THE β–DECAY OF ^{8}B, AND 2^+ STATES OF ^{8}Be

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[*Manuscript received May* 12, 1969]

Summary

The β-decay of ^{8}B has been investigated by measuring the energy distribution of the α-particles from subsequent breakup of ^{8}Be. The data have been analysed, in conjunction with data from α–α elastic scattering, in a three-level R-matrix formalism. Consistent fits are obtained for a channel radius of $6 \cdot 0 \pm 0 \cdot 5$ fm, and the existence of a broad 2^+ state of ^{8}Be near $12 \cdot 0$ MeV, of width 14 MeV, is confirmed.

I. Introduction

The level structure of the nucleus ^{8}Be in the one-channel region below $17 \cdot 25$ MeV has recently been examined in detailed R-matrix analyses (Barker, Hay, and Treacy 1968; Barker 1969). In addition to the well-known sequence of levels of spin–parities (channel energies) 0^+ ($0 \cdot 092$ MeV), 2^+ ($2 \cdot 99$ MeV), and 4^+ ($11 \cdot 5$ MeV) there is evidence for broad 0^+ and 2^+ states near 6 and 9 MeV respectively. These states are very broad, of widths about 10 MeV, and probably do not belong to the lowest shell-model configuration. In order to determine R-matrix channel radii, and consequently level parameters, it is necessary to study simultaneously scattering and reaction data. Thus Barker (1969) analysed in detail the 2^+ states in α–α scattering and both ^{9}Be(p, d)^{8}Be and ^{8}Li β-decay; with these reactions the optimum channel radius was found to be near $7 \cdot 1$ and $6 \cdot 7$ fm respectively, with an overall acceptable range of $6 \cdot 3$–$8 \cdot 0$ fm.

As has been emphasized by Barker (1969), the β-decays of ^{8}Li and ^{8}B provide perhaps the most favourable and unambiguous reaction data for studying 2^+ states of ^{8}Be. The former reaction, studied in detail by Alburger, Donovan, and Wilkinson (1963), has already been referred to. It was thought worth while to obtain data from the latter reaction. Apart from studies of transitions to the well-known narrow levels at $16 \cdot 6$ and $16 \cdot 9$ MeV in ^{8}Be (Matt *et al.* 1964), no accurate data are available on this process. The work described here consists of a measurement of the α-particle energy spectrum following the reaction

$$^6\mathrm{Li}+{}^3\mathrm{He} \rightarrow \mathrm{n}+{}^8\mathrm{B} \xrightarrow{(\beta^+)} \mathrm{n}+{}^8\mathrm{Be} \rightarrow \mathrm{n}+\alpha+\alpha \tag{1}$$

for states of ^{8}Be corresponding to channel energies up to 14 MeV. The experimental method is described in Section II, and the corrections applied for energy losses in absorbers are discussed in Section III. Finally, results of many-level R-matrix fits are given in Section IV and discussed in relation to other similar analyses.

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II. Experimental Procedure

A 3·5 MeV ^{3}He beam from the ANU Tandem Van de Graaff accelerator was passed through narrow collimating slits on to a target of lithium oxide (enriched to 99·6% ^{6}Li) of surface density about 20 μg cm^{-2}, backed by a nickel foil of nominal thickness 50 μin. The normal to the target face was at 50° to the beam. The kinematics of the reaction (1) dictated that, at the beam energy used, all the ^{8}B nuclei formed recoiled forwards in a cone of semi-angle 10·9° and stopped within the nickel backing. A surface-barrier detector for detecting α-particles from decay of ^{8}Be nuclei was placed behind and facing the nickel backing, normal to the target plane. Pulses from the detector were amplified and fed to a multichannel pulse-height analyser.

The half-life of ^{8}B is 0·774 sec (Lauritsen and Ajzenberg-Selove 1966) and, for the purpose of detecting the α-particles, the beam was interrupted by a shutter rotating at 85 r.p.m. and located 300 cm upstream from the target, so that in each cycle the beam was on and off successively twice for about 0·17 sec. A gating signal generated by a micro-switch at the shutter enabled the pulse-height analyser to be activated during only the beam "off" times. In addition a pneumatic shutter, suitably synchronized, was placed so as to intercept radiations to the detector from the target during the "on" cycle. This, while not essential to the experiment, preserved the detector from considerable unnecessary beam and heavy-ion bombardment during target irradiation.

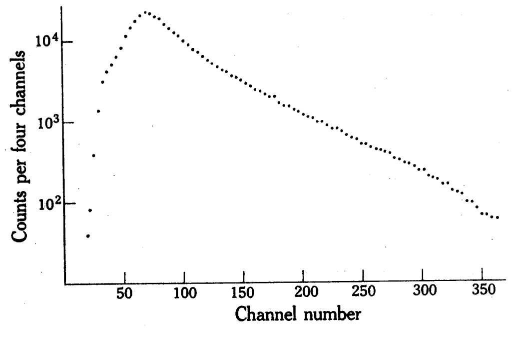

Fig. 1.—"Raw" spectrum of α-particles obtained from the β-decay of ^{8}B. The abscissa scale is 25·2 channels per MeV of channel energy in ^{8}Be. No corrections have been made for energy losses.

The energy scale of the detector was calibrated using 6·043 and 8·776 MeV α-particles from a Th C+C′ source. This was placed in the target position at intervals between runs and a spectrum recorded under conditions closely resembling those of an actual beam run. An α-particle spectrum obtained from the process (1), representing approximately 40 hr running time, is shown in Figure 1. No corrections for energy losses have been applied to the data; the calibrated abscissa scale is 25·2 channels per MeV channel energy in ^{8}Be. For display, points are plotted every four channels, i.e. at intervals of approximately 0·16 MeV.

III. Corrections to Experimental Spectrum

The kinematic spread of ^{8}B energies due to centre-of-mass motion from the ^{6}Li(^{3}He, n) reaction at 3·5 MeV ^{3}He energy is from 1·479 to 0·672 MeV. The corresponding ion ranges were calculated (see Warburton, Olness, and Jones 1966) to be 923 and 579 μg cm^{-2} of nickel. Using these values and assuming isotropy of the ^{8}B recoils (because of the nearness of the beam energy to the reaction threshold at 3·0 MeV), it was possible to determine the distribution of stopped ^{8}B ions in the nickel backing of the target. In addition, allowance was made for range straggling using data interpolated from the results of Powers and Whaling (1962). Using α-particles from a source of ThC+C′, the surface density of the target backing and of the gold layer at the face of the counter were found to be 1095 ± 30 and 41 ± 2 μg cm^{-2} respectively. It was thus possible to calculate the mean energy loss of α-particles entering the detector from ^{8}Be states formed in the target backing. In order to obtain a corrected α-particle spectrum from Figure 1 it was necessary to correct for energy losses by some form of iteration. The following method was adopted for this purpose.

The experimental spectrum of Figure 1, regarded as an approximate unperturbed spectrum, was modified at all α-energies for energy losses from the distribution of stopped ^{8}B ions already determined and a resultant "degraded" spectrum was obtained.* From it and the experimental spectrum an "original" spectrum was deduced by linear extrapolation. This original spectrum is plotted in Figure 2 as a

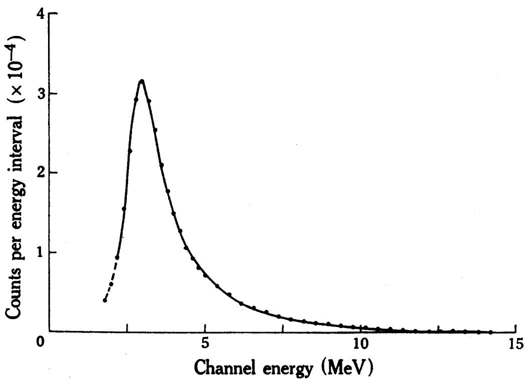

Fig. 2.—Corrected α-particle spectrum from the β-decay of ^{8}B. The full curve represents a theoretical fit, as described in Section IV, to data for channel energies upwards of 2·2 MeV.

function of ^{8}Be channel energy. Consistency of the procedure used in obtaining this spectrum was checked by applying corrections for energy losses to it; the spectrum of Figure 1 was reproduced satisfactorily to an error of less than 0·3% in the region of the main peak. Thus the points of Figure 2 represent our final corrected spectrum of α-particles from ^{8}B decay, which is to be fitted in terms of the β-decay process and the known ^{8}Be states.

IV. Analysis of Results

A detailed fit of data from α–α elastic scattering combined with reaction data involving ^{8}Be final 2+ states has been undertaken by Barker (1969). Among other processes, he investigated the β-decay of ^{8}Li studied by Alburger, Donovan, and Wilkinson (1963). Since we followed his method exactly—his computer programme being available for this analysis—the present discussion will lean on his, both for method and notation, and no attempt at completeness will be made.

* For convenience in this analysis a uniform channel-energy interval of 0·2 MeV over the peak was adopted.

Firstly, three-level fits were obtained to α–α scattering data and a range of sets of level parameters E_λ and γ_λ^2 were obtained for different channel radii with the boundary condition parameter $B_2 = 0$. Next, knowing the widths and positions of the 16·6 and 16·9 MeV levels, feeding amplitudes were obtained to these levels for experimentally observed ^{8}B β-decays to them (Matt *et al.* 1964). Finally, feeding amplitudes, designated by Barker as g_{1G} and g_{2G}, for Gamow–Teller transitions to the lowest two levels in the present experiment, were obtained for all the relevant sets of E_λ and γ_λ^2 at each channel radius. The third level was assumed to be not fed in this process. Best simultaneous fits to all these data were obtained by an analysis of errors defined by the quantities X_2, Y_2, and Z_2 as follows.

For fits to α–α scattering X_2 was defined as a sum of weighted squared deviations divided by the number of degrees of freedom, i.e.

$$X_2 = (N-n)^{-1} \sum \{(\delta_{\exp}-\delta_{\mathrm{calc}})/\epsilon\}^2, \tag{2}$$

where N and n are numbers of data points and of free parameters, $\delta_{\exp}$ and δ_{calc} are the observed and calculated phase shifts, and ϵ is the assigned error. The quantity Y_2 is that correspondingly defined for the ^{8}B β-decay process of the present experiment,

TABLE 1

VARIATION OF Z_2 AS A FUNCTION OF CHANNEL RADIUS a_2

$Z_2 = X_2 + 0\cdot3\ Y_2$ is a measure of the quality of simultaneous three-level fits to the α–α elastic scattering and ^{8}B β-decay data for various values of the channel radius a_2. For each value of the eigenenergy E_1 there is a set of corresponding energies E_λ and reduced widths γ_λ^2 of all three levels. The bold values are best fits (see Table 2)

a_2				Z_2				
(fm)	$E_1 = 2\cdot45$	2·475	2·50	2·525	2·55	2·575	2·60	2·625 MeV
5·5	3·680	2·725	**2·576**	3·469	5·510	8·907		
6·0		9·422	5·289	2·772	**1·739**	2·441	4·451	8·701
6·5			8·923	5·187	3·431	**3·368**	5·622	10·72
6·75				10·49	8·630	9·785	11·82	18·81
7·0					28·40	26·26	26·10	29·4

for data fitted for channel energies upwards of 2·2 MeV; lower values were omitted as they may contain systematic errors in energy losses. (Barker's quantity Y_{2+}, being constant here, was neglected.) The smallest value of X_2 found was near 0·4, and of Y_2 near 1·2, so as a suitable criterion of overall fit the quantity

$$Z_2 = X_2 + 0\cdot3\ Y_2 \tag{3}$$

was chosen. This quantity is listed for a range of channel radii in Table 1. The optimum fit (channel radius $a_2 = 6\cdot0$ fm, lowest eigenenergy $E_1 = 2\cdot55$ MeV) is plotted in Figure 2 and is very close to the data, as judged by eye. Table 2 contains sets of all level parameters corresponding to three fits (bold values) in Table 1, together with implied $\log ft$ values of the levels. For the fit plotted in Figure 2, the peak, due essentially to level 1, is at 2·95 MeV and of width 1·45 MeV; these numbers would not be significantly affected were level 2 not fed in the β-decay process.

The required E_1 value for the fits to our data is rather low. However, from numerical fitting, no evidence was found that the assumption of an error in channel energy could improve the fit. This is evidently so because an increase in abscissa in Figure 2 would require level parameters (chosen from fits to scattering data) such as to *broaden* the peak and result in a poorer overall fit (higher Z_2). This is in contradistinction to the case of ^{8}Li decay as analysed by Barker and displayed in his Figure 5.

TABLE 2

VALUES OF LEVEL PARAMETERS CORRESPONDING TO BEST FITS

The best fits are shown bold in Table 1

a_2 (fm)	E_1 (MeV)	γ_1^2 (MeV)	E_2 (MeV)	γ_2^2 (MeV)	E_3 (MeV)	γ_3^2 (MeV)	$\log(ft)_1$	$\log(ft)_2$
5·5	2·50	0·7140	13·54	1·223	177·7	18·41	5·778	4·388
6·0	2·55	0·5381	10·73	1·004	67·30	6·001	5·813	4·906
6·5	2·575	0·4182	8·793	0·8221	37·71	2·906	5·847	5·138

From the results of Table 1, taking as confidence limits a doubling of Z_2 as defined in (2) and (3), it follows that simultaneous acceptable fits to α–α scattering and ^{8}B β-decay are obtained with $a_2 = 6\cdot0\pm0\cdot5$ fm. The corresponding position of level 2, if it were fed alone, would be $12\cdot0^{-3\cdot0}_{+3\cdot5}$ MeV, and its width 14^{-3}_{+4} MeV. This is in reasonable agreement with Barker's analyses, which led to rather lower values of position and width, namely 9 and 10 MeV respectively, corresponding to the larger optimum channel radius $a_2 \approx 6\cdot75$ fm chosen by him.

V. ACKNOWLEDGMENT

We thank Dr. F. C. Barker for assistance and advice on the analyses of the data and for helpful discussions on the interpretation of this work.

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