Lifetime of the First Excited State of B^{10}†

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We have measured the mean lifetime of the first excited state of B^{10} at 0.72 Mev as 1.05 ± 0.10 mμsec by bombarding B^{10} with pulsed beams of 3-Mev protons and studying the delayed emission of gamma rays. This figure is a little longer than that given by earlier measurements of the $E2$ lifetime using recoil methods. The result is compared with preliminary shell model calculations and it is concluded that it is probably inconsistent with those calculations, at least if one restricts oneself to the value of the intermediate coupling parameter that gives good agreement with the experimental level scheme. It seems that some collective motion must be envisaged even in so light a nucleus as B^{10}.

INTRODUCTION

THE lifetime of any radiative transition in the light nuclei is of great interest because of the many detailed theoretical treatments of these nuclei now becoming available. In particular, $E2$ transitions have added interest because they are sensitive to the admixture of small amounts of collective motion in a description which may otherwise be made satisfactorily in terms of the shell model.

B^{10} is a nucleus of whose low-lying states the shell model in intermediate coupling gives an excellent account,[1] and it is therefore important to test the internal consistency of that description by measuring the dynamical properties of these levels. We should require that the correct lifetimes for the radiative transitions be given by the same value of the intermediate-coupling parameter as gave the correct level scheme. In this paper we report a measurement of the lifetime of the first excited 1+ state at 0.72 Mev for the emission of $E2$ radiation to the 3+ ground state. Two earlier measurements exist of this lifetime and give $(7\pm2)\times10^{-10}$ second[2] and $(8.5\pm2.0)\times10^{-10}$ second.[3] Both these estimates were obtained by recoil methods. The first experiment was dependent to some degree in its interpretation on assumptions about the unknown angular distributions involved for the recoiling excited B^{10}; this difficulty was avoided in the second measurement by the use of a coincidence method. These lifetimes are rather short and it seemed important to obtain confirmation of these results by a direct timing method rather than by the indirect time-of-flight method and also to improve if possible on the accuracy of the measurements so that the test of the shell model should be as sharp as possible.

EXPERIMENTAL METHOD AND RESULTS

For the direct measurement of lifetimes as short as this, two methods are available. The first is the usual method of delayed coincidences in which two detectors are arranged to respond the first to a particle or to a gamma ray leading to the level of interest and the other to the gamma ray from that level. This method has the disadvantage that for determining the "prompt" position of the resolution curve both radiations must be matched and this is rather awkward if the first radiation is a particle. If both radiations are gamma rays and if more than the single cascade is present, there will generally result a complex resolution curve whose analysis is very difficult. Either choice would have brought difficulties in the present case. The second method for lifetime measurement is to make the excited state at a time signalled by something other than a previous radiation. It is then possible to study the desired radiation cleanly without other radiations present if it comes from a first excited state which can be overwhelmingly populated. There is the additional advantage that the determination of the "prompt" resolution curve demands only the matching of the single radiation. We have used this second method in this investigation.

Three-Mev protons from the Brookhaven research Van de Graaff generator bombarded a thick target of B^{10} and excited the state of interest by inelastic scattering. The beam was pulsed by rf sweeping in the terminal of the generator at a frequency of 7.8 Mc/sec. The resulting bursts of protons had a full width at half-maximum of about 4 mμsec. This facility will be described elsewhere.[4] The timing of the bursts of protons was derived from the rf used to sweep the beam near the ion source which was radiated to a pickup probe in the wall of the generator tank. This signal was then used to sweep the electron beam of a Mullard 6218 electronic switching tube. The gamma rays from the B^{10} were detected in a plastic scintillator mounted on an RCA 6655 photomultiplier whose output was amplified by a chain of Hewlett-Packard fast amplifiers,

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[1] D. R. Inglis, Revs. Modern Phys. **25**, 390 (1953); D. Kurath, Phys. Rev. **101**, 216 (1956).
[2] J. Thirion and V. L. Telegdi, Phys. Rev. **92**, 1253 (1953).
[3] J. C. Severiens and S. S. Hanna, Phys. Rev. **104**, 1612 (1956).
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clipped by 14 inches of shorted cable and applied to the control electrode of the 6218. The output of this tube was then amplified, passed through a simple discriminator, and used to indicate "coincidences" between the gamma rays and the rf or incident burst of protons. An additional slow circuit was used to veto these coincidences unless the pulse height from the plastic scintillator, amplified in a separate slow linear circuit, fell in a specified range. It was possible to insert a variable delay in the gamma-ray arm of the 6218 circuit and in this way the resolution curve could be determined, a smaller delay corresponding to later emission of the gamma ray.

Under our conditions two strong gamma rays were seen. These were the desired 720-kev gamma ray from B^{10} and the 430-kev line from the first excited state of Be^7 formed in $B^{10}(p,\alpha)Be^7$. The slow veto channel was set to accept pulses in a narrow range of energy on the Compton plateau of the 720-kev line well clear of the other. There were also very weak higher energy gamma rays which amounted to about 3% of the counts in the slow channel produced by the desired gamma ray. The effect of these gamma rays was neglected. They were presumably of much shorter lifetime than the first excited state. To measure the "prompt" resolution curve, a target of aluminum was substituted for the B^{10}, all other conditions being kept constant so that the energy which we required to be spent in the plastic scintillator by the prompt radiation should be the same as that spent by the delayed B^{10} radiation.

With these conditions both B^{10} and prompt Al resolution curves were measured. In order to minimize the effects of drift in the accelerating voltage and so on, the measurements at each delay were sandwiched between two measurements of counting rate at a standard delay chosen to be on the steepest portion of the resolution curve so as to be most sensitive to drifts. If either of the standard sandwiching runs was unsatisfactory, the measurement was rejected. The runs were monitored by pulses in the slow arm of the circuitry. In this way several resolution curves were taken both with B^{10} and with Al as the target. The two targets were interchanged at each delay so the resolution curves were interlaced. Figure 1 shows a typical comparison of the two curves. The B^{10} curve is seen to be clearly shifted relative to the prompt curve. On the basis of the statistical accuracy and reproducibility of these curves, we could determine the centroid shift between these distributions, which is equal to the mean lifetime of the delayed radiation, to better than ± 0.05 mμsec. However, we feel that possible systematic errors should lead us to increase the error somewhat and we quote for the mean lifetime 1.05 ± 0.10 mμsec.

As a check on the functioning of the apparatus and of the validity of our procedure for determining the prompt resolution curve, we examined the 477-kev gamma ray from the first excited state of Li^7 which we excited by inelastic scattering from a target of LiOH.

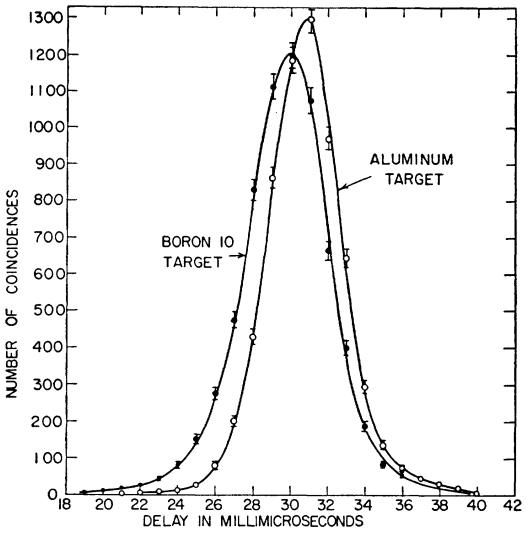

FIG. 1. Prompt and delayed resolution curves given by bombarding aluminum and B^{10} with pulsed beams of 3-Mev protons. The variable delay is inserted in the gamma-ray leg of the coincidence circuit.

All conditions were kept the same as in the work with B^{10} except that the slow channel of the veto circuit was now moved down in energy to the Compton plateau of the 477-kev line. Aluminum was similarly used as the nominal prompt source with this time, of course, the same lower slow channel as for the LiOH runs. Exactly the same sandwiching and interlacing procedure was used as before. Since the lifetime of the 477-kev state is about 10^{-13} second, we should obtain no centroid shift in this case. There was actually a shift of 0.024 mμsec which is covered by the uncertainty of ± 0.05 mμsec which attends the analysis of the resolution curves. We accepted this result as an assurance that the apparatus was functioning correctly.

DISCUSSION

Our result of 1.05 ± 0.10 mμsec is consistent with the earlier time-of-flight results although a little longer than them. The complete comparison with the shell-model calculations is not yet possible since only preliminary figures are available at a few values of the intermediate-coupling parameter a/K.[5] It seems, however, that agreement with these calculations will be difficult to achieve for a realistic value of $\langle r^2 \rangle$ consistent with the electron-scattering results in the light elements.[6] The theoretical lifetime in the region of $a/K \sim 4.5$ which gives a good fit to the level scheme is more than 10 mμsec. Theoretical lifetimes shorter by a factor of 5 may be found in the region of $a/K \sim 1.5$, but such small values of the intermediate coupling parameter give much poorer fit to the level scheme. It therefore

[5] D. Kurath (private communication).
[6] R. Hofstadter, Report to 1956 International Conference on Nuclear Reactions, Amsterdam (to be published).

seems that we may, in even so light an element as boron, have to invoke some collective motion to explain the short lifetime of this $E2$ transition. This is in keeping with results in O^{17}, F^{19}, and possibly N^{16} among the light elements.

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Attenuation of Am^{241} α-γ Angular Correlation in Liquid Film Sources*

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Measurements of the alpha-gamma correlation of Am^{241} have been carried out for liquid sources. Attenuation of the angular correlation pattern with time was measured and λ_2 was determined for HCl, H_2SO_4, and $HClO_4$ media. For HCl and $HClO_4$ $\lambda_2=13.5\pm2$ per μsec and for H_2SO_4 $\lambda_2=21\pm2$ per μsec. These attenuation constants were independent of the concentration. The extrapolated value of A_2 has been compared with a prediction based on the rotational model.

INTRODUCTION

EXPERIMENTS have shown that liquid sources tend to give much more nearly the expected theoretical angular correlation of successive nuclear radiations than do solid sources. Abragam and Pound[1] offered a theory to explain this tendency and gave a quantitative description of the attenuation one should expect in liquid sources. Abragam and Pound assumed that the attenuation in liquids is caused by the interaction of the electric quadrupole moment of the intermediate nuclear state with an electric field which changes continually in a random manner. This changing interaction produces transitions between the sublevels of the intermediate state, and is manifested quantitatively by an attenuation factor,

$$G_k(t)=e^{-\lambda_k t} \tag{1}$$

in the formula for the angular correlation,

$$w(\theta,t)=\sum G_k(t)A_kP_k(\cos\theta). \tag{2}$$

In these expressions, θ is the angle between the directions of the radiations, the P_k are even Legendre polynomials, the A_k are the angular correlation coefficients for the unperturbed correlation, and the λ_k are coefficients which depend on the magnitude of the quadrupole interaction, the correlation time of the fields in the liquid (τ_c) and the spin of the intermediate nuclear state. Equation (1) is valid when the correlation time of the liquid fields is small compared to the time which would be required for the quadrupole interaction to produce an appreciable attenuation. The validity of Eq. (1) can be checked by measurement of $w(\theta,t)$ with suitable delayed coincidence techniques. The G_k and A_k can be obtained separately in such an experiment.

The Zurich Group[2] made a series of measurements with the cascade of Cd^{111} gamma rays which follows K capture in In^{111}. For indium metal dissolved in liquid gallium and for $InCl_3$ dissolved in water, no time-dependent attenuation was observed. Glycerin added to the latter type of sources produced attenuation but experimental difficulties prevented a quantitative comparison with the theory. A measurement[3] of the cascade of Pb^{204m} involved delay times up to 6×10^{-7} sec and no time-dependent attenuation was observed in a nitric acid medium. More recently, Steffen[4] has made measurements similar to those of reference 2 and reports that his results are in agreement with Eq. (1).

We have measured $w(\theta,t)$ for the coincidences between the alpha particles of Am^{241} and the 59.6-kev gamma ray which follows the 7×10^{-8}-sec state of Np^{237} (Fig. 1), in several types of liquid source. In addition to the test of Eq. (1), this problem is of importance in connection with the measurement of the gyromagnetic ratio of the 59.6-kev state of Np^{237}.

APPARATUS AND SOURCES

The electronic apparatus included differential analyzers and a fast-slow coincidence scheme. An anthracene crystal 0.25 inch thick was used to detect the alpha particles and a NaI(Tl) crystal 2.5 inches in diameter and 2 inches thick was used for the gamma rays. The resolving time (2τ) varied between 20 and 35 mμsec. An automatic system controlled the moving

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