Lifetime, Spin, and Parity of the First Excited State of B^{12}†

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The mean lifetime of the first excited state of B^{12} at 0.95 MeV was measured by the Doppler shift attenuation technique using the $B^{11}(d,p)B^{12}$ reaction to populate the state. The result is $\tau=(3.4\pm1)\times10^{-13}$ sec. Sum rules are invoked to show that the deexcitation of this state to the $J^{\pi}=1^{+}$ B^{12} ground state cannot be predominantly $E2$ so that the spin parity of the B^{12} first excited state cannot be 3^{+}. The angular distribution of the ground-state decay from this level was measured at a deuteron energy of 0.8 MeV. The result rules out a zero-spin assignment. It is concluded that the available experimental evidence indicates 2^{+} for the spin parity of the B^{12} first excited state.

INTRODUCTION

THE properties of the electromagnetic transitions from the first three excited states of B^{12} have recently been studied using the $B^{11}(d,p)B^{12}$ reaction to populate the states. This is a report of a portion of this work; namely, a measurement of the lifetime of the first excited state of B^{12} by means of the Doppler shift attenuation technique. The remainder of the work[1] will be published subsequently.

That the B^{12} first excited state at 0.95 MeV has even parity has been shown by the $l_n=1$ stripping pattern obtained in several investigations[2–5] of the $B^{11}(d,p)B^{12}$ (0.95-MeV level) angular distribution. These results also demand that $J\leq3$ for this level.

Theoretically, the B^{12} first excited state is predicted to be 2^{+} not only from independent-particle model calculations[6] but also from the fact that the second $T=1$ state of C^{12}, which is one MeV above the first $T=1$ state in C^{12}, has a spin parity of 2^{+}.[7]

For $J^{\pi}=2^{+}$ we expect the B^{12} $0.95\rightarrow0$ transition to be predominantly $M1$. The Weisskopf estimate[8] for the mean lifetime of a 0.95-MeV $M1$ transition is 3.7×10^{-14} sec and the lifetime corresponding to the mean strengths of $M1$ transitions in light nuclei (i.e., 0.15 Weisskopf units[8]) is 2.5×10^{-13} sec. This estimate is within the range of lifetimes which can be measured by the Doppler shift attenuation technique and as will be seen is close to the measured mean lifetime.

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[2] J. R. Holt and T. N. Marsham, Proc. Phys. Soc. (London) **66A**, 1032 (1953).
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[6] D. Kurath, Phys. Rev. **106**, 975 (1957).
[7] F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. **11**, 1 (1959).
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MEASUREMENT

The $B^{11}(d,p)B^{12}$ reaction ($Q=1.138$ MeV) was used to populate the B^{12} levels. The B^{11} target was 0.3 mg/cm^2 of enriched B^{11} on a 0.001-in. Au backing. The Doppler shift of the 0.95-MeV transition was measured by two methods. The first of these was the direct method of comparing the measured shift between two angles of observation with that predicted by the kinematics of the reaction. In this method gamma-ray spectra from the target were recorded using a 3×3-in. NaI(Tl) crystal positioned alternately at 0° and 130° to the beam axis, with its front face 6.5 in. from the center of the target. A radioactive Cs^{137} source which emits gamma rays of 0.662 MeV was used not only for establishing a reference line in the pulse-height spectrum, but also for stabilizing the gain of the system by means of a Cosmic Radiation Laboratory Model 1001 Spectrastat. The Cs^{137} source was kept in a fixed position relative to the NaI(Tl) detector. The measurements were made at a deuteron energy of 2.1 MeV with a beam intensity of

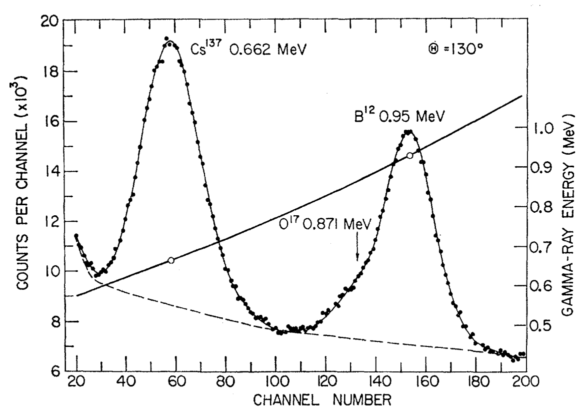

FIG. 1. Singles spectrum from 2.1-MeV deuterons incident on a 0.3 mg/cm^2 B^{11} target with the NaI crystal at 130° to the deuteron beam. The spectrum, which was taken with a bias of 0.54 MeV, contains the full-energy-loss peaks of the Cs^{137} 0.662-MeV gamma ray, and the O^{17} 0.871-MeV and B^{12} 0.95-MeV gamma rays. Note the suppressed zero on the intensity scale. The energy calibration is given by the vertical scale at the right and the slightly curved line passing through the open circles. The dashed curves illustrate the assumed background which was subtracted before the Cs 0.662-MeV gamma ray and the unresolved O^{17} 0.871-MeV and B^{12} 0.95-MeV gamma rays were fitted (solid lines) by a Gaussian least-squares computer program.

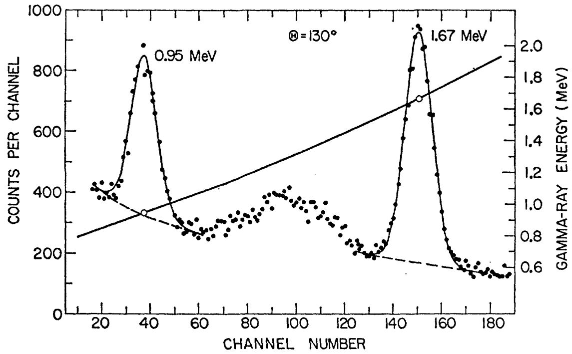

FIG. 2. Gamma-gamma coincidence spectrum from 3.0-MeV deuterons incident on a 0.3 mg/cm² B^{11} target. The display crystal was at 130° to the beam and the gating crystal at 90° to the beam with the gate set from 0.8 to 1.25 MeV. The spectrum was recorded with an analyzer bias of 0.7-MeV. The solid curves are least-squares Gaussian fits to the 0.95- and 1.67-MeV full-energy-loss peaks after subtraction of the backgrounds illustrated by the dashed curves. The energy calibration is given by the vertical scale at the right and the slightly curved line passing through the two open circles.

0.025 μA and consisted of 17 spectra taken alternately at the two angles.

Figure 1 shows a typical spectrum obtained at 130° to the beam. This spectrum was recorded in 200 channels of the RIDL 400-channel analyzer (nine of the spectra were recorded in all 400 channels). The spectra were recorded with a bias of 0.54 MeV. A voltage-versus-channel curve was measured for the analyzer under the conditions of the experiment with a Cosmic Radiation Lab model MP 301 pulser. This curve, which was slightly nonlinear as shown in Fig. 1, was used to convert channel shifts into energy shifts.

The spectra were analyzed to obtain the Doppler shift of the B^{12} 0.95-MeV transition between 0° and 130° to the beam using both the graphical method previously used for the Be^{10} 3.37-MeV transition[9] and a Gaussian least-squares fit computer program.[10] The graphical method of analysis weighs heavily the points nearest the peaks and thus has the advantage in the present case of minimizing the error due to the presence of the O^{17} 0.871-MeV gamma ray. This gamma ray, which is due to the $O^{16}(d,p)O^{17}$ reaction originating from oxygen contamination of the target, causes the asymmetry on the low-energy side of the B^{12} 0.95-MeV peak shown in Fig. 1. The computer program fits up to seven Gaussian peaks to a spectrum after an assumed background has been subtracted. The dashed curves in Fig. 1 show the assumed backgrounds while the solid line drawn through the points is the computer fit, assuming three peaks added to the assumed background. The Cs^{137} peak was fitted independently while the 0.87- and 0.95-MeV peaks were fitted together.

The average shift obtained was 4.5±0.4 keV from the graphical method, and 4.2±0.4 keV from the Gaussian fit method. The internal error which is given is in good agreement with the estimated accuracy of the methods. We adopt 4.35±0.4 keV for the Doppler shift of the B^{12} 0.95-MeV gamma ray under the conditions of the experiment.

At a deuteron energy of 2.1 MeV the second excited state of B^{12} at 1.67 MeV (but not the third excited state at 2.62 MeV) is populated.[1] The B^{12} 1.67-MeV level decays predominantly to the B^{12} ground state with a small (~3%) branch to the 0.95-MeV level. The Doppler shift of the B^{12} $1.67 \rightarrow 0$ transition was also measured at $E_d = 2.1$ MeV using the same method that was used for the B^{12} 0.95-MeV level. Eight spectra were taken alternately at 0° and 130° to the beam using the Na^{22} 1.28-MeV gamma ray to provide a reference peak and to stabilize the gain. These data were also analyzed both graphically and using the Gaussian least-squares fit computer program. The graphical analysis yielded 16.7±0.6 keV and the least-squares method yielded 17.1±0.6 keV where internal errors are given. We adopt 16.9±0.6 keV for the Doppler shift of the B^{12} $1.67 \rightarrow 0$ transition under the conditions of the experiment.

The expression for the Doppler shift between two angles of observation, θ_1 and θ_2 appropriate for the direct method, is

$$\Delta E = \beta_{\mathrm{c.m.}} F' [1 + \gamma^{-1} \langle \cos\theta_{\mathrm{c.m.}} \rangle] (\cos\theta_1 - \cos\theta_2) E_\gamma, \quad (1)$$

where $\beta_{\mathrm{c.m.}}$ is the speed of the center-of-mass in the laboratory system, γ is the ratio of the speed of the center-of-mass in the laboratory system to the speed of the recording nuclei in the center-of-mass system, E_γ is the energy of the transition, and $\langle \cos\theta_{\mathrm{c.m.}} \rangle$ is the average value of the cosine of the angle of the recoiling nuclei to the beam in the center-of-mass system. The quantity F' is a fraction which takes account of the attenuation of the Doppler shift due to the slowing down of the recoiling nuclei in the stopping material. It contains the information of interest on the lifetime of the emitting state. The angular distribution of the protons in the reaction $B^{11}(d,p)B^{12}$ (0.95-MeV level) has been measured at eight energies between $E_d = 1.2$ and 4.0 MeV, including $E_d = 2.1$ MeV.[5] From these results the quantity $\beta_{\mathrm{c.m.}}[1 + \gamma^{-1} \langle \cos\theta_{\mathrm{c.m.}} \rangle]$ for the $B^{11}(d,p)B^{12}$ (0.95-MeV level) reaction for a deuteron energy of 2.1 MeV and a 0.3 mg/cm² target (corresponding to a deuteron energy loss of 70 keV is found to be $(0.607 \pm 0.006) \times 10^{-2}$. From the geometry of our measurement we find $\cos\theta_1 - \cos\theta_2 = 1.641 \pm 0.001$. Combining these values with the measurement $\Delta E = 4.35 \pm 0.4$ keV and using Eq. (1) we obtain $F' = 0.44 \pm 0.04$. In principle this result should be corrected for the small percentage (~3%[1]) of the 0.95-MeV gamma-ray yield, which is due to the B^{12} $1.67 \rightarrow 0.95 \rightarrow 0$ cascade. However, the expected Doppler shift of the 0.95-MeV gamma ray from this source, i.e., $(0.95/1.67)(16.9 \pm 0.6)F'$ keV, is within the uncer-

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[9] E. K. Warburton, D. E. Alburger, and D. H. Wilkinson, Phys. Rev. **129**, 2180 (1963).

[10] P. McWilliams, W. S. Hall, and H. E. Wegner, Rev. Sci. Instr. **33**, 70 (1962).

tainty of the measured shift so that the correction is negligible.

The second variation of the Doppler shift method used to obtain the lifetime of the B^{12} 0.95-MeV level was the gamma-gamma coincidence method described by Warburton, *et al.*[9] The B^{12} 2.62-MeV level, which decays predominantly to the 0.95-MeV level,[1] was populated at a deuteron energy of 3.0 MeV. A 3×3-in. NaI(Tl) crystal was fixed at 90° to the beam with its front face 2.2 in. from the target. A second 3×3-in. NaI(Tl) crystal was rotated between 0° and 130° to the beam with its front face 4.5 in. from the target. The RIDL analyzer displayed those pulses from the rotating crystal which were in coincidence with a gate centered on the 0.95-MeV gamma-ray full-energy-loss peak in the fixed crystal. The Na^{22} 1.28-MeV gamma ray provided the stabilization for the moving crystal spectra. Eight spectra were recorded alternately at the two angles. One of these, taken at 130° to the beam, is shown in Fig. 2. The 0.95-MeV full-energy-loss peak is due to coincidences with that part of the Compton distribution of the 1.67-MeV gamma ray which falls within the gate. The gate was set wide enough so that the 0.95-MeV peak was comparable in intensity to the 1.67-MeV peak. The contribution of random coincidences to the eight spectra was negligible. Thus, the Na^{22} 1.28-MeV peak, which was as intense as the 0.95-MeV peak in the singles spectra, is not apparent in Fig. 2.

The solid lines drawn through the points of the two full-energy-loss peaks of Fig. 2 were generated by the Gaussian least-squares computer program. The exponential background assumed for the coincidence spectra is shown by the dashed curves in Fig. 2. The data were also analyzed by the graphical method. The average values obtained for the Doppler shifts of the B^{12} $2.62 \rightarrow 0.95$ and $0.95 \rightarrow 0$ transitions were 19.1 ± 0.8 and 7.2 ± 0.7 keV for the least-squares method and 20.7 ± 1.0 and 7.9 ± 1.0 keV for the graphical method. We adopt 19.8 ± 0.9 and 7.4 ± 0.7 keV, respectively.

Assuming that the correlation between the recoiling nuclei and the 1.67-MeV gamma ray in the B^{12} $2.62 \rightarrow 0.95 \rightarrow 0$ cascade is negligible, the attenuation factor F' for this method is given by[9]

$$F' = (1.67/0.95)[(7.4\pm0.7)(19.8\pm1.1)],$$

where the uncertainty on the shift of the 1.67-MeV gamma ray includes an estimate of the possible systematic error due to the fact that the Na^{22} 1.28-MeV reference line was not observed in this measurement. The result is $F' = 0.66\pm0.07$. Note that the F' values for the two different methods should not necessarily be equal (see next section). The results of the measurement of the F' values are analyzed in the next section to obtain an estimate of the lifetime of the B^{12} 0.95-MeV level.

ANALYSIS

We use the procedure described by Warburton *et al.*[9] which takes the range-velocity relationship for the recoiling nuclei to be

$$R = \alpha\{v - (2/\pi)v_n \tan^{-1}[(\pi/2)(v/v_n)]\}, \quad (2)$$

where α and v_n are to be evaluated from experimental stopping power and range data for light nuclei. The relationship implies

$$F' = F[1 - \delta(\gamma_i)], \quad (3)$$

where F is the attenuation factor for the range-velocity relationship $R = \alpha v$ and is given by $F = [\lambda\alpha/(1+\lambda\alpha)]$, with λ being the inverse of the mean lifetime γ of the transition, and where $\gamma_i = (\pi/2)v_i/v_n$, with v_i representing the initial velocity of the moving ion. The small correction factor $\delta(\gamma_i)$ is given as a function of $\lambda\alpha$ and v_i/v_n.[9] It should be averaged over the distribution of v_i given by the angular distribution of the recoiling nuclei.

There is no experimental data for the stopping of boron nuclei in boron; therefore, values of α and v_n were obtained by interpolation from data for nearby nuclei[11,12] using the previously described[9] procedure. The results for the stopping of B^{12} in B^{11} are $\alpha = (5.1\pm0.6)\times10^{-13}$ sec and $v_n/v_0 = 0.3$, where $v_0 = c/137$. The uncertainty in the stopping time α is partially due to the uncertainty in our knowledge of the density of the B^{11} target which was taken to be 1.8 ± 0.1 mg/cm^3.

The B^{11} target used was 0.3 mg/cm^2 thick while the range of the recoiling B^{12} ions (all of which travel in the forward direction since the reactions used are endomomental) varies from about 0.015 to 0.25 mg/cm^2. Thus, a significant fraction of the B^{12} ions enter the gold backing and are stopped in it. However, the correction for this effect is small. First we assume that the B^{12} nuclei all stop completely in the B^{11} target. Then we estimate the correction due to this assumption.

For the direct measurement of the 0.95-MeV gamma-ray Doppler shift, the correction factor $\delta(\gamma_i)$ was evaluated by averaging over the angular distribution[5] of the reaction, using the iterative method which has been previously described.[9] The result is $\delta(\gamma_i) = 0.11\pm0.02$ which combines with the experimental value $F' = 0.44 \pm0.04$ to give $F = (0.50\pm0.05)$. For the gamma-gamma coincidence method the angular distribution of the recoiling nuclei is not known; however, the correction factor is smaller and is confined to a smaller range than for the direct method. Thus, the correction factor can be estimated with adequate accuracy. The result of the iterative method is $\delta(\gamma_i) = (0.03\pm0.01)$ and combining this with the measurement of F' we have $F = 0.68\pm0.07$.

The correction for the finite thickness of the B^{11} target is made using an expression given by Devons *et al.*[13] for the attenuation factor F' in the case that the recoiling nuclei traverse a distance x (with $x \leqslant R$) in one

[11] D. I. Porat and K. Ramavataran, Proc. Roy. Soc. (London) **A252**, 394 (1959); Proc. Phys. Soc. (London) **77**, 97 (1961); **78**, 1135 (1961).
[12] D. Powers and W. Whaling, Phys. Rev. **126**, 61 (1962).
[13] S. Devons, G. Manning, and D. St. P. Bunbury, Proc. Phys. Soc. (London) **A68**, 18 (1955).

material before stopping in a more dense material. The expression is derived for the case $R=\alpha v$ which is an adequate representation of the range-velocity relationship for estimating the correction. The stopping time α for B^{12} in gold is obtained by interpretation of data[11] for the stopping power of gold for He^4, C^{12}, N^{14}, and O^{16} and is $(3.07\pm0.15)\times10^{-13}$ sec. Using the relationship given by Devons *et al.*[13] we estimate a $(4\pm2)\%$ increase in the F value for the direct method and a $(2\pm1)\%$ increase for the gamma-gamma coincidence method. Applying these corrections and averaging the two independent measurements gives $F=(0.60\pm0.06)$ where we have retained the 10% uncertainty of the two individual measurements since they do not overlap.

Using the relation $F=\lambda\alpha/(1+\lambda\alpha)$ and the final averaged value $F=(0.60\pm0.06)$ results in $\lambda\alpha=1.5\pm0.4$ where the uncertainty has been rounded off. Using $\alpha=(5.1\pm0.6)\times10^{-13}$ sec we obtain a mean lifetime $\tau(=\lambda^{-1})$ for the B^{12} 0.95-MeV level of $(3.4\pm1)\times10^{-13}$ sec.

LIMIT ON THE INTENSITY OF $E2$ RADIATION

Wilkinson[8] lists three sum rules which are applicable to $E2$ transitions. For a 0.95-MeV transition in B^{12} his Eqs. (19), (20), and (22) give upper limits on the $E2$ radiative width of 6, 145, and 25 times the Weisskopf estimate, respectively. The first limit is not rigorous while the other two are much stricter. We adopt the last limit given above which arises from the rule $\Gamma_\gamma\leqslant Z^2\Gamma_{\gamma w}$, where $\Gamma_{\gamma w}$ is the Weisskopf estimate of the $E2$ radiative width evaluated for a radius constant $r_0=1.2F$. Using this limit we find for a 0.95-MeV transition in $B^{12}\Gamma_\gamma\leqslant2.57\times10^{-5}$ eV which corresponds to an upper limit on the mean lifetime of 2.6×10^{-11} sec. Since we have measured the mean lifetime of the ground-state decay of the B^{12} 0.95-MeV level to be $\tau=(3.4\pm1)\times10^{-13}$ sec, we conclude that this transition must be predominantly $M1$, and since the B^{12} ground state has $J^\pi=1^+$, the B^{12} 0.95-MeV level must have $J\leqslant2$.

We can now use the limit on the $E2$ radiative width to set a limit on δ^2, the intensity ratio of $E2$ to $M1$ radiation for the B^{12} $0.95\rightarrow0$ transition. We take the experimental lower limit on the mean lifetime to be two standard deviations from the measured value and obtain $\delta^2\leqslant5.4\times10^{-13}/2.6\times10^{-11}=0.02$.

ANGULAR DISTRIBUTION OF THE B^{12} 0.95-MeV GAMMA RAY

The angular distribution of the B^{12} $0.95\rightarrow0$ transition following the $B^{11}(d,p)B^{12}$ reaction has been measured[14] at a deuteron energy of 0.8 MeV. The measurement was inconsistent with the form $W(\theta)=1+A_2P_2(\cos\theta)$ and was interpreted to demand relatively large terms in $P_\nu(\cos\theta)$ with $\nu\geq4$, thus fixing the limit $J\geq2$ for the B^{12} 0.95-MeV level. In view of the limit on the intensity of $E2$ radiation which we have found from the lifetime measurement, such an angular distribution would be surprising. This is so because the coefficient of the P_4 term would be proportional to δ^2 for $J=2$ and zero for $J=1$. For this reason the angular distribution of the B^{12} $0.95\rightarrow0$ transition was remeasured at a deuteron energy of 0.8 MeV.

The distribution was measured using the same apparatus and target as was used for the Doppler shift measurements. The angular distribution table was aligned to 0.5%, using the isotropic 0.87-MeV gamma ray from the $O^{16}(d,p)O^{17}$ reaction with the 3×3-in. NaI crystal 7.9 in. from the target. Spectra were recorded every 15° between 0° and 90° to the beam axis. A least-squares analysis of the data yielded $W(\theta)=1-(0.035\pm0.01)P_2(\cos\theta)$ with no evidence for terms of higher order. This result is in marked disagreement to the previous measurement.[15] We conclude that the angular distribution, being nonisotropic, rules out $J=0$ but allows $J=1$ or 2.

SPIN PARITY OF THE B^{12} 0.95-MeV LEVEL

There is further evidence which, when combined with that which we have presented, gives a strong preference for the 2^+ assignment. This evidence is from a measurement by Gorodetzky *et al.*[3] of the $p-\gamma$ angular correlation in the $B^{11}(d,p)B^{12}$ $(0.95\rightarrow0)$ reaction at a deuteron energy of 5.5 MeV. With the proton counter set at 20° to the beam the angular correlation was found to be $W(\theta)=1+(0.35\pm0.07)P_2(\cos\theta)$ where θ is the angle between the gamma-ray detector and the recoil axis. This result also rules out $J=0$ but allows $J=1$, 2, or 3 if there are no limitations on δ^2. For $J=2$ the angular correlation is consistent with any value of δ^2. However, for $J=1$ the plane-wave stripping model gives agreement with the measured angular correlation only for values of δ^2 greater than 0.16. Since our upper limit on δ^2 is 0.02, it is clear that a plane-wave stripping interpretation of the measurement of Gorodetzky *et al.*,[3] when combined with the present work, is inconsistent with a $J^\pi=1^+$ assignment to the B^{12} 0.95-MeV level. We note that distortion effects in the $B^{11}(d,p\gamma)B^{12}$ reaction are not expected to increase the anisotropy of the $p-\gamma$ correlation but may decrease it.[16] The result of this is that the lower limit on δ^2 of 0.16 obtained for the $p-\gamma$ correlation for $J^\pi=1^+$ will possibly be raised by distortion effects but should not be lowered by such effects. For $\delta^2\leqslant0.02$ the largest value of the coefficient A_2 allowed in the $p-\gamma$ angular correlation by the plane-wave theory is $A_2\simeq0.1$, which is about three standard deviations below the measured value of Gorodetzky *et al.*[3] (Similar arguments to those given here based on work of Garg *et al.*,[17] have been presented to show that

[14] E. Kondaiah and C. Badrinathan, Nucl. Phys. **15**, 254 (1960).

[15] That something is wrong with the previous measurement (Ref. 14) of the angular distribution is indicated by the fact that it deviates from symmetry about 90° by >7 standard deviations.

[16] R. Huby, M. Y. Refai, and G. R. Satchler, Nucl. Phys. **9**, 94 (1958).

[17] J. B. Garg, N. H. Gale, and J. M. Calvert Nucl. Phys. **37**, 319 (1962).

the B^{10} 5.16-MeV level does not have[18] $J^\pi=1^+$.) We conclude that the experimental evidence indicates $J^\pi=2^+$ for the B^{12} first excited state.

CONCLUSIONS

The Doppler shift attenuation method was used to obtain an estimate of $(3.4\pm1)\times10^{-13}$ sec for the lifetime of the B^{12} first excited state at 0.95 MeV. The accuracy of the method was limited by several considerations. The presence of an O^{16} impurity in the B^{11} gave rise to a 0.871-MeV gamma ray which limited to some extent the accuracy of the determination of the shift with angle of the 0.95-MeV gamma ray. The oxygen impurity was considerably worse with several thin (~30 μg/cm^2) targets which were tried; thus, the target thickness used was a compromise between the desire for sharp definition of the kinematics (thin target) and low oxygen impurity (thick target). For the medium thick target which we used, a correction for partial stopping in the gold backing was necessary. These considerations apply mainly to the direct method. For the gamma-gamma coincidence method a limitation was the absence of a reference line in the coincidence spectra. This difficulty could have been avoided, as in a previous measurement,[9] if the Doppler shift of one of the decay modes of the B^{12} 2.62-MeV level had been measured in a separate experiment. However, the B^{12} $2.62\rightarrow0$ transition is too weak to use[1] and the major decay mode, $2.62\rightarrow0.95$, has practically the same energy as the B^{12} $1.67\rightarrow0$ transition and therefore cannot be used for a direct measurement of the Doppler shift. A further limitation was that the stopping time α for B^{12} in B^{11} had to be determined by interpolation from other data since the stopping of boron nuclei in boron has not been measured; and, furthermore, the density of the B^{11} target was not accurately known.

We have also reported measurements of Doppler shifts of the B^{12} $1.67\rightarrow0$ transition (at $E_d=2.1$ MeV) and the B^{12} $2.62\rightarrow0.95$ transition (at $E_d=3.0$ MeV). When angular distributions for the reactions $B^{11}(d,p)B^{12}$ (1.67-MeV level) at $E_d=2.1$ MeV and $B^{11}(d,p)B^{12}$ (2.62-MeV level) at $E_d=3.0$ MeV are measured, these Doppler shift measurements can be analyzed to yield information on the lifetimes of these states. In the meantime we can, without a detailed analysis, set coarse limits from our measurements of $\tau\lesssim5\times10^{-13}$ sec for both levels just because the Doppler shifts observed were not far from those expected for the deuteron energies used and assuming the angular distributions of the unobserved protons are not vastly different from those usually encountered.

The measurement of the Doppler shift by the gamma-gamma coincidence method was analyzed assuming that the correlation between the recoil nuclei and the cascade gamma rays can be neglected. Rough estimates of the effects of reasonable correlations indicate that this assumption is valid. The assumption was also made that the lifetime of the B^{12} 2.62-MeV level is fast compared to the stopping time α. If this assumption were wrong it would influence the analysis through the correction factor $\delta(\gamma_i)$. The measured Doppler shift of the B^{12} $2.62\rightarrow0.95$ cascade shows that this assumption cannot be greatly in error. We note that the effect of a long-lived B^{12} 2.62-MeV level would be to increase the F value obtained from this measurement, thus increasing the disagreement between the two determinations of the F value which we have reported.

It was shown that the B^{12} $0.95\rightarrow0$ transition is fast enough so that it must be predominantly dipole, thus demanding $J\leq2$ for the B^{12} 0.95-MeV level. Also, the angular distribution of the 0.95-MeV gamma ray at a deuteron energy of 0.8 MeV was nonisotropic so that $J=0$ is ruled out. We conclude that the experimental evidence reviewed or presented in this paper indicates $J^\pi=2^+$ for the B^{12} 0.95-MeV level

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