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BETA-DELAYED TRITON EMISSION IN THE DECAY OF ^{8}He

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ABSTRACT

A β-delayed triton branch with an intensity of $(0.9 \pm 0.1)\%$ has been observed in the decay of ^{8}He. The triton energy spectrum was measured with a specially designed ΔE–E telescope. These data as well as an earlier measured β-delayed neutron spectrum cannot be explained from the known levels in ^{8}Li, but it turns out that the main features of both the delayed triton and the delayed neutron spectra from ^{8}He could be understood if one assumes a new state in ^{8}Li at about 8.8 MeV excitation energy.

E | Radioactivity ^{8}He: measured t spectrum, branching ratio for β-delayed tritons, new level in ^{8}Li assumed, n energy spectrum reinterpreted, log ft values.

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1. INTRODUCTION

Mass data[1)] show that β-delayed triton emission is energetically possible for some light isotopes and among them the best cases, which are due to high production yields, are the nuclides ^{11}Li and ^{8}He. The Q-value for the ^{8}He decay is 10.653 MeV[2)] and the thresholds for breakup of ^{8}Li into $\alpha + t + n$ and ^{5}He + t are 4.50 and 5.39 MeV, respectively.

A first attempt[3)] to measure β-delayed tritons in the decay of ^{8}He failed owing to interference both with α particles from the ^{8}Li daughter and with β-particles from the ^{8}He itself. Beta-delayed triton emission was first observed in the decay of ^{11}Li by Langevin et al.[4)] using a ΔE -E telescope. The same detector has been used in this work to search for β-delayed tritons in the decay of ^{8}He.

2. EXPERIMENTAL SET-UP

The ^{8}He activity was produced by fragmentation reactions in a 40 g/cm^2 thick thorium-oxide powder target bombarded by 600 MeV protons from the CERN Synchro-cyclotron. The target was equipped with a cooled transfer line so that only the noble gases could pass into the ion source of the on-line mass separator (ISOLDE). The ion beam from the separator corresponding to a yield of 1×10^5 ^{8}He ions was focused per second onto a 100 μg/cm^2 carbon-foil collector in front of the charged particle detector. The foil thickness was chosen so that it would stop 60 keV ^{8}He ions.

The ΔE–E telescope detector consisted of a 2 cm thick ΔE proportional counter filled with 30 mb propane (C_3H_8) gas with an 80 μg/cm^2 formvar window, and housing a 300 mm ^{2}–100 μm thick Si surface barrier detector. The solid angle of the detector was $0.02 \times 4\pi$ sr. The rate of registered events (ΔE–E coincidences) was about 100 per second. A schematic view of the set-up is shown in fig. 1.

Alpha particles from a ^{244}Cm source (E_α = 5.8 MeV) placed at the position of the collector foil were used for energy calibration. The energy losses in the different media (carbon foil, formvar window, 40 μg/cm^2 gold dead layer of the Si detector) which do not contribute to the signal were calculated from the Range and Stopping Power Tables[5)] of Ziegler. From the geometry of the system the average thickness of the ΔE detector was estimated to be 126 μg/cm^2 of C_3H_8. The uncertainty in the energy calibration for the ΔE detector is ~ 10%.

3. EXPERIMENTAL RESULTS

The two-dimensional (ΔE–E) spectrum obtained after two hours of data taking is shown in fig. 2. The spectrum shows β-background at low values of ΔE and E. There are also some random events scattered all over the spectrum owing to instabilities in the proportional counter, caused by the high counting rate. The ΔE–E energy distributions for α and t calculated from ref. 5 are in good agreement with the experimental spectrum. Gates were set according to the calculated distribution to select the tritons from the background. The selection of alphas was easily done because of the high counting rate compared to the background. In this way the tritons produced in eleven hours of data taking were selected. A total of 3535 ± 60 events were identified as tritons in the energy range from 0.6 to 3 MeV.

It is known[3)] that 84% of the ^{8}He β-decays feed the 0.981 MeV level of ^{8} Li (see the level scheme in fig. 3) followed by gamma-ray emission and ultimately the breakup of ^{8}Be into two alpha particles. The angle between these two alphas is > 170°, which implies that only one of the alphas from each decay is seen by the detector. Thus, by comparing the above number of tritons with the number of alphas $(651.1 \pm 0.8) \times 10^3$ we get a branching ratio for the β-delayed triton emission of (0.9 ± 0.1)%.

The triton energy spectrum is shown in fig. 4. No significant structure is observed in the spectrum. The presence of tritons of energy up to 3 MeV implies that a relatively highly excited state of ^{8}Li is strongly fed in the β-decay of ^{8}He. The study of the ^{9}Be(p,2p) ^{8}Li reaction by different authors[6)] indicates the existence of a broad excited level in ^{8}Li at 9 MeV ($\Gamma_{cm} = 6$ MeV, $J^\pi = 2^-$ or 1^-). However, for a level to be fed with reasonable strength in β-decay from the ground state of ^{8}He ($J^\pi = 0^+$, $T = 2$) a 1^+ state is needed. So we have assumed the existence of an excited level with $J^\pi = 1^+$, calculated the shape of the triton spectrum, and compared it with the measured one. From this fit the energy and width of the level could be derived. Once these parameters of the level are known a check can be made whether the resulting distribution of the neutron spectrum agrees with the measured one from ref. 3.

There are two possible branches for producing tritons:

$$\begin{tikzcd} {}^8\mathrm{He} \arrow[r, "\beta^-"] & {}^8\mathrm{Li}^* \arrow[r, "n"] \arrow[dr, "t"] & {}^7\mathrm{Li}^* \arrow[r, "t"] & \alpha & \text{(I)} \\ & & {}^5\mathrm{He} \arrow[r, "n"] & \alpha & \text{(II)} \end{tikzcd}$$

The shapes of the triton and neutron spectra were calculated in the following way:

i) The levels have been assumed to have Breit–Wigner shapes.

ii) The β-decay populates broad states in ^{8}Li asymmetrically since the Breit–Wigner shape of the level is weighted by the phase-space factor $f(Z,Q - E)$. In the calculation Wilkinson's parametrization[7)] of f was used.

The shape of the triton spectrum is obtained from an integration over the broad ^{8}Li excited level fed in the β-decay of ^{8}He and the intermediate state in ^{7}Li or the ground state of ^{5}He before the breakup into $\alpha + t + n$ particles. The penetrabilities for the charged particles are calculated according to Fröberg[8)] and for the neutrons from the formula of Blatt and Weisskopf[9)], and these were used to weight the different branches. For the light system studied here recoil effects are, of course, very important. A more detailed explanation of this calculation can be found elsewhere[10)].

A least squares adjustment to the experimental energy distribution of the triton spectrum was carried out, leaving free the width and energy of the new level assumed to be in the range 5–10 MeV.

The contribution of the first branch (I), if it exists, has to proceed via the 4.63 MeV ($J^\pi = 7/2^-$) level of ^{7}Li (see fig. 3). The branching ratio for the neutrons to this level, compared to the feeding to the 0.4776 MeV ($J^\pi = 1/2^-$) and the ground state ($J^\pi = 3/2^-$), is calculated to be 0.15%. Therefore this branch cannot account for the production of the tritons and has been disregarded in the first approximation.

The best fit to the energy distribution of the tritons is obtained considering an excited state in ^{8}Li at 8.8 MeV and with a FWHM of the Breit–Wigner shape equal to 1 MeV. The continuous line in fig. 4 gives the calculated distribution of tritons emitted from an 8.8 MeV level in ^{8}Li fed in the β-decay of ^{8}He.

In order to check the validity of our results and at the same time deduce the ft value of the 8.8 MeV level, we need to refit the measured neutron spectrum from ref. 3, considering the contribution of this new level. Recent studies of the response function for ^{3}He neutron spectrometers[11,12)] used in ref. 3 show an unexpected structure at energies lower than about 400 keV. Therefore this part of the neutron spectrum ($E < 0.4$ MeV) will be disregarded from here on. Bjørnstad et al.[3)] calculated the shape of the neutron energy spectrum from the 3.21 MeV level and considered the 5.4 MeV state as a good candidate to explain the high-energy part of the neutron spectrum. Their fitting to the neutron data is shown in the inset of fig. 5. In the present work, we have calculated the neutron energy spectra from the 3.21, 5.4, and 8.8 MeV levels. For the 5.4 and 8.8 MeV levels two different neutron spectra are obtained, one from the decay of the state into $\alpha + t + n$ and the other from the feeding to the first excited and ground states of ^{7}Li. These five contributions once normalized were fitted to the experimental neutron spectrum. The coefficients obtained for the best fit give the branching ratio to these levels in the decay of ^{8}He (the branching ratio of β-delayed neutron emission is known to be 16%); from the branching ratio, the log ft values are deduced. To take into account that these excited levels of ^{8}Li have a certain width ($\Gamma_{cm} \approx 1$ MeV) we have calculated an average log ft value by integrating the phase-space factor$^{7)}$ over the profile of the state. The results obtained are shown in table 1. Once the relative contribution of each component is known we can deduce the feeding to the 0.4776 MeV excited state of ^{7}Li. The calculated value is 30.3%, in good agreement with the experimental one$^{3)}$ of (32 ± 3)%. It should be noticed that the decrease in the relative feeding to this level from the 8.8 MeV level compared to the one from the 5.4 MeV level is due to the influence of the phase-space factor. The very low branching ratio for the 5.4 MeV level justified, *a posteriori,* that the triton spectrum was fitted with only the contribution of the 8.8 MeV level. From this fit the contribution of tritons of energies lower than 0.6 MeV has been estimated to be 4% of the number of detected tritons (see fig. 4). This possible contribution has been included in the error bars given to the value of the branching ratio. From the calculated neutron spectrum, the branching ratio of the 8.8 MeV level for the breakup into ^{5}He + t is (6.4 ± 1.3)% of the total feeding to the level. Therefore the value deduced for the β-delayed triton emission is (0.78 ± 0.15)%, in good agreement with the experimental value found from the comparison between the alphas and the tritons.

4. CONCLUSIONS

Beta-delayed triton emission was detected in the decay of ^{8}He by means of a telescope detector. The branching ratio for this decay mode is (0.9 ± 0.1)%.

The measured neutron$^{3)}$ and triton spectra from the ^{8}He decay cannot be understood using the known level scheme of ^{8}Li. In an attempt to describe the triton spectrum we have assumed a level in ^{8}Li at 8.8 MeV excitation energy ($\Gamma_{cm} = 1$ MeV). Such a state is not observed in reaction data and we cannot make a firm claim of its existence. We note, however, that also the neutron energy spectrum and the branching ratios obtained in a calculation with such a level are in good agreement with our data. With the present information we cannot speculate further about the new level but it may be worth while to make a new careful search for it in nuclear reaction experiments. Our reinterpretation of the neutron spectrum also produced new log ft values of the 3.21 and 5.4 MeV levels. The value of 5.0 found for the 3.21 level confirmed the assignment to this level as 1^+. For the assumed level at 8.8 MeV the log ft value found would be 4.3, which implies a positive parity and spin 1.

DEDICATION

We dedicate this work to our co-author and friend Michel Langevin who died suddenly in April 1985 some weeks after the completion of this experiment.

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Table 1

Levels in ^{8}Li used to fit the β-delayed neutron spectrum of ^{8}He

Levels in ^{8}Li (MeV)	Γ_{cm} (MeV)	Neutron feeding to 0.48 MeV state in ^{7}Li (%)	β-feeding (I_n = 16%)	log ft
3.21	1.0	29.4	3.7	5.0
5.4	0.65	41.7	4.8×10^{-3}	7.5
8.8	1.0	30.6	12.3	4.3

Figure captions

Fig. 1 Schematic view of the experimental set-up. The solid angle of the (ΔE–E) telescope detector is $0.02 \times 4\pi$ sr.

Fig. 2 Two-dimensional ΔE–E spectrum of charged particles associated with the β-decay of ^{8}He. The spectrum corresponds to two hours of data taking. The calculated losses of energy for alphas and tritons (continuous line shown in the figure) are in agreement with the experimental distributions shown in this picture. The theoretical energy losses in the different media were used to distinguish the tritons from the background in the areas of low intensity.

Fig. 3 Decay scheme of ^{8}He proposed in this work. The figure shows the branching ratio deduced for the levels fed in the β^--decay of ^{8}He. Most of the energies, spins, and parities shown in this picture come from ref. 2.

Fig. 4 The experimental and calculated energy spectrum of β-delayed tritons emitted in the ^{8}He decay. The experimental points include error bars coming from pure statistical considerations. The theoretical curve (continuous line) has been calculated assuming that the tritons from an 8.8 MeV level in ^{8}Li (1 MeV broad) feed the ground state of ^{5}He (Γ_{cm} = 0.6 MeV) which breaks up into $\alpha + n$.

Fig. 5 Experimental and calculated energy spectrum of β-delayed neutrons from ^{8}He. The data are taken from the work of Bjørnstad et al.[3] and the continuous line is the theoretical fit obtained in this work considering the decay from a) the 3.21 MeV and b) the 8.8 MeV levels of ^{8}Li into ^{7}Li + n, and c) the 8.8 MeV level decay into $\alpha + t + n$. The contribution of the 5.4 MeV level of ^{8}Li is too small to be distinguishable from the axis line. The inset shows the fit done in ref. 3. The bad fit at low energies is not fully understood but it is most likely due to the effect of the recently found structure in the response function of the neutron spectrometer[11,12] used in ref. 3.

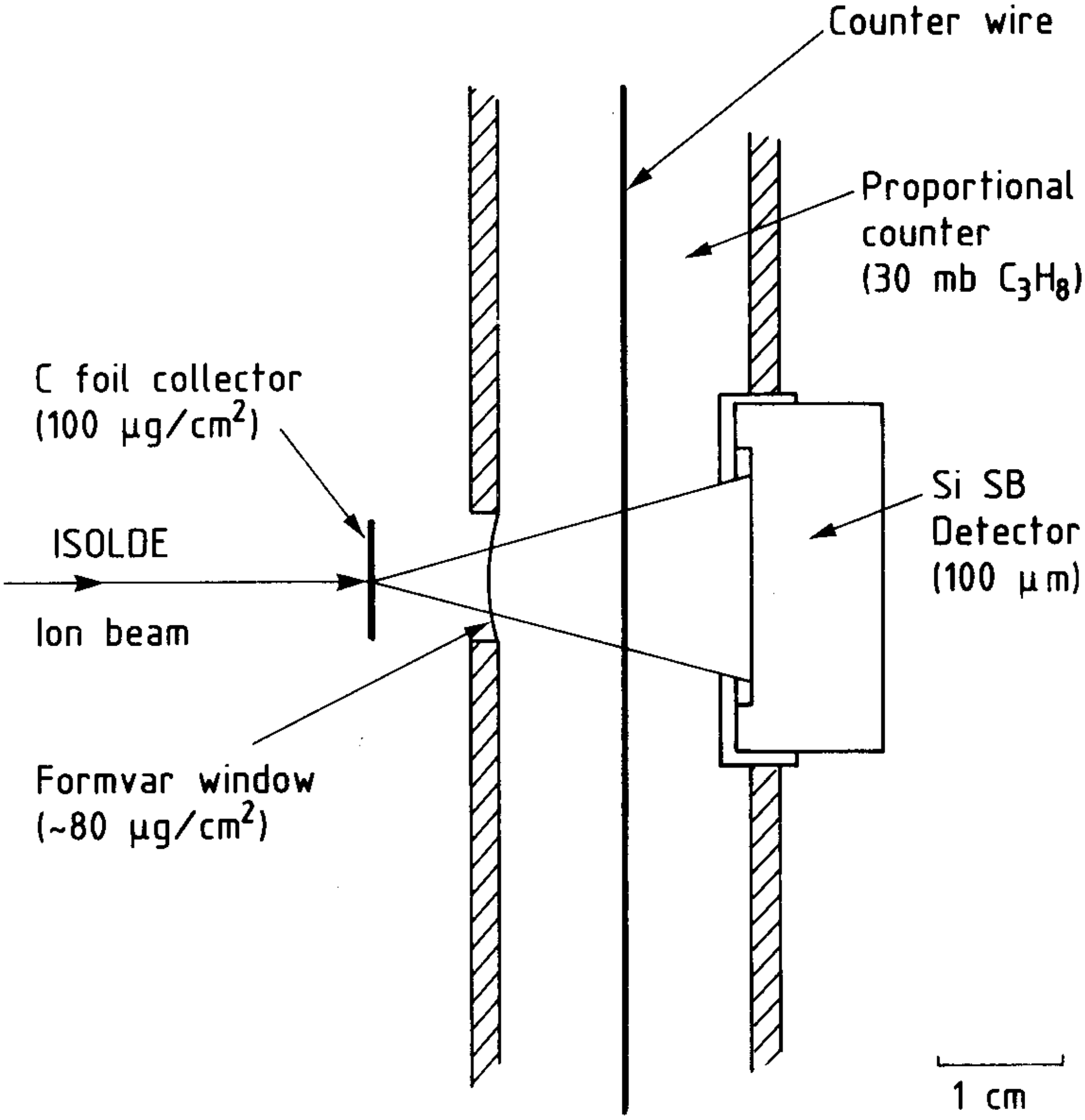
Counter wire
Proportional counter
(30 mb C3H8)
C foil collector
(100 µg/cm2)
ISOLDE
Ion beam
Si SB Detector
(100 µm)
Formvar window
(~80 µg/cm2)
1 cm

Fig. 1

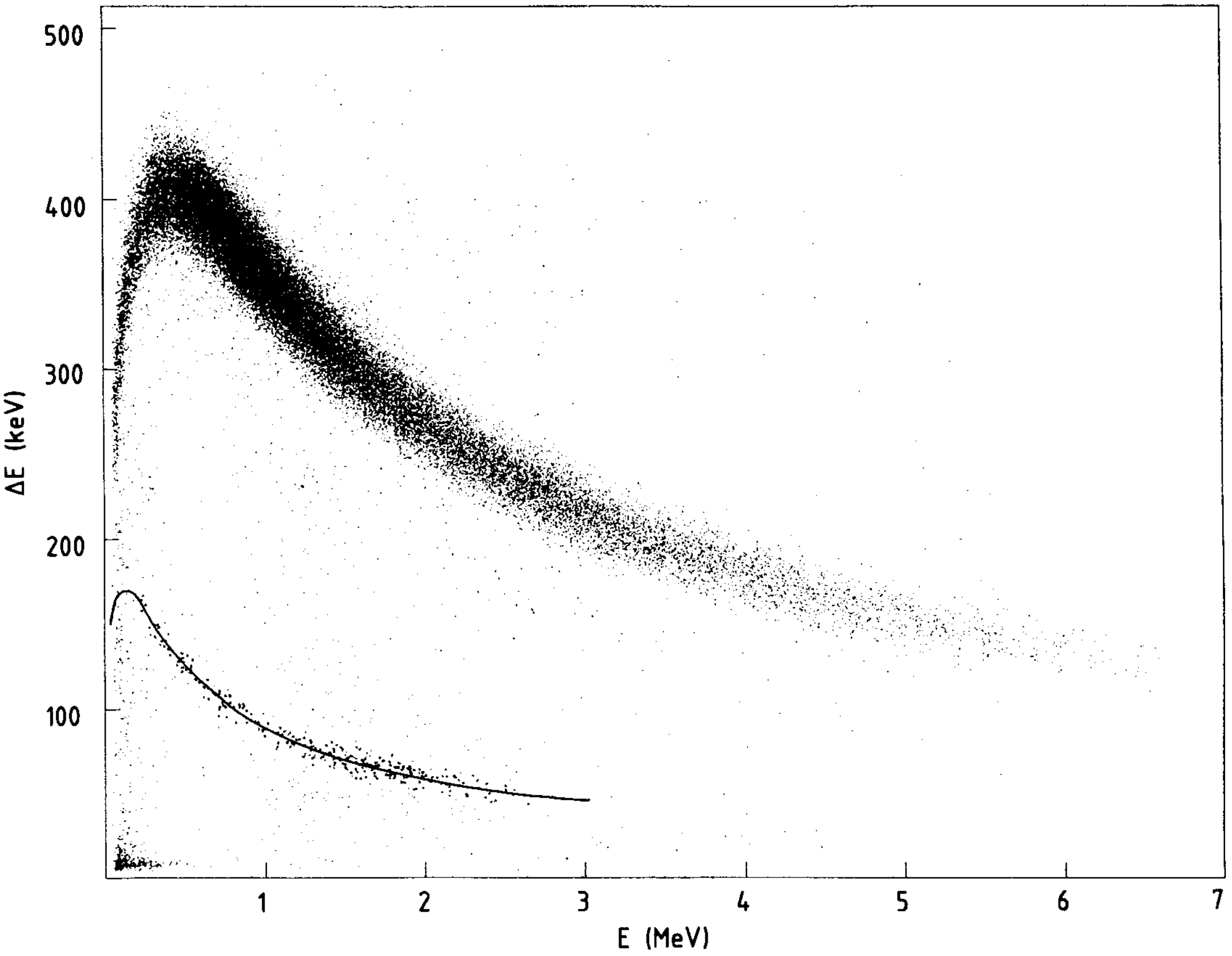

Fig. 2

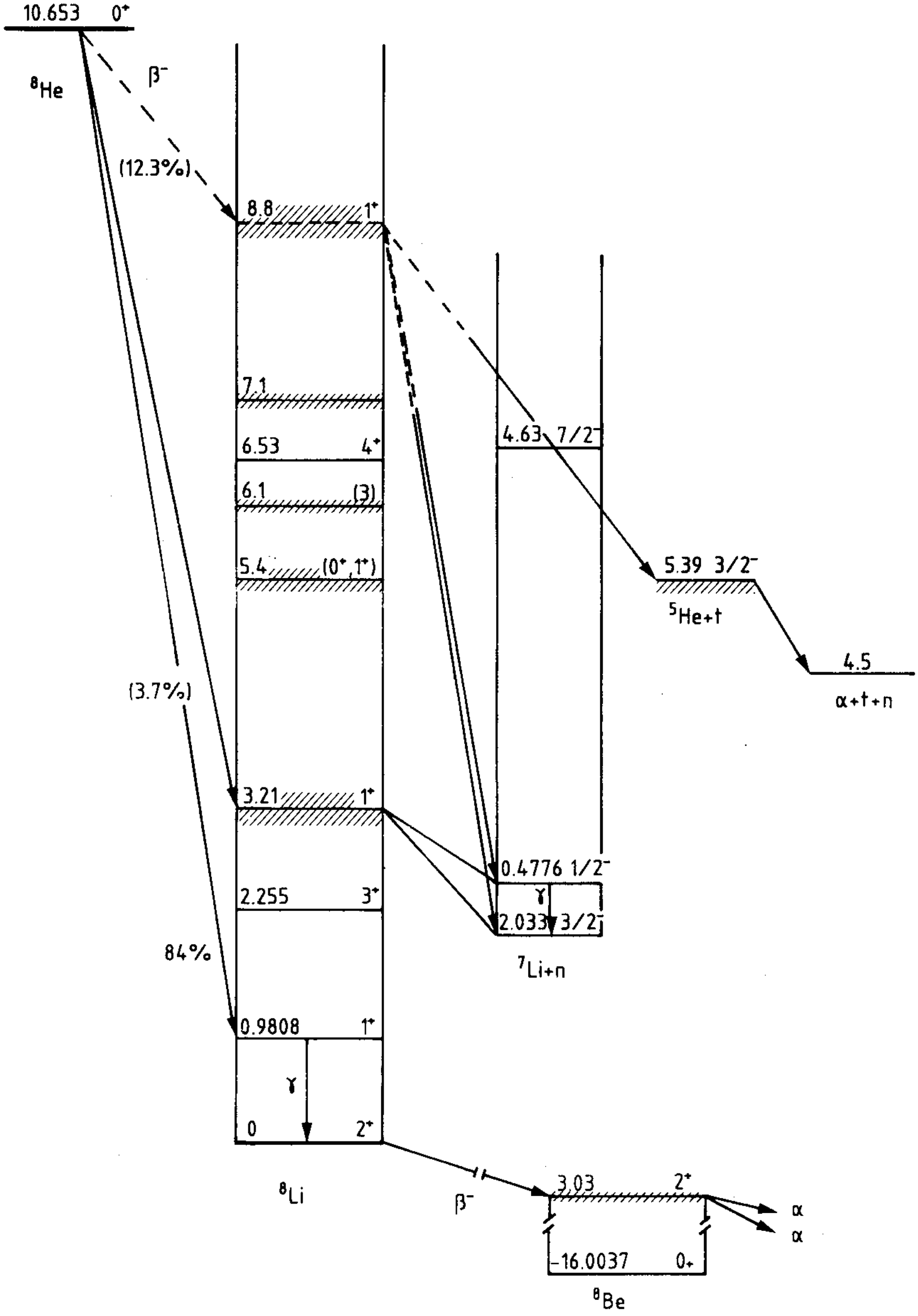
10.653 0⁺
⁸He
β⁻
(12.3%)
(3.7%)
84%
8.8 1⁺
7.1
6.53 4⁺
6.1 (3)
5.4 (0⁺, 1⁺)
3.21 1⁺
2.255 3⁺
0.9808 1⁺
γ
0 2⁺
⁸Li
4.63 7/2⁻
0.4776 1/2⁻
γ
2.033 3/2⁻
⁷Li+n
5.39 3/2⁻
⁵He+t
4.5
α+t+n
β⁻
3.03 2⁺
α
α
−16.0037 0+
⁸Be

Fig. 3

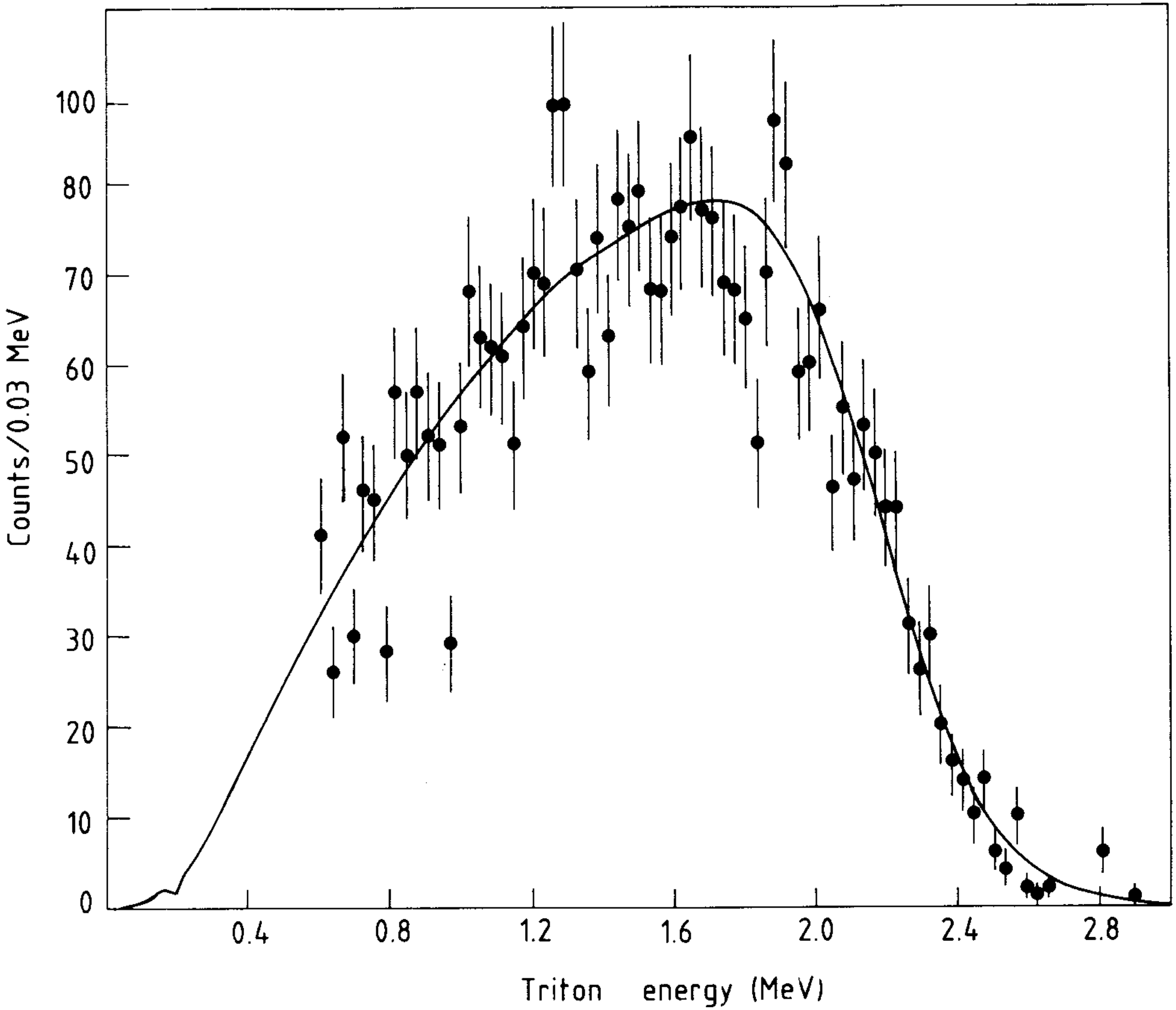
Counts/0.03 MeV
100
80
70
60
50
40
30
20
10
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
Triton energy (MeV)

Fig. 4

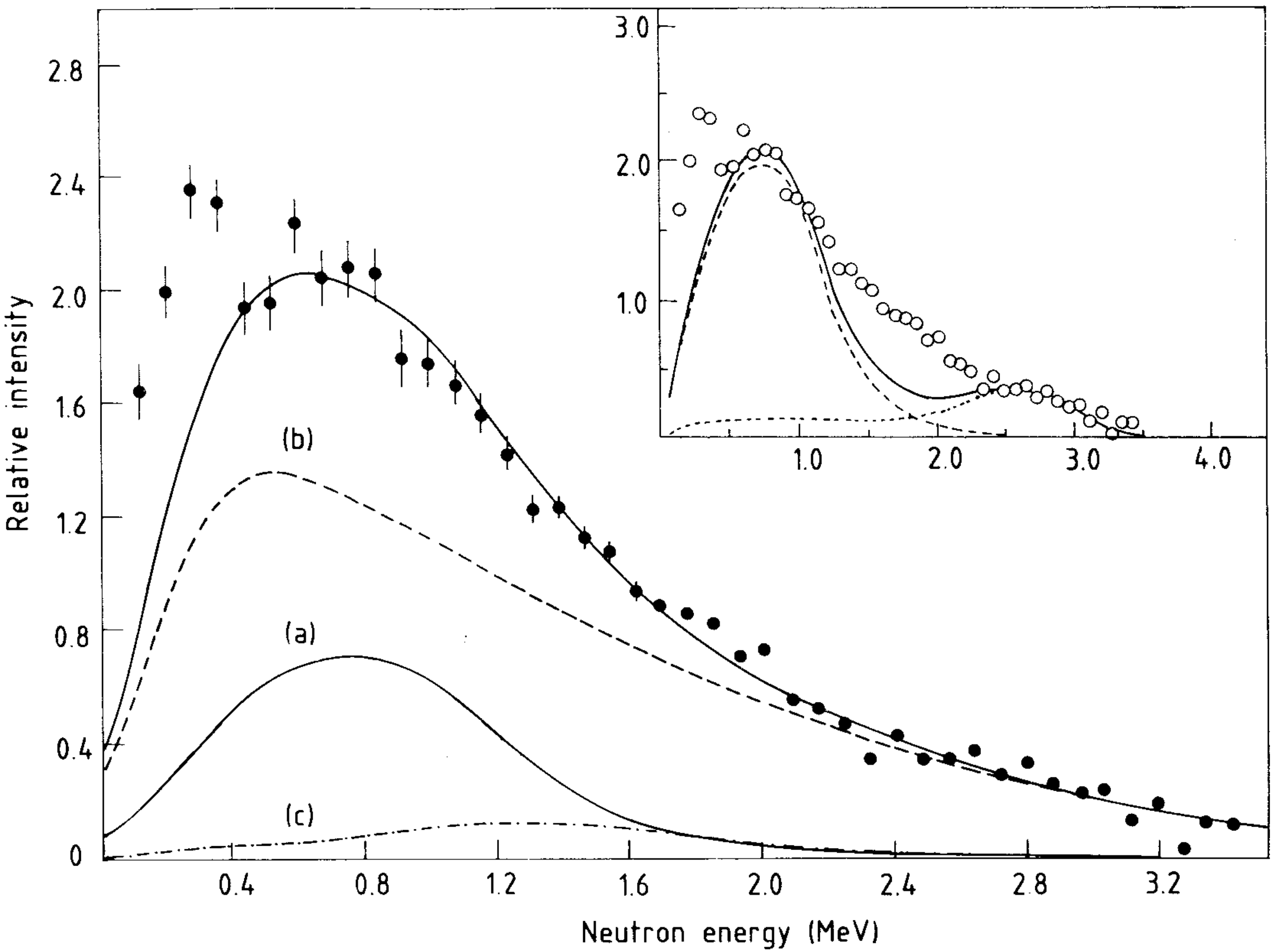
Relative intensity
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
Neutron energy (MeV)
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
(a)
(b)
(c)
1.0
2.0
3.0
1.0
2.0
3.0
4.0

Fig. 5