β-DELAYED CHARGED PARTICLES FROM ^{9}Li AND ^{11}Li

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Abstract

β-delayed emission of α particles from ^{9}Li and of both α and ^{6}He particles from ^{11}Li is observed. New β branches are reported which populate high-energy levels in the daughter nuclei. The branching ratios are measured and the β delayed neutron emission probabilities Pn for ^{9}Li and P_{3n} for ^{11}Li are deduced.

1. INTRODUCTION

The very high Q_β values of the particle stable ^{11}Li nucleus opens several new β-delayed channels. Indeed, multiple-neutron delayed emission was recently reported [1,2]. Besides the 2n emission, through the $^{11}Be^{x} \rightarrow {}^{9}Be + 2n$ channel with a threshold B_{2n} = 7.323 MeV, as much as five more exotic channels leading to beta-delayed charged particles are energetically allowed.

The weakness of β branches from ^{11}li to particle stable levels of ^{11}Be, and the occurence of multiple-neutron emission, indicate [3] a total neutron emission probability, $P_n = \sum_i i\, P_{in}$, close to 100 %. And indeed the previous value [4] of $P_n = 60.8 \pm 7.2$ % should be superseded by a recent measurement [5] of 95 ± 8 % which also indicates that the P_n value of ^{9}Li used for normalization was erroneous. Since all the excited states of ^{9}Be are unstable to neutron emission, the erroneous P_n value implies that a remeasurement of the β branches from ^{9}Li is in order. Actually, previous experiments [6,7,8] give different branching ratios to the ^{9}Be ground state. Furthermore there are theoretical predictions [9,10] of broad negative-parity states at low excitation energy in ^{9}Be which can be populated by β decay and are not yet definitely identified.

2. EXPERIMENTAL METHODS

The Li isotopes are formed in fragmentation reactions induced by 23 GeV protons from the CERN synchrotron in a 30 g/cm^2 thick iridium target. The Li atoms are selectively ionized, mass-separated on line, and focused onto a carbon collecting foil in a remote, well-shielded counting area [11]. The number of collected ^{11}Li ions is 10^3 per typical beam burst of 5×10^{12} incident protons. The much higher yields of ^{8}Li and ^{9}Li ions require a reduction of the ion beam intensity to avoid saturating the detectors. The β-delayed charged particles are detected by 300 mm^2 80 μm thick Si surface-barrier detectors in three types of experiments : β-coincident singles energy spectra in a well defined geometry ; time of flight measurements and particle-particle two-dimensional energy spectra in a very close geometry.

The very short (∼3 μs) fast-extraction beam pulses, spaced by at least 1.2s, allow the measurement of the time occurence of the β-delayed events, and hence theidentification of short half-lives

At low energy, β particles, and even some pile-up due to the high instantaneous counting rate, contribute to the singles energy spectra. The corresponding energy spectrum is measured for ^{8}Li where it is not obscured by low-energy α particles. It is accordingly subtracted from the energy spectra of ^{9}Li and ^{11}Li.

The number of collected Li ions per incident proton is recorded before and after each measurement by use of an electron multiplier automatically moved into the position of the carbon collecting foil. This information is used to derive an absolute value of each of the branching ratios of the β-delayed charged particles observed in the experiments.

3. ^{11}Li EXPERIMENTAL RESULTS

The energy spectrum of β-delayed charged particles from ^{11}Li is shown in fig. 1. It can contain contributions from different charged particles, α, ^{6}He, and even t, because of the various decay channels open.

To characterize these contributions, a two-dimensional E_1 versus E_2 energy spectrum is measured (fig. 2) for coincident charged particles observed within a short time (< 60 ms) after each beam burst. The contour drawn corresponds to the five-body phase space of the 3n + 2α break-up of a ^{11}Be excited state at 18.5 MeV. There are two regions of enhancement over a smooth distribution of events within this contour, one in the region $E_1 + E_2 \sim 2$ MeV, and the other at lower energy.

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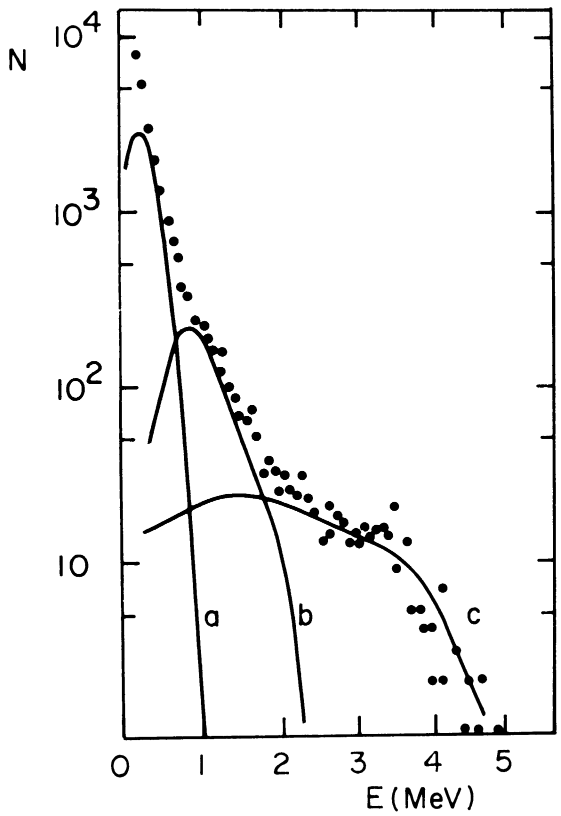

Fig. 1 - Energy spectrum of β-coïncident charged particles from ^{11}Li; Components a and b correspond to the processes a and b of fig. 3. Component c corresponds to β-delayed particles from an excited state at 18.5 MeV in ^{11}Be (process c of fig. 3).

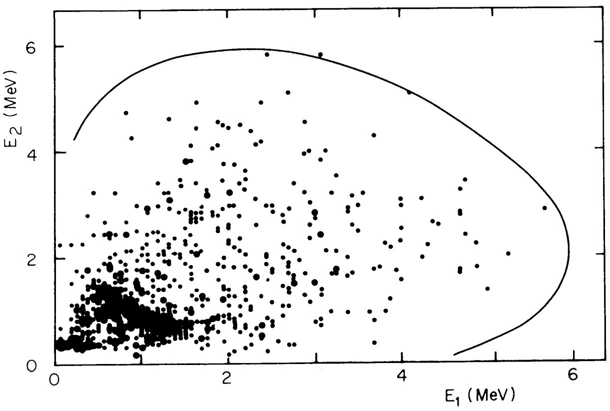

Fig. 2 - Two-dimensional E_1 versus E_2 spectra of two coïncident β-delayed charged particles from ^{11}Li. The contour drawn shows the phase-space limit for a 3n + 2α break-up of a 18.5 MeV excited state in ^{11}Be

This becomes clearly apparent if the two-dimensional spectrum is transformed into a $E_1 + E_2$ energy spectrum (fig. 3).

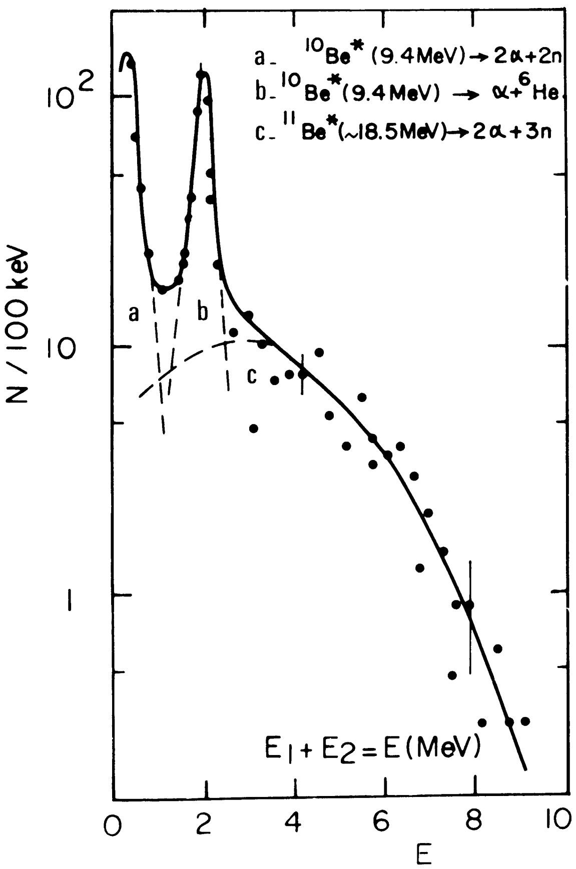

Fig. 3 - $E_1 + E_2$ spectrum of the events of fig. 2. The components a, b and c of fig. 1 are clearly distinguished. The enhancement of component 3 over a smooth phase space around $E_1 + E_2 \sim 3$ MeV indicates that the 2 α + 3n break-up proceeds at least partly through the 2.94 MeV 2^+ state of ^8Be.

The very narrow peak near 2 MeV can be readily explained by the two-body break-up ^{10}Be (9.4 MeV) → α + ^{6}He. This assignment is confirmed below by the time of flight measurement. The bump at lower energy would then correspond to the other open decay channel of the 9.4 MeV ^{10}Be state i.e. 2 α + 2n.

The kinematical spreading observed along the $E_1 + E_2 \sim 2$ MeV ridge of fig. 2 indicates that the neutron emitted in the preceeding $^{11}Be^{x} \rightarrow {}^{10}Be$ (9.4 MeV) + n decay has an energy close to 0.4 MeV, hence that the emitting ^{11}Be state lies at some 10.5 MeV excitation energy. This state can be identified with the 10.59 ± .05 MeV level observed [12] in $^{9}Be(t,p)^{11}Be$.

Similar two-dimensional energy spectra were also obtained for longer-lived activities (time elapsed after the beam burst larger than 60 ms). They exhibited two well-separated islands due to the β-delayed α + ^{7}Li break-up of the long-lived ^{11}Be daughter (fig. 4).

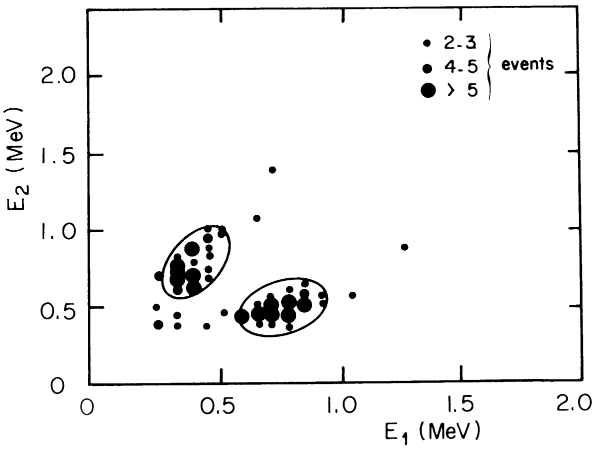

Fig. 4 - Two-dimensional E_1 versus E_2 spectra of coincident particles and ^{7}Li recoil nuclei from the β-delayed α + ^{7}Li break up of ^{11}Be. The contours drawn correspond to the expected location of events, taking into account the natural width of the $^{11}B^{x}$ (9,88 MeV) excited level.

The time of flight of the β-delayed charged particles is also measured (fig. 5).

The M = 4 locus (fig. 5a) is obtained by observing the β-delayed α particles from ^{9}Li. The deduced M = 6 locus is properly corrected for plasma delay effects. The results of fig. 5 give positive evidence for the emission of both α and ^{6}He β-delayed particles. The few counts in the lower left corner of fig. 5a cannot be securely assigned because of the unreliability of time-of-flight measurements at such extremely low energy. They might be due to the most energetic recoiling ^{9}Be nuclei.

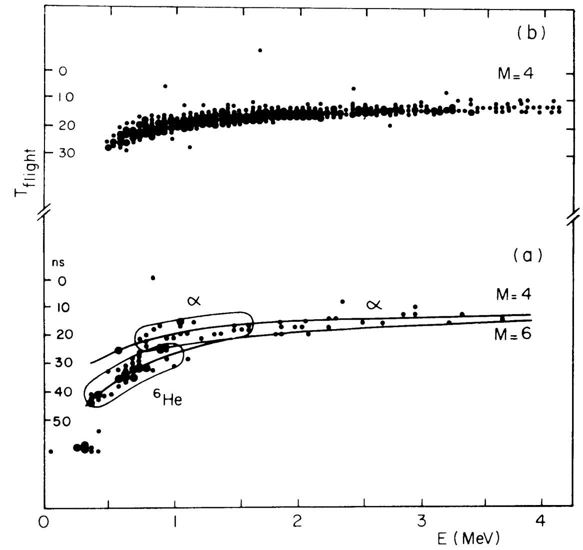

Fig. 5 - Two dimensional energy versus time-of-flight spectrum of β-delayed charged particles from ^{11}Li (fig. 5a) and ^{9}Li (fig. 5b). The loci for particles of mass 4 and 6 are indicated. The contours drawn (fig. 5a) correspond to the expected locations of events from the ^{10}Be 9.4 MeV state break-up into α + ^{6}He.

The branching ratios cannot be measured in the two-dimensional E_1, E_2 energy spectra since the detection efficiency strongly varies with the kinematics of the break-up. However, singles energy spectra provide a reliable value of the branching ratios. In fig. 1 the assignment of components a and b to the β-delayed decays ^{11}Be (∼ 18.5 MeV) → 2 α + 3n and ^{10}Be (9.4 MeV) → α + ^{6}He, respectively, is now unambiguous from the above analysis. The respective branching ratios are 0.30 ± 0.05 % and 0.9 ± 0.3 %. Component c corresponds to about 8 % of the number of ^{11}Li β-decays. It includes the ^{10}Be (9.4 MeV) → 2 n + 2 α break-up and the recoiling ^{9}Be nuclei from $^{11}Be^{x} \rightarrow {}^{9}Be$ + 2n. The recently reported[1,5] P_{2n} value of ^{11}Li leaves a branching ratio of 2.0 ± 0.6 % for the ^{10}Be (9.4 MeV) → 2n + 2 α break-up.

The results are summarized in the partial decay scheme of fig. 6.

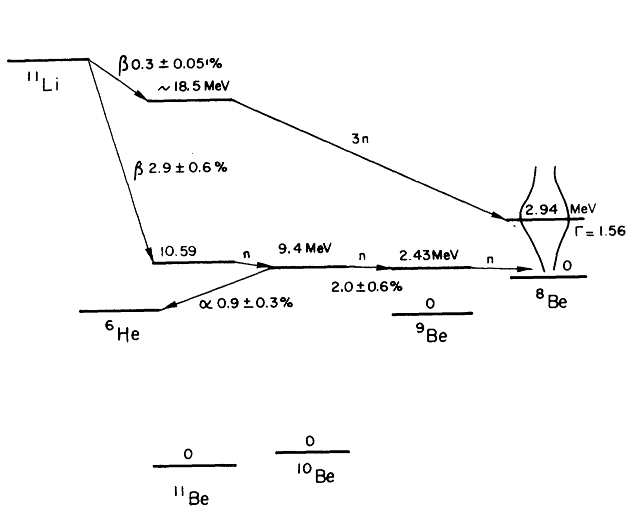

Fig. 6 - β-decay channels of ^{11}Li which are shown in the present work to account for the β-delayed charged particles observed. Their respective branching ratios are also indicated.

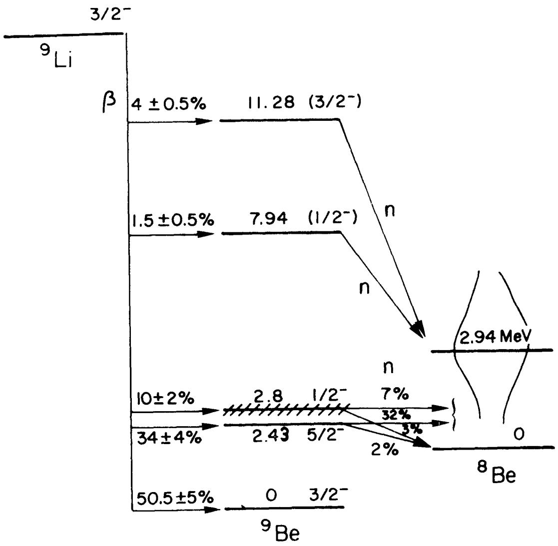

Fig. 7 - Decay-scheme of ^{9}Li including the branching ratios measured. Also represented are the two weak branches to the ^{8}Be ground state from the 2.43 and 2.78 MeV ^{9}Be levels previously measured [8,12] as 2 and 3 %, respectively, since their contribution to the energy spectrum cannot be observed in our experiment over the large β background at very low energy.

Further details on the experimental results and analysis are given in ref. 13).

4. ^{9}Li EXPERIMENTAL RESULTS

The occurence of a high energy component ending abrupt ly at about 5.5 MeV observed in the energy spectrum of β-delayed α particles from ^{9}Li shows a marked difference with previous results[8]. Single energy spectra and twodimensional energy spectra of coincident particles experimental results are obtained. A detailed analysis of these experimental results is given in ref.13. It leads to a new decay scheme for ^{9}Li (fig. 7).

5. CONCLUSION

New β branches from both ^{9}Li and ^{11}Li to high-energy levels of ^{9}Be and ^{11}Be, respectively are observed. The very low (~ 3.1) log ft values deduced from the β branching ratios of ^{9}Li → ^{9}Be (11.28 MeV) and ^{11}Li → ^{11}Be (18.5 MeV) could suggest that these levels of the daughter nuclei are anti-analog states of the parent's ground state.

The other log ft values deduced are not unusual for allowed Gamow-Teller transitions.

The observation of these new β branches put the P_n value of ^{9}Li at 49.5 ± 5% and the P_{3n} value of ^{11}Li at 2.3 ± 0.6%. Both values are in good agreement with the recent direct determination by neutron counting, 50 ± 4% (ref. 5) and 1.9 ± 0.2% (ref. 2), respectively.

The method used in this experiment often allows the identification of the excited states of the daughter nuclei associated with the β-delayed particle emissions. In the case of the ^{11}Li → ^{11}Be (10.59 MeV) β branch, the identification of an intermediate state, i.e. the 9.4 MeV excited state of ^{10}Be, in the three-neutron emission indicates that, for that case at least, the process is sequential.

A similar conclusion had been drawn earlier[16] for the two-neutron emission from a ^{10}Be compound nucleus.

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