PHYSICAL REVIEW C VOLUME 17, NUMBER 5 MAY 1978

Core excited $T = 2$ levels in $A = 12$ from studies of ^{12}Be[†]

D. E. Alburger[*]
Brookhaven National Laboratory, Upton, L.I., New York 11973

D. P. Balamuth, J. M. Lind, L. Mulligan, K. C. Young, Jr., R. W. Zurmühle, and R. Middleton
Physics Department, University of Pennsylvania, Philadelphia, Pennsylvania 19104

(Received 9 December 1977)

Levels of ^{12}Be have been studied using the $^{10}\text{Be}(t,p)^{12}\text{Be}$ reaction. The spin of an excited state at $E_x = 2.110 \pm 0.015$ MeV is determined model independently as $J = 2$ using a measurement of the proton-γ angular correlation in an axially symmetric geometry. A mechanically chopped beam was used to study β activity following the irradiation of ^{10}Be by 12 MeV tritons. A least squares analysis of the resulting decay curve yields $T_{1/2}(^{12}\text{Be}) = 24.4 \pm 3.0$ msec. A ^{3}He neutron detector was used to search for delayed neutrons; a 1σ upper limit on a delayed neutron branch of 1% is obtained. The above results support the suggestion that low-lying states in ^{12}Be involve the excitation of particles into the $1s$-$0d$ shell.

NUCLEAR REACTIONS $^{10}\text{Be}(t,p\gamma)$, $E = 12$ MeV measured $\sigma(E_p)$, $p\gamma(\theta)$, E_γ. ^{12}Be deduced levels, J, π. Enriched target.
RADIOACTIVITY ^{12}Be [from $^{10}\text{Be}(t,p)$]; measured $T_{1/2}$ from β activity. Searched for delayed neutrons.

I. INTRODUCTION

The structure of the low-lying $T = 2$ levels in the $A = 12$ system has been an important open problem in nuclear physics for some time. One source of the difficulty lies in the fact that to date all attempts to observe $T = 2$ levels in ^{12}C as resonances in the isospin forbidden channels $^{10}\text{B} + d$, $^{11}\text{B} + p$, and $^9\text{Be} + {}^3\text{He}$ have been unsuccessful.[1-3] A possible explanation for this fact is provided by the work of Barker,[4] who has suggested that the low-lying $T = 2$ levels in $A = 12$ may contain two particles excited to the ($1s$-$0d$) oscillator shell. Such states would presumably have small reduced widths for particle decays to the ground states of p-shell nuclei. Also, $M1$ decays to $T = 1$ levels would be weakened because of the predominantly p-shell character of the $T = 1$ levels. Barker cites as additional evidence in support of this argument the fact that the $^{14}\text{C}(p,t)^{12}\text{C}$ and $^{14}\text{C}(p,{}^3\text{He})^{12}\text{B}$ reactions populate two $T = 2$ levels in ^{12}C and ^{12}B with strengths almost an order of magnitude smaller than typical yields to $T = 2$ levels in other light nuclei.[5] This would, of course, follow naturally from the fact that the ^{14}C ground state is mainly $(0s)^4(0p)^{10}$. The separation of these two observed $T = 2$ levels ($\Delta E = 2.1$ MeV) is much less than the excitation energy of the first excited $T = 2$ state as obtained from the p-shell wave functions of Cohen and Kurath[6] ($E_x = 4.4$ MeV). On the other hand, the β-decay half-life of ^{12}Be suggested by Poskanzer *et al.*[7] ($T_{1/2} = 11.4 \pm 0.5$ msec) agrees with the value of 12 msec obtained from p-shell wave functions. However, as pointed out by Barker, the identification of this activity is uncertain in view of the subsequent discovery[8] that ^{11}Li is particle stable.

Attempts to compare the (p,t) and $(p,{}^3\text{He})$ data of Ref. 5 with the predictions of Barker[4] have thus far met with contradictory results. For example, the near degeneracy of ($0p$) and ($1s$-$0d$) orbits assumed in his model requires the presence of two low-lying 0^+ $T = 2$ levels, which are mixtures of the configurations $(0s)^4(0p)^8$ and $(0s)^4(0p)^6(1s\text{-}0d)^2$. In Ref. 5 the (p,t) angular distributions leading to $T = 2$ levels at 27.57 and 29.63 MeV in ^{12}C appear to favor $L = 0$ (and hence $J^\pi = 0^+$) for both levels. However, the angular correlation of decay protons from the upper $T = 2$ level was found to be anisotropic, which is inconsistent with $J^\pi = 0^+$. Part of the difficulty in the above measurements stems from the extremely small production cross section for the $T = 2$ states; in particular, the angular correlation measurements suffer from quite poor statistics.

An alternative approach to the study of these important $T = 2$ levels lies in studying the neutron-rich $T_z = 2$ nucleus ^{12}Be. ^{12}Be has been observed previously in the $^7\text{Li}(^7\text{Li}, 2p)^{12}\text{Be}$ reaction[9] in which the ground state and a tentative excited state at $E_x = 0.81$ MeV were identified. The ground state mass was confirmed by Ball *et al.*[10] using the $^{14}\text{C}(^{18}\text{O}, {}^{12}\text{Be})^{20}\text{Ne}$ reaction; in addition an excited state at $E_x = 2.09 \pm 0.05$ MeV was observed, in agreement with the energy difference of about 2.1 MeV between the two $T = 2$ levels seen in the $^{14}\text{C}(p,t)^{12}\text{C}$ reaction.[5]

In the present work we have formed ^{12}Be using the $^{10}\text{Be}(t,p)^{12}\text{Be}$ reaction. Our measurements include the determination of the spin of a level at $E_x = 2.110 \pm 0.015$ MeV using a particle-γ angular correlation technique, and a measurement of the β decay half-life using a mechanically chopped beam and a plastic scintillation detector. An attempt was also made to observe delayed neutrons using the chopped beam and a ^{3}He neutron detector. Only an upper limit was obtained for this last measurement.

II. EXPERIMENTAL PROCEDURE

In all of the experiments reported in this paper ^{12}Be was produced using the ^{10}Be$(t,p)^{12}$Be reaction. A triton beam with intensity between 50 and 150 nA (limited by singles counting rates) was obtained from a Middleton-type negative ion sputter source[11] and accelerated to 12 MeV using the University of Pennsylvania tandem Van de Graaff accelerator. For the particle-γ coincidence experiments the target[12] consisted of 100 μg/cm^2 of 94% enriched ^{10}BeO mounted on a 1 mg/cm^2 platinum backing. Outgoing protons were detected at 0° with respect to the beam by a solid state position-sensitive detector located in the focal plane of a magnetic spectrometer.[13] A thin (0.00127 cm) tantalum foil was placed over the detector to stop any tritons which might strike the detector as a result of pole-face scattering. γ rays were detected in time coincidence with protons at angles of 90°, 113°, 136°, and 159° with respect to the beam by an array of 7.62×10.16 cm NaI(Tl) scintillation detectors. Standard fast-slow coincidence techniques were used. The data, consisting for each event of particle energy, γ energy, time difference, and routing information, were written onto magnetic tape for subsequent off-line analysis.

For the experiments involving the decay of ^{12}Be a mechanically chopped beam was obtained using a rotating slotted wheel with associated electronic circuitry which controlled the irradiation-counting cycle. The target (600 μg/cm^2 ^{10}BeO on a thick Pt backing) was placed at the center of a 2.5 cm diameter glass target chamber. In all cases the target was bombarded for 20 msec and counting was started 5 msec after the end of the irradiation. In the experiment to measure the half-life, β rays were detected by a 7.5 cm diameter by 5 cm thick NE102 scintillation crystal. (A discriminator was set corresponding to β rays with energies greater than some minimum energy; $E_{\min} = 3$ and 6 MeV were used.) Counts were multiscaled in 0.8 msec time bins for 400 msec.

An attempt was made to observe delayed neutrons using the same setup except replacing the β detector by a ^{3}He neutron detector placed ~ 5 cm from the target. The entire target-detector region was filled with paraffin blocks to thermalize neutrons following techniques described previously.[14]

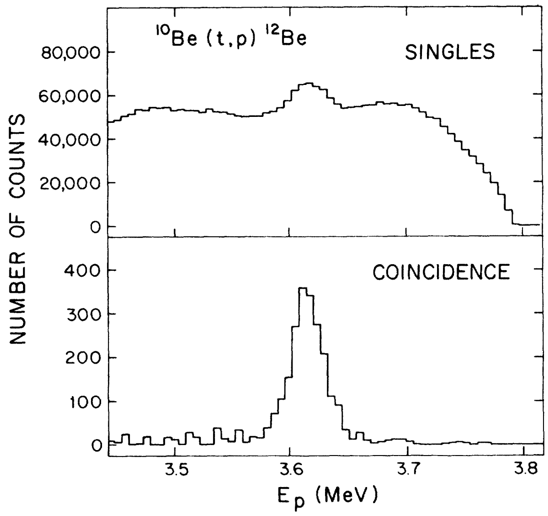

FIG. 1. Top: Singles proton spectrum from the ^{10}Be$(t,p)^{12}$Be reaction near the excited level at $E_x = 2.110$ MeV. Bottom: Same spectrum with the additional requirement of a p-γ coincidence.

III. ANALYSIS AND RESULTS

A. Particle-γ coincidence measurements

Singles and coincidence proton spectra in the vicinity of the $E_x = 2.110$ MeV level are shown in Fig. 1. Part of the background in the singles spectrum results from protons leading to highly excited states in ^{18}O. These states are above the neutron emission threshold and consequently do not contribute to the coincidence spectrum (Accidental coincidences have been subtracted from the coincidence spectrum.) The remaining non-coincident background is mainly from protons knocked out of the absorber foil by tritons which have been degraded in energy by various scatter-

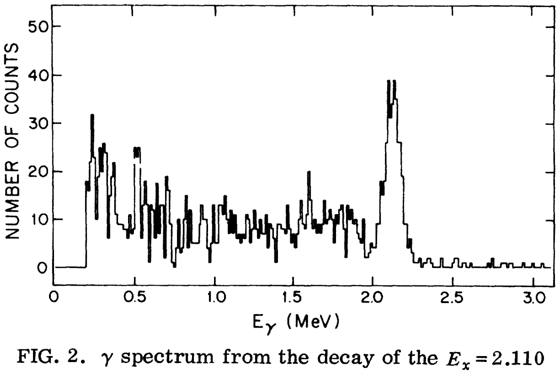

FIG. 2. γ spectrum from the decay of the $E_x = 2.110$ MeV level (sum of four γ detectors).

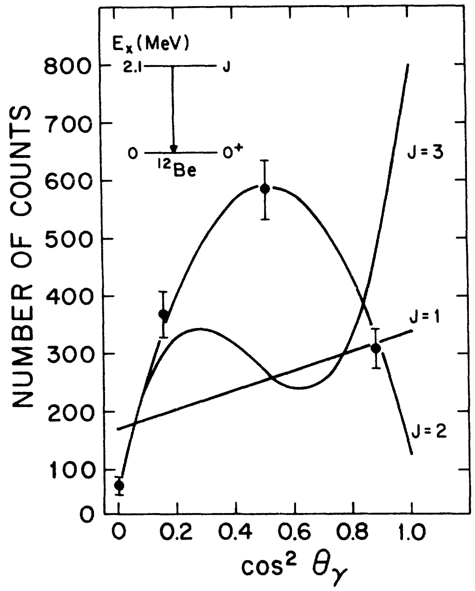

FIG. 3. Angular correlation of the γ rays from the 2.110 MeV→0 transition in ^{12}Be. The curves are the best fits for the spins shown.

ing processes. From a comparison of the spectrum in Fig. 1 with a similar one obtained for the ^{12}Be ground state, the excitation energy of the excited state is found to be 2.110± 0.015 MeV. A less precise value, obtained from the γ spectra, was consistent with this number. The result is in good agreement with the reported value of 2.09 ± 0.05 MeV of Ball *et al.*[10]

The γ spectrum (sum of four detectors) is shown in Fig. 2. Only a ground state transition is observed; other decay branches constitute less than about 10% of the decay strength. The total number of γ rays emitted, as obtained from a fit to Legendre polynomials, agrees to within 10% with the number expected on the basis of the number of counts in the singles spectrum and the known efficiency of the γ detectors. This sets an upper limit on the (t,p) cross section of a possible unresolved state which does not γ decay, e.g., a 0^+ state. The angular correlation obtained from the four individual γ spectra (integrating all counts above $E_\gamma = 0.51$ MeV) is shown in Fig. 3. The errors shown include the effect of uncertainties in integrating the spectrum, in addition to counting statistics.

TABLE I. Results of least squares fits to angular correlations shown in Fig. 3.

J	χ^2/ν	$P(0)$
1	52.0	0.0[a]
2	1.1	0.89±.05
3	34.5	0.10±.05

[a] The best fit gave a negative population parameter.

Assuming the ^{10}Be ground state has $J^\pi = 0^+$, the axially symmetric geometry of the present experiment requires that the alignment of the excited state is completely described by the fraction of nuclei in the $M=0$ and $|M|=1$ magnetic substates. For a direct (t,p) reaction in which a dineutron is transferred with $S=0$, $T=1$ only the $M=0$ state is allowed (neglecting spin-orbit coupling). The data shown in Fig. 3 were fitted treating the relative populations of the $M=0$ and $|M|=1$ substates as a free parameter. Spins of 1, 2, and 3 were considered. (Spin zero is ruled out by the observation of the ground state γ decay; spins ≥ 4 are ruled out by lifetime considerations.) Also since the state has a (t,p) cross section comparable to the ground state, we assume natural parity. For a given spin a computer program calculated the normalized χ^2 and the best fit population parameter. The results are given in Table I. All spins except $J=2$ are ruled out at greater than 99.9% confidence. For $J=2$ the $M=0$ substate received 89% of the strength, in good agreement with expectation for a direct (t,p) reaction.

The results of the present experiment demonstrate $J=2$ for the $E_x = 2.110$ MeV level in ^{12}Be. The assumption that the $E_x = 29.63$ MeV level in ^{12}C reported in the work of Ashery *et al.*[5] is the analog of this level requires $L=2$ for the ^{14}C$(p,t)^{12}$C transition to this level, despite the apparent preference for $L=0$ exhibited by the angular distribution. Of course the possibility of a degenerate doublet with spins 0^+ and 2^+ cannot be ruled out.

B. Half-life measurements

The decay curves obtained by multiscaling the counts from the β detector were analyzed using a least squares fitting procedure. The form of the fitting function was obtained by considering the activities known to be produced by tritons incident on ^{10}Be or ^{9}Be. ($t + {}^{16,17,18}$O produces no short-lived activities.) The main reactions and their associated activities are shown in Table II. Note

TABLE II. β activities expected from the bombardment of ^{10}Be or ^{9}Be with 12 MeV tritons.

Activity	$T_{1/2}$ (msec)	Reaction
^{9}Li	176	^{10}Be(t,α)
^{8}Li	850	^{10}Be$(t,\alpha n)$ or ^{9}Be(t,α)
^{12}B	20.4	^{10}Be(t,n) or ^{12}Be(β^-)
^{12}Be	?	^{10}Be(t,p)

that because ^{12}B is produced both directly by the (t,n) reaction and indirectly from the decay of ^{12}Be the predicted decay curve is not of the form $\sum_\alpha A_\alpha e^{-\lambda_\alpha t}$, where A_α is proportional to the initial abundance of the αth isotope.

The data were fitted using a least squares procedure to an equation of the form:

$$\begin{aligned} N(t) = {} & A_{^8\mathrm{Li}}\lambda_{^8\mathrm{Li}}e^{-\lambda_{^8\mathrm{Li}}t} + A_{^9\mathrm{Li}}\lambda_{^9\mathrm{Li}}e^{-\lambda_{^9\mathrm{Li}}t} \\ & + A_{^{12}\mathrm{Be}}\lambda_{^{12}\mathrm{Be}}e^{-\lambda_{^{12}\mathrm{Be}}t} + A_{^{12}\mathrm{B}}\lambda_{^{12}\mathrm{B}}e^{-\lambda_{^{12}\mathrm{B}}t} \\ & + A_{^{12}\mathrm{Be}}\frac{\lambda_{^{12}\mathrm{Be}}\lambda_{^{12}\mathrm{B}}}{\lambda_{^{12}\mathrm{B}} - \lambda_{^{12}\mathrm{Be}}}\left(e^{-\lambda_{^{12}\mathrm{Be}}t} - e^{-\lambda_{^{12}\mathrm{B}}t}\right), \end{aligned} \tag{1}$$

where $N(t)$ is the activity and λ_i and A_i are the decay constant and initial abundance, respectively, for the indicated isotope. The last term takes account of the fact that ^{12}B is produced as a daughter in the ^{12}Be decay in addition to the direct production via the $^{10}\mathrm{Be}(t,n)^{12}\mathrm{B}$ reaction. In the least squares fitting procedure the λ_i for ^{8}Li, ^{9}Li, and ^{12}B were fixed at the values given in Table II. A value was chosen for $\lambda_{^{12}\mathrm{Be}}$ and a linear least squares fit was made to the data treating the initial abundances A_i as unknown parameters. The value of $\lambda_{^{12}\mathrm{Be}}$ was then changed and the entire procedure was repeated. For each step the quantity

$$\chi^2 = \sum_i \left[\frac{N_i(\mathrm{exp.}) - N_i(\mathrm{calc.})}{\Delta N_i}\right]^2$$

was computed where $N_i(\mathrm{exp.})$ is the number of counts in the ith time bin, $\Delta N_i = [N_i(\mathrm{exp.})]^{1/2}$, and $N_i(\mathrm{calc.})$ is obtained from Eq. (1). This quantity is expected to have a χ^2 distribution with ν degrees of freedom (ν is the number of data points fitted minus the number of free parameters; in the present work $\nu \cong 500$).

Figure 4 shows a plot of χ^2/ν as a function of the assumed half-life of ^{12}Be. The best fit, corresponding to $\chi^2/\nu = 0.977$, is obtained for $T_{1/2}(^{12}\mathrm{Be}) = 23.0$ msec. A purely statistical estimate of the error can be obtained by locating the intersection of the curve of Fig. 4 with the line $\chi^2 = \chi^2_{\mathrm{min}} + 1$; this yields an error of approximately ± 1 msec in the half-life. A second independent determination from another set of data yielded a best fit value of $T_{1/2} = 25.8 \pm 1.0$ msec, with $\chi^2/\nu_{\mathrm{min}} = 1.018$. A final estimate of the uncertainty in the measurement must also include the contributions of possible systematic effects, such as deficiencies in our assumptions about the long-lived activities which are present. For example, while the presence of ^{8}Li and ^{9}Li is clearly reasonable *a priori*, it is not required by the data in the sense that an acceptable fit can be obtained, for example, with a superposition of ^{12}Be, ^{12}B, and a fictitious 400 msec activity. The best fit value for the ^{12}Be half-life in this case is 27.5 ± 1.0 msec. We feel this latter fit to be unphysical, since there is no reasonable candidate for the 400 msec activity, so we confine our fits to known activities which should be produced by tritons on ^{10}Be and ^{9}Be. To be conservative, however, we arbitrarily increase the estimated uncertainties in our measurement to accommodate possible systematic errors and arrive at a "best" value for the half-life of ^{12}Be of $T_{1/2} = 24.4 \pm 3.0$ msec. An example of the data along with the best fit is shown in Fig. 5. For comparison, Fig. 6 shows the same data assuming the presence of only ^{8}Li, ^{9}Li, and ^{12}B. The fit is clearly much worse, yielding a reduced χ^2 of 11.8. [It should be noted that the theoretical function (1) does not reduce to the above case for $T_{1/2}(^{12}\mathrm{Be}) = T_{1/2}(^{12}\mathrm{B})$ because of the parent-daughter relation between the two isotopes.]

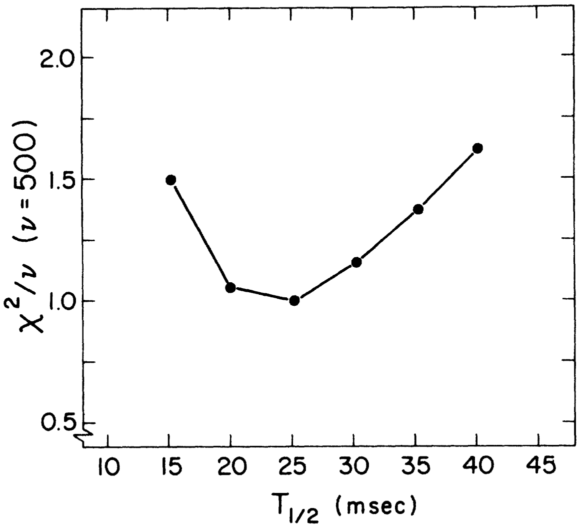

FIG. 4. Goodness-of-fit parameter χ^2 as a function of assumed half-life of ^{12}Be, as described in the text.

As a by-product of the fitting procedure we de-

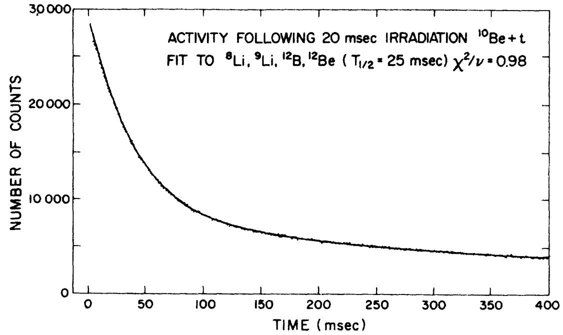

FIG. 5. Data points are the result of multiscaling β rays in 0.8 msec time bins; the solid curve is the result of the least squares fit described in the text and includes contributions from ^{8}Li, ^{9}Li, ^{12}B, and ^{12}Be.

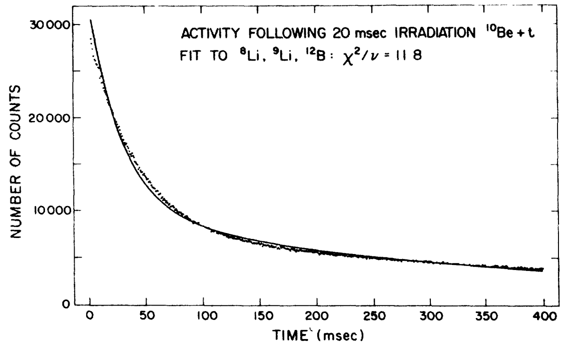

FIG. 6. Same data as Fig. 5 but fitted assuming the presence of ^{8}Li, ^{9}Li, and ^{12}B only.

termine the initial abundances of the various activities produced although it must be re-emphasized that the relative abundances obtained for the longer-lived isotopes depend sensitively on the assumptions involved in the fit, as discussed above. The results of these fits have been converted to relative production cross sections assuming a bombardment time of 20 msec. (A correction was made for the long half-lives because in cycle n some activity is left from cycle $n-1$, etc.) The results are shown in Table III. These results provide a crude consistency check on our data reduction procedure. For example, the yield of the ^{10}Be(t, α) reaction is found to be 4.3 times the yield of the ^{10}Be(t,p) reaction. This is consistent with very preliminary results from a measurement of the cross sections for these two reactions using the multiangle magnetic spectrograph.[15] Also, the ^{10}Be(t,n) cross section is found to be larger than the ^{10}Be(t,p) cross section. This is consistent with the more positive Q value for the (t,n) reaction, and is also qualitatively consistent with theoretical calculations made using the distorted wave Born approximation code DWUCK to calculate the total cross sections as predicted from the Cohen and Kurath wave functions.[6] (This last comparison does not mean a great deal, however, since there is clearly appreciable two-particle transfer strength to configurations outside the 0p shell.)

TABLE III. Relative production cross sections for activities produced in ^{10}Be + t.

Activity	σ production
^{12}Be	1.0 [a]
^{12}B	3.5
^{9}Li	4.3
^{8}Li	7.0

[a] Assumed.

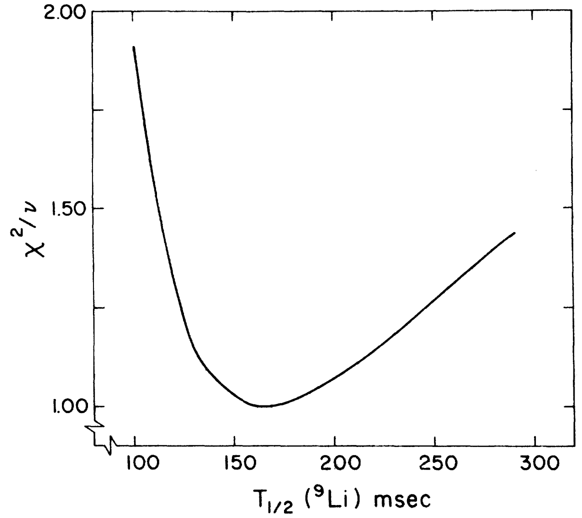

FIG. 7. Goodness-of-fit parameter χ^2 as a function of $T_{1/2}$(^{9}Li) obtained from fitting data from bombardment of thick natural lithium target by 12 MeV tritons.

As a final overall check on the data reduction procedure, the same method was used to analyze β spectra produced using the same experimental setup except that the ^{10}Be target was replaced by a thick natural lithium target. Activities considered were ^{6}He [from ^{7}Li(t, α)], ^{8}Li [from ^{6}Li(t,p) and/or ^{7}Li(t,d)], and ^{9}Li [from ^{7}Li(t,p)]. Since the half-lives of ^{8}Li and ^{6}He are quite similar (850 and 802 msec, respectively[16]) the data cannot distinguish between them; we have arbitrarily fitted the observed data to a superposition of ^{6}He and ^{9}Li. In order to simulate an actual half-life measurement, the half-life of ^{9}Li was varied. The results are shown in Fig. 7; the value obtained for $T_{1/2}$(^{9}Li) by our method is 166 ± 5 msec, in agreement with the accepted value $T_{1/2}(^9\text{Li}) = 176 \pm 2$ msec.[16] (The above error estimate is purely statistical.) Because the observed yields correspond to an infinitely thick target it was not considered worthwhile to try to interpret the relative abundances which were obtained from the fitting procedure in this case.

C. Limit on delayed-neutron branch

The results of multiscaling counts corresponding to thermalized neutrons as measured with the ^{3}He detector for a period of 200 msec are shown in Fig. 8. The solid curve is obtained by assuming that ^{9}Li is the only delayed-neutron activity present. The fit is quite good ($\chi^2/\nu = 1.06$) and the results show no evidence for any delayed neutrons with the characteristic half-life of ^{12}Be. A quantitative upper limit on a delayed-neutron branch can be obtained by assuming that the initial abundances

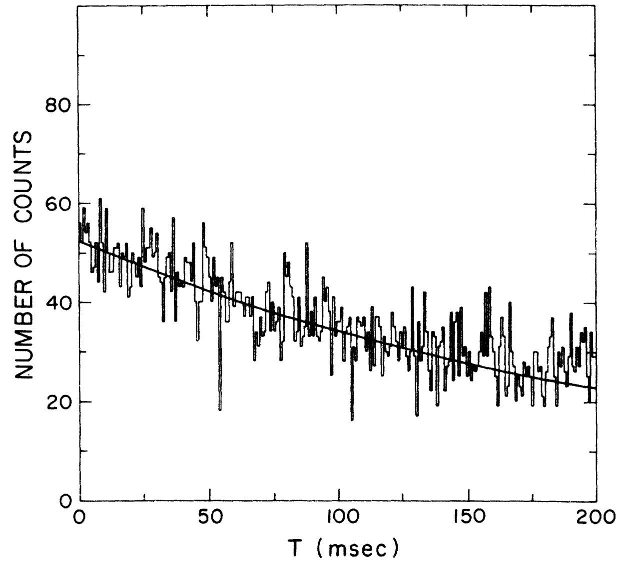

FIG. 8. Data points are the result of multiscaling delayed thermalized neutrons in 0.8 msec time bins; the solid curve assumed ^{9}Li is the only delayed-neutron activity present.

of ^{9}Li and ^{12}Be are given by the values obtained in fitting the β-decay data. (Recall that this requires the assumption that the only long-lived activities present are ^{8}Li and ^{9}Li.) A least squares fit to the data of Fig. 8, assuming activities due to both ^{12}Be and ^{9}Li, leads to an initial abundance of ^{12}Be consistent with zero. Taking the error obtained in the fit as a one standard deviation upper limit, and using the production cross section ratios from Table III and the known delayed-neutron branching ratio of 0.35 for ^{9}Li[16] yields an upper limit of 1% for a delayed-neutron branch in ^{12}Be. This is substantially less than the 7% found in the work of Ref. 7, but the different half-life observed in that work makes it clear that another activity (possibly ^{11}Li) was involved.

IV. DISCUSSION

The present work has demonstrated the existence of a 2^+ level in ^{12}Be with a (t,p) cross section at $E_t = 12$ MeV comparable to that of the ground state. These results are consistent with the basic picture given by Barker's calculation[4]; configuration mixing undoubtedly plays an important role in lowering the energy of the first 2^+ state to 2.1 MeV, as compared with $E_x = 4.4$ MeV predicted by the p-shell calculation of Cohen and Kurath.[6] For the present the location of the predicted excited 0^+ level [which is expected to be weakly excited in the (t,p) reaction] remains unknown. Possibly more realistic shell model calculations using a larger basis will shed additional light on this problem.

Additional evidence for the presence of core-excitation in the ground state of ^{12}Be comes from the measured β decay half-life, $T_{1/2} = 24.4 \pm 3.0$ msec. This value corresponds to a reduction in strength of more than a factor of 2 compared with the prediction of the $0p$-shell calculations of Cohen and Kurath.[6] Presumably the $(1s\text{-}0d)^2$ admixtures do not have any β-decay strength to the low-lying states of ^{12}B, which are well described by $(0p)$-shell wave functions. The observed half-life is in reasonable agreement with the value obtained by Barker,[4] $T_{1/2}(\text{theory}) = 31$ msec.

---

†Work supported by the National Science Foundation.

*Work supported by the Energy Research and Development Administration.

[1] K. A. Snover, Ph.D. thesis, Stanford University, 1969 (unpublished).

[2] E. K. Warburton, H. M. Kuan, D. E. Alburger, P. Paul, and K. A. Snover, Phys. Rev. C 6, 375 (1972); S. S. Hanna, M. Hass, Z. Shkedis, and Y. S. Horowitz, Nucl. Phys. A195, 91 (1972).

[3] A. M. Nathan and J. W. Noé, Bull. Am. Phys. Soc. 22, 552 (1977).

[4] F. C. Barker, J. Phys. G 2, L45 (1976).

[5] D. Ashery, M. S. Zisman, G. W. Goth, G. J. Wozniak, R. B. Weisenmiller, and J. Cerny, Phys. Rev. C 13, 1345 (1976).

[6] S. Cohen and D. Kurath, Nucl. Phys. A141, 145 (1970).

[7] A. M. Poskanzer, P. L. Reeder, and I. Dostrovsky, Phys. Rev. 138, B18 (1965).

[8] A. M. Poskanzer, S. W. Casper, E. K. Hyde, and J. Cerny, Phys. Rev. Lett. 17, 1271 (1966).

[9] H. H. Howard, R. H. Stokes, and B. Y. Erikkla, Phys. Rev. Lett. 27, 1086 (1971).

[10] G. C. Ball, J. G. Costa, W. G. Davies, J. S. Forster, J. C. Hardy, and A. B. McDonald, Phys. Lett. B49, 33 (1974).

[11] R. Middleton and C. T. Adams, Nucl. Instrum. Methods 118, 329 (1974).

[12] Target fabricated by D. R. Goosman.

[13] R. W. Zurmühle, P. F. Hinrichsen, C. M. Fou, C. R. Gould, and G. P. Anastassiou, Nucl. Instrum. 71, 311 (1969).

[14] D. E. Alburger and D. H. Wilkinson, Phys. Rev. C 13, 835 (1976).

[15] H. T. Fortune, D. E. Alburger, R. Middleton, S. Mordechai, M. E. Cobern, and R. Kollarits (unpublished).

[16] F. Ajzenberg-Selove and T.Lauritsen, Nucl. Phys. A227, 1 (1974).