator.

(*) with a typical intensity of $2 \times 10^{12}$ protons every 2.4 s

As an improvement over our previous work[7], three pieces of information are stored on tape for each $\beta$-$\gamma$ coïncidental event : the $\gamma$ energy (E), the time (T) elapsed between the proton beam burst and the detection of the $\beta$-$\gamma$ coïncidence, and the time between the $\beta$ and $\gamma$ 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.

Fig. 1 shows a $\gamma$ energy spectrum with no restriction on T. As a result, $\gamma$ rays from the 8.5 ms $^{11}Li$ coexist with the 2125 keV $\gamma$ ray from its 14 s $^{11}Be$ daughter.

One major aim of this work was to measure the absolute intensity $I_\gamma$ of the observed $\gamma$ rays. The absolute 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 1 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 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 desintegration 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 1n 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 $P_n(^{9}Li)$ 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 independant 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 independant 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 6263 keV level but the two $\gamma$ rays associated with the decay of the 6179 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 3368 keV $2^+$ level is observed. The $\beta$-delayed neutron feeding of a $^{10}$Be level is defined as the difference between the $\gamma$ intensities from and to this level.

Fig. 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 $^{10}$Be ground state through neutron emission.

Even if $^{11}$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 $^{32}Na$ [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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## T A B L E 1

$\gamma$ activities observed from the $\beta$ decay of $^{11}Li$

| $E_\gamma$ (keV) | $E_i \rightarrow E_f$ (keV) | | $I_\gamma$[(a)] (%) |
|---|---|---|---|
| 219 | 6179 → 5960 | in $^{10}Be$ | 0.95 ± 0.35 |
| 320 | 320 → 0 | in $^{11}Be$ | 5.2 ± 1.4 |
| (2125)[(b)] | 2125 → 0 | in $^{11}B$ | 1.8 ± 0.7 |
| 2590 | 5958,5960 → 3368 | in $^{10}Be$ | 3.5 ± 1.0 |
| 2811 | 6179 → 3368 | in $^{10}Be$ | 1.65 ± 0.70 |
| 3368 | 3368 → 0 | in $^{10}Be$ | 21 ± 6 |

(a) The uncertainties include estimated uncertainties of 20 % for the number of collected $^{11}Li$ ions and 12 % for the Ge(Li) efficiency.

(b) This 14 sec $\gamma$ activity from $^{11}Be$ decay is listed here for intensity comparison with the 320 keV $\gamma$-ray from the beta decay of $^{11}Li$ (see text).

## Figure captions

Fig.1 - $\gamma$-ray spectrum observed in the decay of 8.5 ms $^{11}Li$. Peaks are labelled in keV and their origine are indicated in Table 1. (s) and (d) stand for single and double escapes.

Fig.2 - A partial $\beta$-decay scheme of $^{11}Li$ as established from the observed $\gamma$-activities. Beta decay intensities are given per 100 desintegrations of $^{11}Li$.

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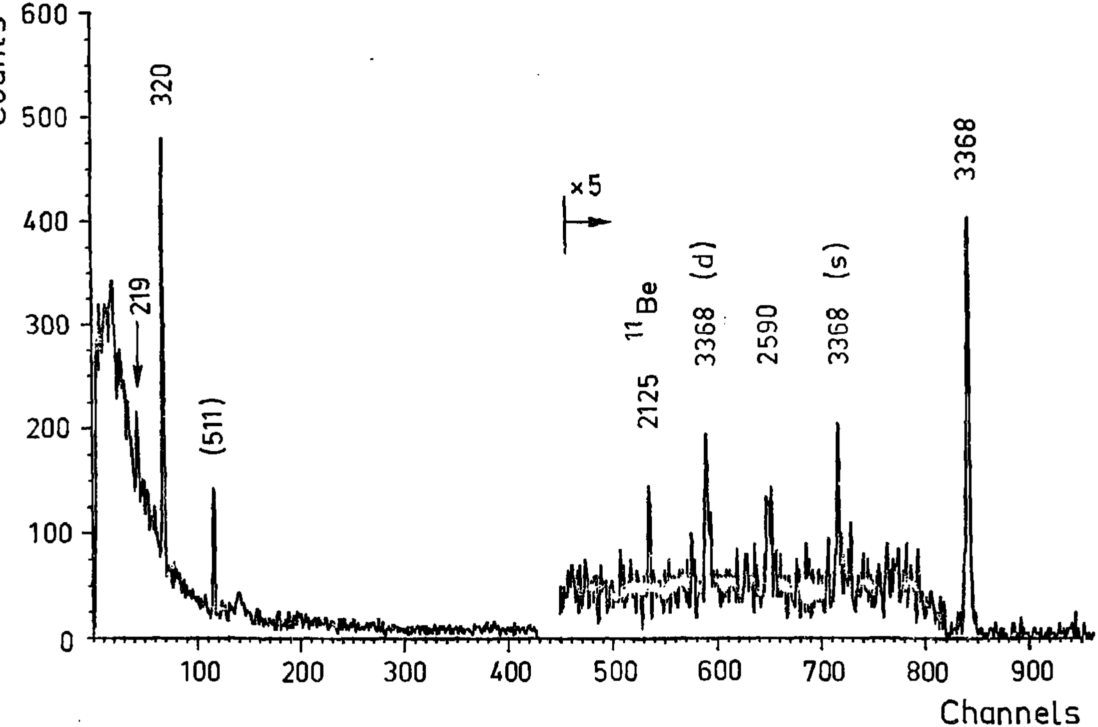
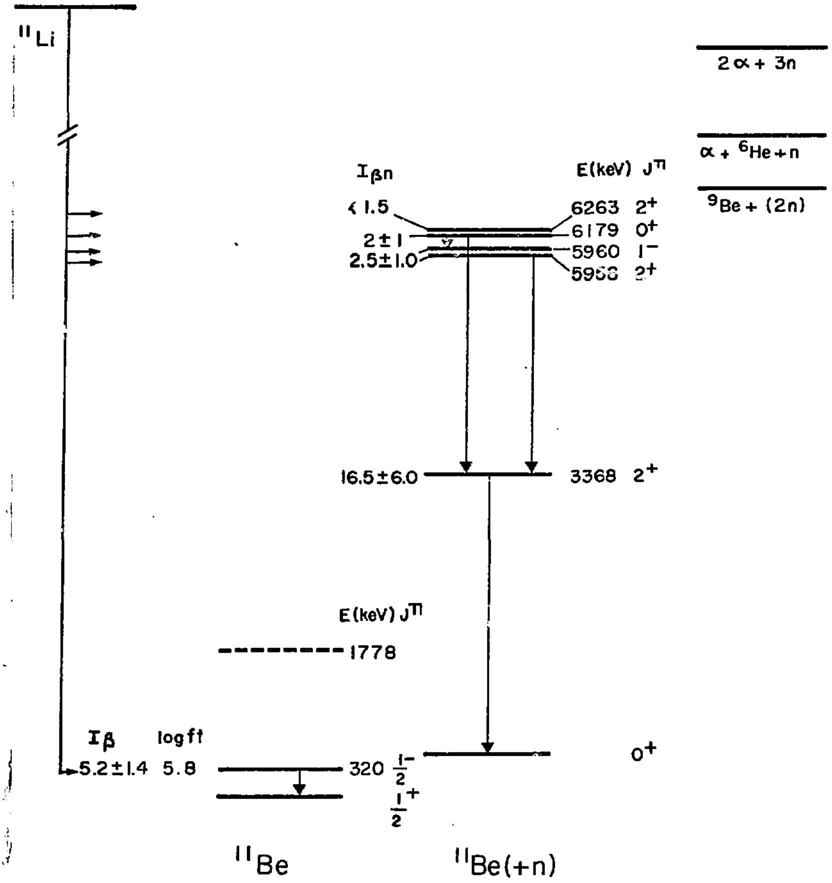

Counts
600
500
400
300
200
100
0
100
200
300
400
500
600
700
800
900
Channels
320
219
(511)
×5
2125
11Be
3368 (d)
2590
3368 (s)
3368

Fig. 7



11Li
2α + 3n
α + 6He + n
9Be + (2n)
Iβn
E(keV) Jπ
< 1.5
2 ± 1
2.5 ± 1.0
6263 2+
6179 0+
5960 1−
5958 2+
16.5 ± 6.0
3368 2+
E(keV) Jπ
1778
Iβ
log ft
5.2 ± 1.4
5.8
320 1/2−
1/2+
0+
11Be
11Be(+n)


fig 2