Lifetime of the First Excited State of C^{15}

R. A. Mendelson, Jr., and R. T. Carpenter
Department of Physics and Astronomy, University of Iowa, Iowa City, Iowa
(Received 1 September 1967)

The lifetime of the first excited state of C^{15}(0.750 MeV, $\frac{5}{2}^+$) produced in the $Be^9(Li^7,p)C^{15}$ reaction was measured using the delayed-coincidence technique. A solid-state detector was used to measure the energies of the protons as well as to produce timing signals. The mean lifetime was determined to be $(3.77\pm0.11)\times10^{-9}$ sec. This result is in good agreement with an earlier value of $(3.73\pm0.23)\times10^{-9}$ sec obtained using a pulsed-beam method. Disagreement with weak-coupling collective-model predictions based on neighboring $2s_{1/2}\rightarrow 1d_{5/2}$ transitions is thus not removed.

I. INTRODUCTION

Recent independent-particle-model calculations have rather successfully described level schemes and $M1$ transition rates in the $1p$ and $2s-1d$ shells.[1,2] Observed $E2$ transition rates in these nuclei, however, are generally enhanced over predicted values, presumably because of collective effects.

This disagreement has recently led to more accurate measurements of $E2$ transition rates near $A=16$.[3,4] In particular, the lifetimes of the $2s_{1/2}\rightarrow 1d_{5/2}$ single-neutron and single-proton transitions have been remeasured because of their relevance to this problem of $E2$ enhancement.[4]

This work was undertaken to further this study by the measurement of the lifetime of the 0.750-MeV first excited state of C^{15}. The decay of this state represents a single $1d_{5/2}\rightarrow 2s_{1/2}$ neutron transition outside of a $J^\pi=0^+$, C^{14} core. A previous measurement of this lifetime was made utilizing a pulsed beam with the reaction $C^{14}(d,p)C^{15}$.[5] The γ-ray energy was determined by means of a NaI(Tl) crystal which was also used for timing purposes. The value obtained in this experiment[5] was $\tau_m=3.73\pm0.23\times10^{-9}$ sec. The greatest source of error was from uncertainties in background subtraction due, in part, to the possibility of neutron groups distorting the data.

In the present experiment, the technique consisted of measuring the time differences between protons signifying the formation of the state and the decaying γ rays from the state. A solid-state detector was used to determine the proton's energy as well as to produce a timing signal. The γ ray was detected by a plastic scintillator mounted on a fast photomultiplier. This technique provided positive identification of the state, ensured that neutrons could not distort the data, and gave superior time resolution when compared with the pulsed-beam and NaI(Tl) crystal method.

[1] D. Kurath, Phys. Rev. **101**, 216 (1965).
[2] S. Cohen and D. Kurath, Nucl. Phys. **73**, 1 (1965).
[3] J. A. Becker, J. W. Olness, and D. H. Wilkinson, Phys. Rev. **155**, 1089 (1967).
[4] J. A. Becker and D. H. Wilkinson, Phys. Rev. **134**, B1200 (1964).
[5] J. Lowe, C. L. McClelland, and J. V. Kane, Phys. Rev. **124**, 1811 (1962).

II. EXPERIMENTAL

The 0.750-MeV first excited state of C^{15} was generated by the reaction

$$Be^9(Li^7,p)C^{15}+9.12\text{ MeV},$$

using a 5.10-MeV Li^7 ion beam obtained from the University of Iowa type CN Van de Graaff accelerator.

The target was Be^9 metal evaporated on 1-mil copper backing. The thickness was approximately 300 keV to the 5.10-MeV Li^7 ion beam. An additional 8 mils of copper was used to degrade the proton energy in order that they stop in the surface-barrier detector.

A Naton-136 plastic scintillator (3.8 cm long$\times$3.2 cm in diameter) viewed the target at 90° to the beam axis and had its front face 1.3 cm from the target center. The solid-state detector was located on the beam axis 3.2 cm from the target and subtended an angle of $\pm10°$. The detector used was 1000 μ thick, total depleted, of 100-mm² area.

The electronics used here (Fig. 1) were very similar to those described elsewhere.[6] A pile-up gate has been added in order to further decrease the pulse-pair resolution.[7] The time-to-pulse-height converter (TPHC) used was of the stop-start variety with the output delayed about 600 nsec from the occurrence of the coincidence event. This allowed the pile-up gate to inspect for pulse pairs whose separation was less than 600 nsec and inhibit the TPHC output if such a pair were present. This system had a minimum pulse-pair resolution time of about 10 nsec, which when combined with the fast linear gate (100 nsec) virtually eliminated pile-up of γ-ray pulses in the slow electronics.

The linear signals were processed by the usual slow electronics. A triple slow (1-μsec) coincidence between the linear signals opened the linear gates to pass the γ ray and time signal to the computer-based two-parameter analyzer. Data were accumulated with 2048-channel detail on the time axis and 30 channels on the γ-ray energy axis. A window was set on the particle group corresponding to the first excited state of C^{15}.

[6] R. A. Mendelson, Jr., and R. T. Carpenter, Phys. Rev. **152**, 1002 (1966).
[7] All fast electronics, other than amplifiers, are commercial units produced by E. G. and G., Inc., 35 Congress Street, Salem, Mass.

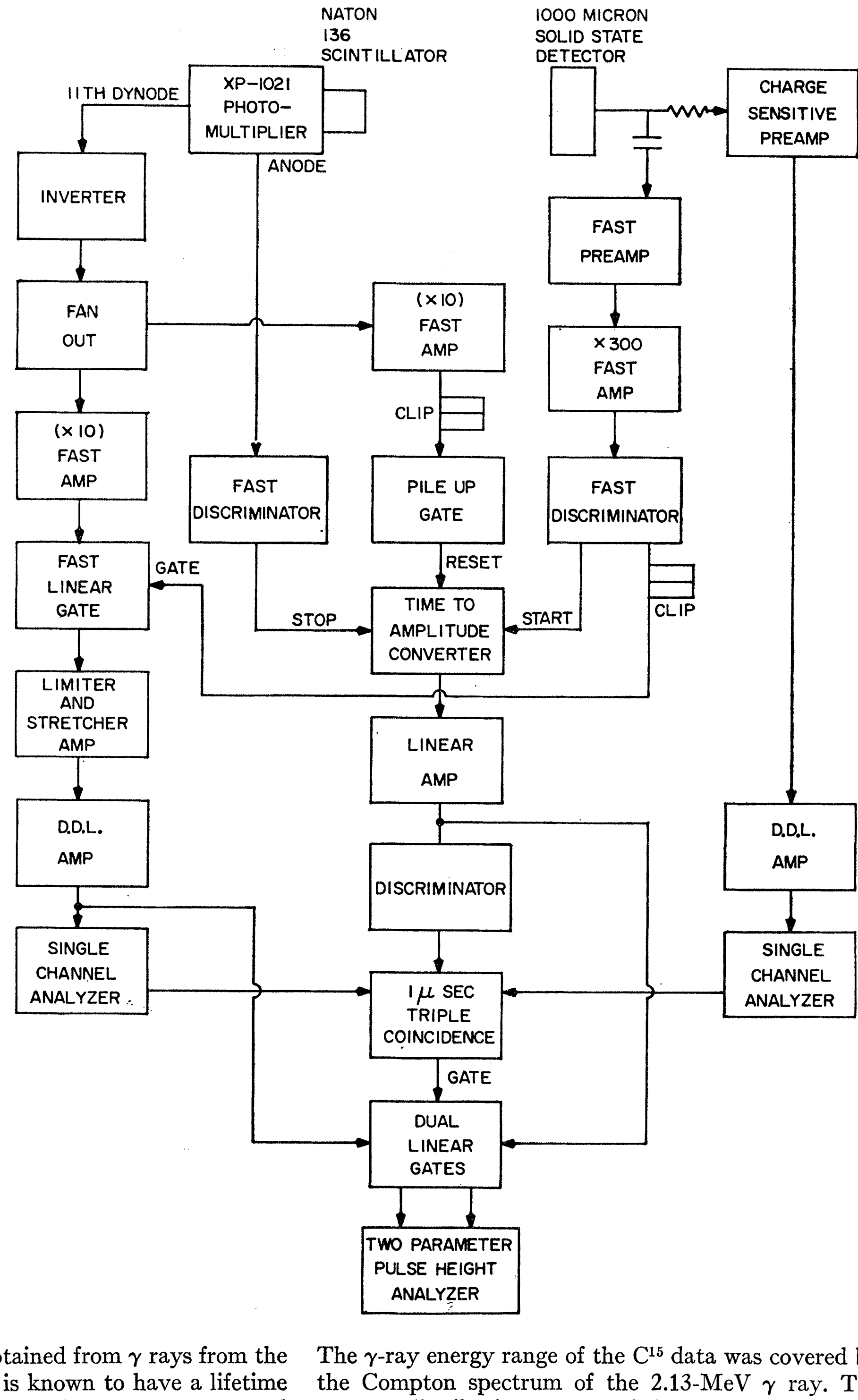

FIG. 1. Block diagram of electronic equipment.

The prompt peak was obtained from γ rays from the B^{11} 2.13-MeV state, which is known to have a lifetime of $\tau_m = (4.6\pm0.6)\times10^{-15}$ sec.[8] This state was generated by the reaction $Be^9(He^3,p)B^{11}+10.33$ MeV. The He^3 bombarding energy was adjusted so that the particle group fell in the same window as used for the C^{15} data. The γ-ray energy range of the C^{15} data was covered by the Compton spectrum of the 2.13-MeV γ ray. The prompt distribution was used for pulse-height compensation as has been described previously.[6] Approximately 70% of the Compton spectrum was used.

The possible contaminants for the reaction were

$$C^{12}(Li^7,p)O^{18}+8.41 \text{ MeV},$$

$$O^{16}(Li^7,p)Ne^{22}+9.48 \text{ MeV}.$$

[8] F. R. Metzger, C. P. Swann, and V. K. Rasmussen, Phys. Rev. 110, 906 (1958).

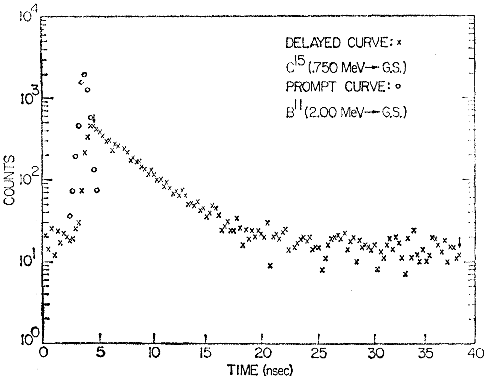

FIG. 2. Lifetime data for 0.750-MeV level in C^{15}. Arrows show region of least-squares fit used to obtain final value of lifetime.

The Q value of the carbon reaction was such that the first excited state (1.98 MeV) would be about 2 MeV below the C^{15} 0.75-MeV state. On the other hand, for the oxygen reaction, the first excited state of Ne^{22} (1.27 MeV) would fall within the C^{15} proton group window. It was expected that the yield from this contaminant would be quite small compared to that from beryllium because of the use of a fairly thick beryllium target as well as for the tendency of total cross section to drop sharply with increasing target Z for these bombarding energies. If there had been significant contaminant yield, the time distribution of γ rays from this state would have been prompt because of the short lifetime ($\sim 6\times 10^{-12}$ sec) associated with this state.[9] The observed time distribution (Fig. 2) showed no evidence for a prompt component. The time axis was calibrated using General Radio air lines. The root-mean-square deviation from the average time calibration was 1.2%; hence, only a very small error was introduced due to nonlinearities.

The data were fitted with the function

$$N_i = Ae^{iB} + C,$$

where N_i is the counting rate in channel i and A, B, C are parameters of the fit. The fitting program calculated the best A, B, and C and their errors by minimizing χ^2. The program was run 20 times for different values of initial and final fitting channels. Figure 3 shows parametric curves of the results of plotting the goodness-of-fit parameter $\lambda = (2\chi^2)^{1/2} - (2\nu - 1)^{1/2}$ versus initial channel (where ν is the number of degrees of freedom in the fit). Since the λ-versus-initial-channel curves (Fig. 3) were relatively flat, the variations in λ are apparently only due to statistical considerations. Hence, the initial and final channels giving the least λ (and best statistics) were chosen. The fitted curve with the background subtracted is shown in Fig. 4.

The statistical uncertainty was 2.1%. Including 2% for possible systematic errors gave $\tau_m = (3.77 \pm 0.11) \times 10^{-9}$ sec or $\tau_{1/2} = (2.61 \pm 0.07) \times 10^{-9}$ sec.

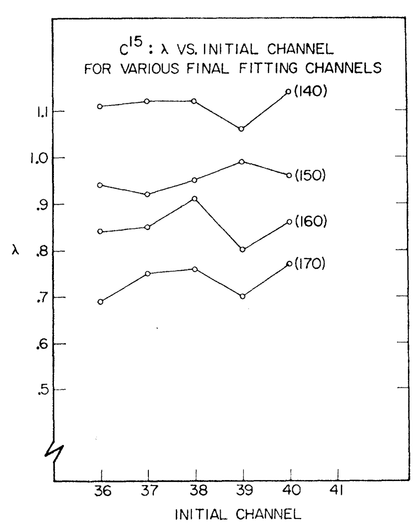

FIG. 3. $\lambda = (2\chi^2)^{1/2} - (2\nu - 1)^{1/2}$ versus initial channel of region of data to be fit. The parametric curves are for various final channels of region of fit.

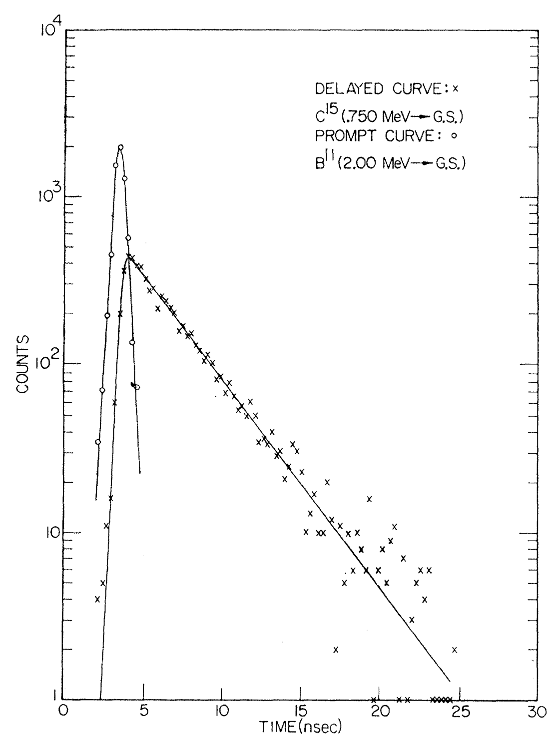

FIG. 4. Data with background subtracted. Exponential part of delayed curve shows fitted function (solid line).

[9] M. A. Erswan and C. Broode, Can. J. Phys. 42, 1311 (1964).

III. RESULTS

The measured mean life of $\tau_m=(3.77\pm0.11)\times10^{-9}$ sec is in good agreement with the results of Lowe *et al.*[2] who obtained a value of $(3.73\pm0.23)\times10^{-9}$ sec. This corresponds to a single-particle $E2$ lifetime of 0.4 Weisskopf (proton) unit.[10]

Raz has made weak-coupling calculations for nuclei in this region with good agreement for ratios of $E2$ transitions in neighboring nuclei.[11] In this model, the transition is considered to take place through oscillations of the surface of the core induced by the odd neutron. Raz's prediction of $(5.20\pm0.37)\times10^{-9}$ sec for the mean life of this C^{15} state is based on the deformability of the O^{17} core deduced for the $s_{1/2}\rightarrow 1d_{5/2}$ transition in O^{17}. The fact that the agreement is not satisfactory is explained for this model by assuming that the C^{14} core is more easily deformable than the O^{16} core[5].

[10] O. H. Wilkinson, in *Nuclear Spectroscopy, Part B*, edited by F. Ajzenberg-Selove (Academic Press Inc., New York, 1960), p. 852.

[11] B. J. Raz, Phys. Rev. **120**, 169 (1960).

PHYSICAL REVIEW VOLUME 166, NUMBER 4 20 FEBRUARY 1968

Model He^3 Problem with Separable Interactions*

S. Adya
Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania
(Received 21 September 1967)

The bound-state three-body system, with two of the particles charged, is considered using two approximate forms of the Coulomb Green's function $G^c(W)$. The nuclear potential between each pair is assumed to be of the separable s-wave form. The binding energy of the model He^3 system is calculated numerically for each of the two approximations for the Coulomb Green's function, and these results are compared with a first-order perturbation calculation.

I. INTRODUCTION

The aim of this paper is to study the three-body bound-state problem with two of the particles charged, and in particular to study various approximation schemes for including the Coulomb force. Using a simplified model for He^3, the binding energy is calculated using two different approximations for the Coulomb Green's function. The first of these is based on an approximate form of the Coulomb Green's function in momentum space, suggested by Schulman. The second is basically an improved version of Schulman's approximation. For brevity, these approximations will be called, respectively, approximations A and B, and are discussed in detail in Sec. III.

The results of the numerical calculations show that approximation A is not satisfactory, but approximation B gives a result which is not too unreasonable. Presumably, the latter result can be improved by using a better model for the short-range nuclear interaction than the one assumed here.

Finally, the Coulomb repulsion energy is calculated in a straightforward manner using first-order perturbation theory. This result will be denoted by C.

We treat the particles, which are taken to be of equal mass M, as distinguishable. Particles 1 and 2 are considered to be charged. As far as the short-range interactions are concerned, we assume only pairwise interactions. Intrinsic three-body forces are not considered. We also leave out spin, tensor forces, and hard-core saturation effects.

The two-body short-range interaction is taken to be of the separable s-wave form

$$\langle q'|V|q\rangle=\lambda v(q')v(q)\,,$$

where

$$v(q)=(\beta^2+q^2)^{-1}$$

is the Yamaguchi potential.

Qualitatively, λ and β are, respectively, the coupling strength and the inverse range of the short-range interaction in configuration space.

We proceed in the following manner:

(1) Using the modified Faddeev equations,[1] the Fredholm determinant for the problem of three *uncharged* particles is set up. The vanishing of the Fredholm determinant gives the binding energy of the simplified model of the triton. Initially we take $\beta=1.33$ F^{-1}. This value of β is approximately the average of the singlet and triplet values[2] $\beta_s=1.16$ F^{-1} and $\beta_t=1.44$ F^{-1}. The coupling parameter λ is related to β through the fact that the two-body scattering matrix T, which satisfies the usual Lippmann-Schwinger equation, has

* Supported in part by the National Science Foundation.

[1] L. Faddeev, *Mathematical Aspects of the Three-Body Problem in Quantum Scattering Theory* (Israel Program for Scientific Translations, Jerusalem, 1966).

[2] Y. Yamaguchi, Phys. Rev. **95**, 1628 (1954). We use the low-energy n-p scattering data quoted in this reference.