Submitted to Nuclear Physics

RECEIVED
LAWRENCE
RADIATION LABORATORY

NOV 19 1970

LIBRARY AND
DOCUMENTS SECTION

UCRL-19954
Preprint

c.2

THE REACTIONS $^{11}B(p, {}^{3}He)^{9}Be$ AND $^{11}B(p, t)^{9}B$: IS THERE STRONG ISOSPIN MIXING IN MASS 9?

J. C. Hardy, J. M. Loiseaux, Joseph Cerny,
and Gerald T. Garvey

August 1970

AEC Contract No. W-7405-eng-48

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 5545

UCRL-19954 c.2

LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

THE REACTIONS $^{11}B(p,^3He)^9Be$ AND $^{11}B(p,t)^9B$: IS THERE STRONG ISOSPIN MIXING IN MASS 9?*

J. C. Hardy, J. M. Loiseaux, Joseph Cerny, and Gerald T. Garvey

NUCLEAR REACTIONS $^{11}B(p,t)$, $(p,^3He)$, E = 45 MeV, measured $\sigma(E_t, E_{^3He}, \theta)$. ^9B, ^9Be deduced levels J,π,T,Γ. Enriched Target.

THE REACTIONS $^{11}B(p,^3He)^9Be$ AND $^{11}B(p,t)^9B$: IS THERE STRONG ISOSPIN MIXING IN MASS 9?*

J. C. Hardy†, J. M. Loiseaux††, and Joseph Cerny

Lawrence Radiation Laboratory
and Department of Chemistry
University of California
Berkeley, California 94720

and

Gerald T. Garvey

Joseph Henry Laboratories
Princeton University
Princeton, New Jersey 08540

August 1970

Abstract

The reactions $^{11}B(p,^3He)^9Be$ and $^{11}B(p,t)^9B$ have been studied at 45 MeV proton energy. New T = 1/2 states have been observed at 15.96 ± 0.04 MeV in ^9Be and at 15.29 ± 0.04 MeV and 15.58 ± 0.04 MeV in ^9B; and in addition there is a possible state or states at ∿ 15.13 MeV in ^9Be. The results were compared with DWBA calculations using (1p)-shell wave functions and there is reasonable agreement for the ground states, lowest $5/2^-$ excited states and the lowest $3/2^-$ (T = 3/2) analogue states. Several candidates are proposed for a $3/2^-$ (T = 1/2) state near the analogue state. The results are discussed in terms of isospin mixing in the analogue states, prompted by previously observed deviations of their masses from the quadratic multiplet mass equation. All the experimental evidence indicates that isospin mixing of more than few percent is extremely unlikely.

*Work performed under the auspices of the U. S. Atomic Energy Commission.

†Present Address: Chalk River Nuclear Laboratories, AECL, Chalk River, Ontario, Canada.

††NATO Fellow; permanent address: I.P.N., Orsay, France.

1. Introduction

If it is assumed that two-body forces are responsible for charge dependence in nuclei then, to first order, the masses of members of an isobaric multiplet are related by the so-called isobaric multiplet mass equation (IMME),

$$M(A,T,T_z) = a(A,T) + b(A,T)T_z + c(A,T)T_z^{\,2} \quad , \tag{1}$$

where the coefficients are related to diagonal reduced matrix elements of the charge-dependent part of the total Hamiltonian. The states themselves are assumed to be characterized by a unique isospin T. By using second-order perturbation theory the IMME can be extended to include[1]) the additional terms $dT_z^{\,3} + eT_z^{\,4}$. The coefficients d and e are functions only of off-diagonal matrix elements, and the other coefficients must be redefined to include off-diagonal as well as diagonal elements.

Experimentally it is possible, by measuring the masses of all four members of a T = 3/2 quartet, to determine the magnitude of the coefficient d <u>independently</u> of any assumptions about e. What light this may shed on the extent of isospin mixing is illustrated by considering the interaction between two states--one with T = 3/2, the other with T = 1/2--which appear in a $|T_z| = 1/2$ nucleus. The perturbed energy of the T = 3/2 level can be expanded with the help of the Wigner-Eckart theorem in powers of T_z, where the coefficient of the $T_z^{\,3}$ term is[2])

$$d = -[\sqrt{15}\,(E_{3/2} - E_{1/2})]^{-1} \langle T = \tfrac{3}{2} \| H_{CD}^{(1)} \| \tfrac{1}{2} \rangle \langle \tfrac{3}{2} \| H_{CD}^{(2)} \| \tfrac{1}{2} \rangle \quad . \tag{2}$$

Here $H_{CD}^{(i)}$ is the ith rank tensor component of the charge-dependent part of the Hamiltonian and E_T is the excitation energy of the state with isospin T.

The corresponding amplitude α of the T = 1/2 component admixed into the T = 3/2 analogue-state wave function is

$$\alpha(T_z = \pm \tfrac{1}{2}) = (E_{3/2} - E_{1/2})^{-1} \{\frac{1}{\sqrt{6}} \langle \tfrac{3}{2} \| H_{CD}^{(1)} \| \tfrac{1}{2} \rangle \pm \frac{1}{\sqrt{10}} \langle \tfrac{3}{2} \| H_{CD}^{(2)} \| \tfrac{1}{2} \rangle \} \quad , \tag{3}$$

where the $\pm$ signs correspond to $T_z = \pm 1/2$. Under these restrictive limits of only two-state mixing, it is now possible to derive from Eqs. (2) and (3) several relationships which are otherwise model independent:

$$\alpha^2(\pm \tfrac{1}{2}) \pm (E_{3/2} - E_{1/2})^{-1} \underline{d} \geqslant 0 \tag{4}$$

$$\alpha^2(-\tfrac{1}{2}) - \alpha^2(+\tfrac{1}{2}) = 2\underline{d}(E_{3/2} - E_{1/2})^{-1} \quad . \tag{5}$$

Thus, it is evident that even if the $\underline{d}$ coefficient is measured to be zero, isospin mixing cannot be precluded; and conversely, a significant $\underline{d}$ coefficient is compatible with no isospin mixing in <u>one</u> of the $|T_z| = 1/2$ nuclei but not in both.

There has been recent experimental activity[2-4]) in determining the value of $\underline{d}$ from isobaric-quartet mass measurements. The most accurate results at present relate to masses 9, 13, and 21 for which the measured $\underline{d}$ coefficients are +9.1 ± 3.7 keV, -0.9 ± 2.9 keV and 6.3 ± 4.9 keV, respectively. It appears that the only quartet which displays a significantly non-zero $\underline{d}$ coefficient is in mass 9--this involves the ground states of ^9C and ^9Li, and the lowest T = 3/2 states in ^9B and ^9Be. It is then of particular interest to study the mass-9 system with a view to isospin mixing so as to discover what special circumstances have determined the size of its $\underline{d}$ coefficient.

In probing this question previously, Jänecke[1]) has pointed out that two T = 1/2 states of uncertain spin lie at ∿ 500 keV and ∿ 2500 keV below the $3/2^-$ (T = 3/2) analogue states in both ^{9}B and ^{9}Be; if one of these states were also $3/2^-$, then it might well mix with the analogue state, perturbing its energy sufficiently to cause the observed d value. However, by assuming such two-state mixing he requires very large off-diagonal Coulomb matrix elements and predicts isospin impurities in the analogue state of ∿ 16% if mixing occurs with the nearer T = 1/2 state or ∿ 4% if it is with the other. These predictions are very nearly the same for both ^{9}B and ^{9}Be.

It now seems unlikely from the measured widths of the levels involved that such large isospin impurities in the analogue state could occur, particularly in ^{9}Be. All excited states in ^{9}Be are unstable to neutron emission and consequently almost all known T = 1/2 states have $\Gamma \gtrsim 100$ keV. The lowest T = 3/2 state, if it had pure isospin, would be bound to isospin-conserving particle decay and its width would be determined by radiative decay. Certainly some impurity must be present since its width is measured to be 0.4 keV[5]), but the size of the impurity will be approximated by $0.4/\Gamma_{1/2}$ where $\Gamma_{1/2}$ is the width of the T = 1/2 state with which it is assumed to mix. For $\Gamma_{1/2} \gtrsim 100$ keV, the corresponding impurity must be <u>less than</u> 0.5%. Since both T = 1/2 states suggested by Jänecke have widths of more than 400 keV, such large impurities as he suggests are improbable.

If mixing does occur with a T = 1/2 state at lower excitation energy, then it can be seen from Eq. (5) that a larger impurity is to be expected in the analogue state in ^{9}B than in ^{9}Be; since only an upper limit of <15 keV[6]) has been set experimentally on its width, this possibility cannot be ruled out. Similarly,

Eqs. (4) and (5) can be used to set limits on the mixing if it occurs with $T = 1/2$ states at higher energy, but few such states have been observed[5]), particularly within a few MeV of the analogue state.

We have studied the reactions $^{11}B(p,t)^{9}B$ and $^{11}B(p,{}^{3}He)^{9}Be$. If the lowest analogue states in ^{9}B and ^{9}Be were pure isospin-3/2, then the angular distributions of the corresponding reaction products would have the same shape and their relative intensities would be given by[7])

$$R = \frac{d\sigma/d\Omega\ (p,t)}{d\sigma/d\Omega\ (p,{}^{3}He)} = \frac{k_t}{k_{^{3}He}} = 0.96 \quad . \tag{6}$$

Should the impurity of the analogue state in ^{9}B be greater than for ^{9}Be--which must be true for two-state mixing if $E_{1/2} < E_{3/2}$ and d is positive--then one of two possibilities will occur depending upon the spectroscopic amplitude for production of the interacting $T = 1/2$ state. If the amplitude is small compared to that for production of the $T = 3/2$ state, then the ratio R will be reduced by approximately the percentage-impurity of the state; if the amplitudes are comparable then R may increase or decrease but in either case the $T = 1/2$ state itself should be produced with comparable intensity to the analogue state. Of course, only relatively large impurities could be observed by changes in R since the statistical uncertainties of the experiment and the approximation inherent in Eq. (6) do not warrant great precision. However, it was hoped that even if such large effects did not exist, new $T = 1/2$ states just above the analogue state might be discovered to explain the apparent discrepancy.

2. Experimental Procedure and Results

The (p,t) and (p,^{3}He) reactions were carried out using the external 45 MeV proton beam from the Berkeley 88-inch cyclotron. Reaction products were detected and identified using a solid-state counter telescope. Tritons and ^{3}He particles were detected simultaneously and spectra were recorded at seven angles between $20° \leqslant \theta_{cm} \leqslant 60°$ with an energy resolution of $\sim$ 120 keV (full width at half maximum) for tritons and $\sim$ 150 keV for ^{3}He. A detailed description of the apparatus has been given elsewhere[8]).

Triton and ^{3}He spectra taken at $\theta_{lab} = 31.5°$ are shown in fig. 1; the data were taken using a 300 μgm/cm^2 self-supporting boron target enriched to 98 % in ^{11}B. Impurities are marked in the spectra, while peaks due to states in ^{9}B or ^{9}Be can be observed by comparison with the level schemes which are also shown. Below the T = 3/2 analogue states at $\sim$ 14.5 MeV in both nuclei these schemes are the same as those which appear in ref. [5]) and we see no evidence for additional states. However, above this energy we observe new T = 1/2 states at 15.96 ± 0.04 MeV in ^{9}Be and at 15.29 ± 0.04 MeV and 15.58 ± 0.04 MeV in ^{9}B; and in addition there is a possible state or states at $\sim$ 15.13 MeV in ^{9}Be. Although some of these states are weak in the figure, they do appear clearly at other angles and their identification was based upon consistent kinematic behavior.

Angular distributions are shown in fig. 2 for those states which were observed with sufficient intensity and statistical definition. The curves in the figure are the result of distorted-wave Born-approximation (DWBA) calculations performed using the computer program DWUCK[9]). Optical-model parameters for the proton channel were taken from 45.5 MeV elastic scattering[10]) on ^{12}C

while, for the mass-3 channel, parameters from 29 MeV ^{3}He scattering[11]) on ^{14}N were used. Spectroscopic amplitudes were calculated[12]) using the (1p)-shell wave functions of Cohen and Kurath[13]). The configurations of states shown in the top half of the figure were associated with their predictions for the ground state and excited states at 2.94 MeV and 13.61 MeV in the mirror mass-9 nuclei. The agreement in shapes is seen to be excellent and the relative magnitudes which are compared in the top half of table 1 certainly agree to within the expected accuracy of two-nucleon transfer reactions[14]), particularly considering the range of excitation energies being studied. These data have been used to confirm $5/2^-$ for the spin of the 2.33 MeV level in ^{9}B which is the mirror of the 2.43 MeV level in ^{9}Be.

The angular distributions shown in the bottom half of fig. 2 are for T = 1/2 states in the neighborhood of the analogue state. The three (p,t) curves are identical, as are those for (p,^{3}He), and represent DWBA calculations for the $3/2^-$ states predicted to lie at 10.04 MeV. Clearly, the poor statistics and the uncharacteristic shapes of the angular distributions make it impossible to positively identify any of the observed states as being $3/2^-$ or not. Since ^{11}B is $3/2^-$, all negative parity states with $J \leqslant 7/2$ in mass 9 can be produced by L = 2 transfer, all with angular distributions more or less like those in fig. 2. The calculated and measured relative cross sections are compared in the bottom of table 1 from which it is evident that the observed transitions are generally weaker than predicted. In addition, the $3/2^-$ state expected at 4.66 MeV does not appear at all in our spectra. Thus, no conclusion can be made regarding the spins of the three pairs of observed states, although negative parity seems most probable.

Further comparison with the shell-model calculations[12,13]) indicates several discrepancies, most notably the absence of the $1/2^-$ state predicted to appear with appreciable strength at $\sim$ 2 MeV. A state has been reported[15]) at 2.78 MeV in ^{9}Be which was thought to be $1/2^-$, but we see no indication of it. We do see, however, the broad states at $\sim$ 7 MeV in ^{9}Be and ^{9}B, and it appears from our data that the 7.1 MeV state in ^{9}B is mirror to the $7/2^-$ state at 6.66 MeV in ^{9}Be.

3. Discussion

In discussing the possibility of two-state mixing, between the analogue state and a nearby T = 1/2 state, it is convenient to divide the approach between two possibilities: $E_{1/2} < E_{3/2}$ and $E_{1/2} > E_{3/2}$. The first possibility has been discussed at some length in sec. 1 where the significance of the cross-section ratio for the analogue states was pointed out; the experimental value is $R = 1.10 \pm 0.10$. This value is, if anything, higher than the calculated 0.96 (see eq. (6)) and precludes strong mixing with a weakly populated T = 1/2 state in ^9B. The most intense T = 1/2 level within a few MeV below the analogue state is that at 12.06 MeV, but even it is a factor of four weaker than the analogue. Thus we can rule out the possibility of significant isospin mixing with T = 1/2 levels at lower excitation. Of course, if either of the pairs of levels at $\sim$ 12 MeV or $\sim$ 14 MeV were $3/2^-$, which the results in sec. 2 indicate as a possibility, then there will certainly be a weak interaction ($\lesssim 1\%$) with the analogue state and this could be sufficient, at least within the limitations of eqs. (4) and (5), to explain the observed $\underset{\sim}{d}$ coefficient.

There are now at least two pairs of T = 1/2 levels at higher excitation energy than the analogue with which the possibility of mixing must be considered. For these levels $E_{1/2} - E_{3/2} \approx 750$ keV and ≈ 1.5 MeV. Where $E_{1/2} > E_{3/2}$, eq. (5) indicates that the mixing in ^9Be must be greater than in ^9B, and since the width of the T = 1/2 levels is approximately independent of T_z, this means that the width of the T = 3/2 state in ^9B must be $\Gamma < 0.4$ keV which is the width of its analogue in ^9Be. At present only an experimental upper limit has been set[6]) and it is too high to test this hypothesis. Further, eq. (4) can now be written:

$$\alpha^2(^9Be) \geqslant \underset{\sim}{d}(E_{1/2} - E_{3/2})^{-1} \quad ,$$

or

$$\frac{0.4}{\Gamma_{1/2}} \geqslant \frac{9.1}{E_{1/2} - E_{3/2}} \quad , \tag{7}$$

where $\Gamma_{1/2}$ is the width of the T = 1/2 state. This indicates that, if mixing with the 15.13 MeV "state" is to explain the observed $\underset{\sim}{d}$ coefficient, then its width must be $\Gamma \lesssim 40$ keV while if the 15.96 MeV state is responsible, $\Gamma \lesssim 80$ keV. In either case, the impurity in the analogue state might be as little as 1%. It does seem unlikely, though, that a $3/2^-$ (T = 1/2) level at this excitation energy would be narrower than 40 keV, and in fact our data determine the width of the 15.96 MeV level to be $\sim$ 300 keV. Thus it is improbable that strong isospin mixing occurs with T = 1/2 levels at higher excitation energy than the analogue state.

The present results, taken together with previously measured level-energies and widths in ^{9}B and ^{9}Be, make the possibility of very significant isospin mixing in the lowest-energy T = 3/2 analogue states rather remote. The sensitivity of existing methods, though, is such that mixing of the order of a percent or less could not be experimentally precluded. Examination of eqs. (4) and (5) indicates that for mixing with any of the pairs of T = 1/2 states we have discussed, a one percent impurity might be sufficient to explain the observed $\underset{\sim}{d}$ coefficient. However, even this small an impurity would require an off-diagonal charge-dependent matrix element of more than 100 keV which is a factor of three higher than most experimental examples[16]). It would require a very special set of circumstances to explain the $\underset{\sim}{d}$ coefficient in terms of two-state mixing with T = 1/2 states.

It is interesting to note that charge-dependent mixing with another T = 3/2 state can also cause a $\underline{d}$ coefficient through a relationship very similar to eq. (2). In that event even large mixing would have little effect on the width of either state, and all experimental criteria might be satisfied with relatively little actual isospin impurity.

Recently, the effects of the Coulomb interaction on levels in mass 9 have been investigated theoretically by Tomaselli[17]) who used the calculated energies and ($1p$)-shell wave functions of Barker[18]). Five T = 1/2 states and one T = 3/2 state (all $3/2^-$) are considered as interacting with the lowest analogue state, and the result for its width in ^{9}Be agrees well with experiment giving an isospin impurity of $\sim$ 0.03% ($\sim$ 0.7% for ^{9}B). We have made a simple extension of that calculation to derive a value[19]) of $\underline{d}$, but the result, -2.6 keV, involved a coherent sum of larger quantities so that the significance of its disagreement with experiment is difficult to evaluate. No charge-dependence in the nuclear force was considered in the foregoing calculations.

If strong two-state mixing is unlikely and the experimental results must be explained by the cumulative effects of roughly-similar interactions with many states, then it may well be difficult to explain why the $\underline{d}$ coefficient for mass 9 is apparently so much larger than for mass 13. Possibly the most fruitful course at this point would be to remeasure the relevant masses and also determine the width of the lowest T = 3/2 analogue state in ^{9}B.

References

1) J. Jänecke, Nucl. Phys A128 (1969) 632

2) G. T. Garvey in Nuclear Isospin, ed. by J. D. Anderson, S. D. Bloom, J. Cerny, and W. W. True, (Academic Press, New York, 1969) pg. 703

3) J. Cerny, Ann. Rev. Nucl. Sci. 18 (1968) 27

4) J. M. Mosher, R. W. Kavanagh, and T. A. Tombrello, Bull. Am. Phys. Soc. 14 (1969) 1167 (mass 9); G. F. Trentelman, B. M. Preedom, and E. Kashy, Phys. Rev. Letters 25 (1970) 530 (masses 9, 13 and 21); R. Mendelson, G. J. Wozniak, A. D. Bacher, J. M. Loiseaux, and J. Cerny, Phys. Rev. Letters 25 (1970) 533 (masses 13 and 21)

5 T. Lauritsen and F. Ajzenberg-Selove, Nucl. Phys. 78 (1966) 1; more recent information relating to the width of the lowest T = 3/2 level in ^{9}Be can be found in H. G. Clerc, K. J. Wetzel, and E. Spamer, Phys. Letters 20 (1966) 667

6) $\Gamma_{T=3/2}$ is < 15 keV from the reaction ^{7}Li(^{3}He,n)^{9}B, E. Adelberger, private communication; see also F. S. Dietrich, Nucl. Phys. 69 (1965) 49

7) J. C. Hardy, H. Brunnader, and J. Cerny, Phys. Rev. Letters 22 (1969) 1439

8) J. C. Hardy, H. Brunnader, J. Cerny, and J. Jänecke, Phys. Rev. 183 (1969) 854

9) The program DWUCK was written by P. D. Kunz; we appreciate his making it available. The modification for two-nucleon transfer was made by us, and follows the "zero-range interaction" approximation (see N. K. Glendenning, Phys. Rev. 137 (1965) B102)

10) Potential set NV from G. R. Satchler, Nucl. Phys. A100 (1967) 497

11) Potential set X from J. C. Hiebert, E. Newman, and R. H. Bassel, Phys. Rev. 154 (1967) 898

12) S. Cohen and D. Kurath, Nucl. Phys. A141 (1970) 145; we should like to thank Dr. Dieter Kurath for sending his calculations to us prior to publication.

13) S. Cohen and D. Kurath, Nucl. Phys. 73 (1965) 1

14) I. S. Towner and J. C. Hardy, Advances in Phys. 18 (1969) 401

15) Y. S. Chen, T. A. Tombrello, and R. W. Kavanagh, Nucl. Phys. A146 (1970) 136

16) S. D. Bloom in Isobaric Spin in Nuclear Physics, ed. by J. D. Fox and D. Robson (Academic Press, New York, 1966) p. 123

17) M. Tomaselli, Z. Physik. 233 (1970) 240

18) F. C. Barker, Nucl. Phys. 83 (1966) 418

19) For this calculation, the mixing amplitudes and energies in Tables 1 and 2 of ref. 17 were used to derive the matrix elements, and a generalized version of our eq. (2) then permitted a calculation of $\underline{d}$.

Table 1. Comparison of experiment and DWBA calculations for the reactions $^{11}B(p,{}^3He)^9Be$ and $^{11}B(p,t)^9B$

$^{11}B(p,{}^3He)^9Be$			Calculated Levels		$^{11}B(p,t)^9B$		
$Ex(^9Be)$ (MeV)	$\frac{d\sigma}{d\Omega}^a$ (exp)	$\frac{d\sigma}{d\Omega}^{a,b}$ (theory)	Ex (MeV)	J^π,T	$\frac{d\sigma}{d\Omega}^a$ (theory)	$\frac{d\sigma}{d\Omega}^a$ (exp)	$Ex(^9B)$ (MeV)
0.00	0.32	0.45	0.00	$3/2^-,1/2$	1.00	1.00	0.00
2.43	0.22	0.20	2.94	$5/2^-,1/2$	0.31	0.23	2.33
14.39	0.16	0.40	13.61	$3/2^-,3/2$	0.40	0.16	14.67
		0.077	4.66	$3/2^-,1/2$	0.18		
11.82	0.030					0.039	12.06
13.72	0.019	0.094	10.04	$3/2^-,1/2$	0.050	0.011	14.01
15.96	0.014					0.049	16.02

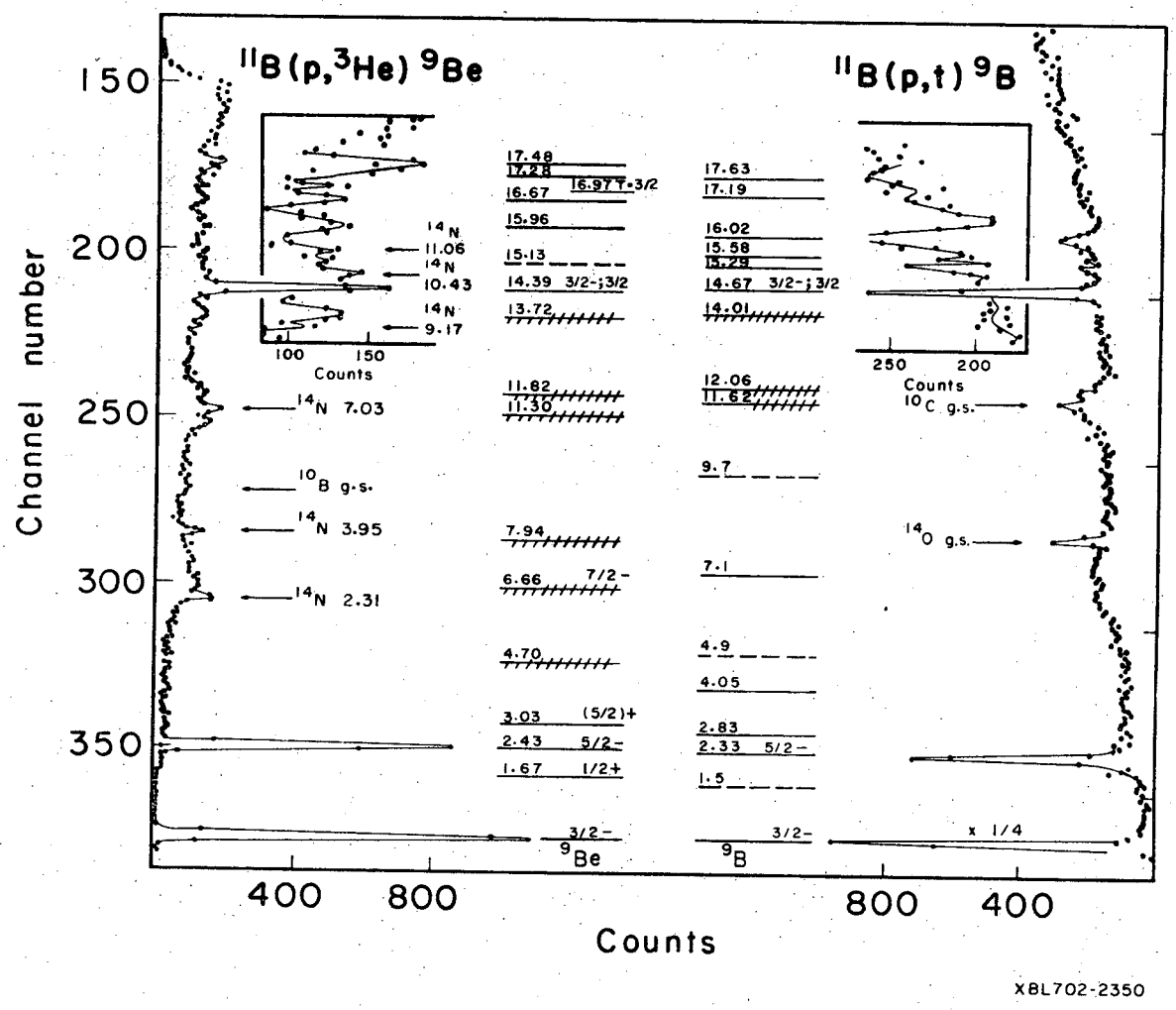
[a]Cross sections are quoted at $\theta_{cm} = 37°$, the peak of the observed (p,t) angular distribution to the ground state of ^9B; they are all normalized to that transition.

[b]The $(p,{}^3He)$ cross sections were calculated using a spin-dependence factor[14]) $D(1,0)/D(0,1) = 0.55$.

Figure Captions

Fig. 1. Spectra of tritons and ^{3}He particles from the reactions $^{11}B(p,^{3}He)^{9}Be$ and $^{11}B(p,t)^{9}B$ recorded at 31.5° for 1940 μC. The energy level diagram is taken from ref. [5]) with additional levels at ∿ 15 MeV from this work. The slight difference in the energy scale between ^{9}Be and ^{9}B is due to the effects of energy loss by the reaction products in the target and counter dead-layers.

Fig. 2. Measured angular distributions for states observed in the reactions $^{11}B(p,^{3}He)^{9}Be$ and $^{11}B(p,t)^{9}B$. The curves are results of DWBA calculations which are described in the text.



XBL702-2350

Fig. 1

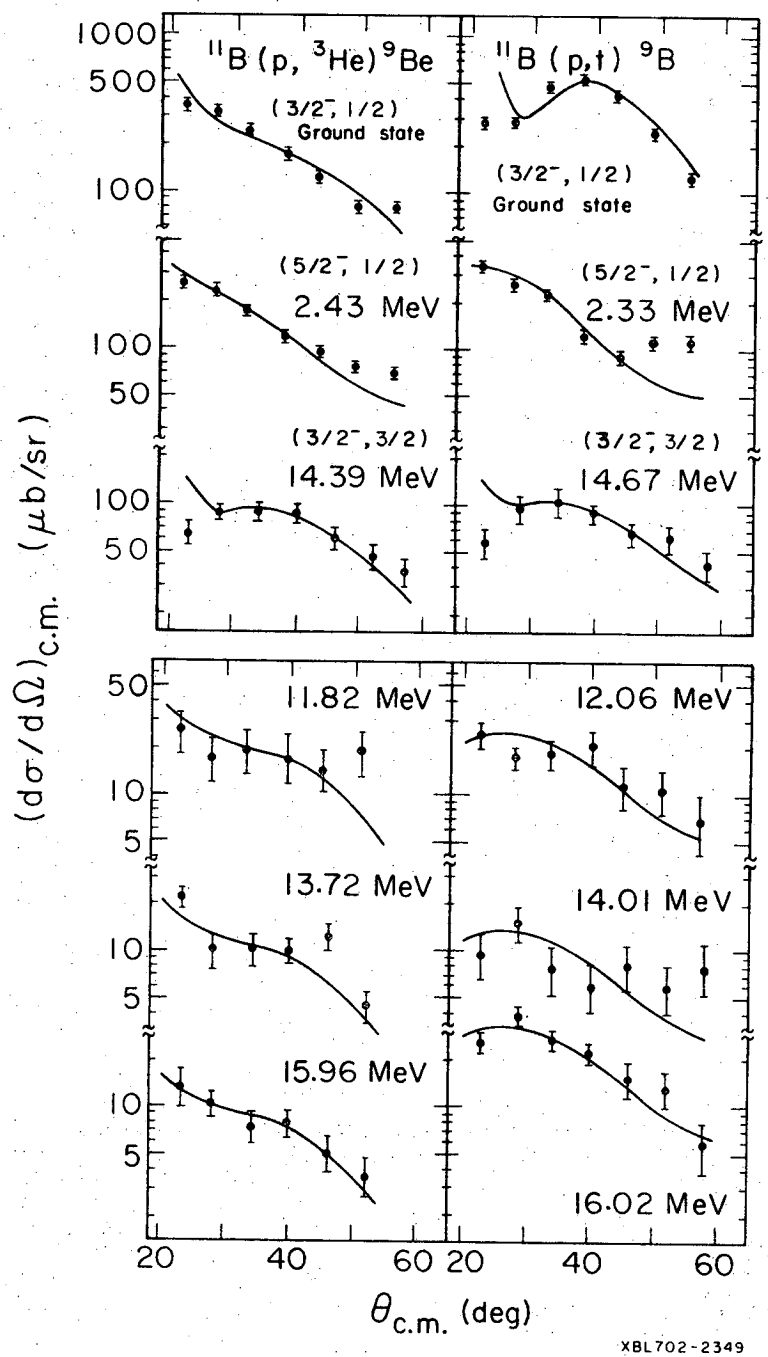

^{11}B (p, ^{3}He) ^{9}Be
^{11}B (p,t) ^{9}B
(3/2$^-$, 1/2)
Ground state
(3/2$^-$, 1/2)
Ground state
(5/2$^-$, 1/2)
2.43 MeV
(5/2$^-$, 1/2)
2.33 MeV
(3/2$^-$, 3/2)
14.39 MeV
(3/2$^-$, 3/2)
14.67 MeV
11.82 MeV
12.06 MeV
13.72 MeV
14.01 MeV
15.96 MeV
16.02 MeV
$(d\sigma/d\Omega)_{c.m.}$ (μb/sr)
$\theta_{c.m.}$ (deg)
XBL702-2349

Fig. 2

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

TECHNICAL INFORMATION DIVISION
LAWRENCE RADIATION LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720