PHYSICAL REVIEW VOLUME 141, NUMBER 3 JANUARY 1966

Lifetime of the 1.02-MeV State in Ne^{23}

D. B. FOSSAN, R. E. MCDONALD, AND L. F. CHASE, JR.
Lockhead Palo Alto Research Laboratories, Palo Alto California

(Received 2 August 1965)

The lifetime of the $\frac{1}{2}^+$ 1.02-MeV state in the Ne^{23} has been measured with a fast time-to-height converter. A half-life of (178±10) psec was obtained from the logarithmic slope of the distribution of time delays between protons from the $Ne^{22}(d,p)$ Ne^{23} reaction detected in a solid-state counter and gamma rays detected with a plastic scintillator. This lifetime measurement implies a $\frac{5}{2}^+$ assignment for the ground state in Ne^{23}; the deduced $B(E2)$ transition probability is consistent with the Nilsson model.

I. INTRODUCTION

LIMITED experimental information exists regarding the Ne^{23} nucleus. Using the $Ne^{22}(d,p)Ne^{23}$ reaction, Freeman[1] has observed the positions of 17 energy levels with a broad-range magnetic spectrograph. Stripping angular distributions[2] from the same reaction to the ground state and 1.02-MeV first excited state indicate the transfer of $l_n=2$ and $l_n=0$ neutrons, respectively, which implies a $\frac{1}{2}^+$ assignment for the 1.02-MeV level and either $\frac{5}{2}^+$ or $\frac{3}{2}^+$ for the ground state. De-excitation gamma-ray studies[3] indicate as most probable the assignments of $\frac{5}{2}^+$ for the ground state and $\frac{3}{2}^-$ for the 3.22-MeV state. McClelland *et al.*[4] have placed an upper limit of 3×10^{-10} sec to the mean life of the first excited state by a pulsed beam technique.

Successful interpretations[5,6,1] of the properties of odd-mass nuclei with N or Z equal to 13 have been made in terms of the Nilsson model.[7] In particular the ground states and the first excited states have been identified respectively with the $\frac{5}{2}^+$ [202] Nilsson orbit No. 5 and the $\frac{1}{2}^+$ [211] orbit No. 9. Evidence for the $\frac{5}{2}^+$ assignment suggested for the Ne^{23} ground state can be obtained by experimentally determining the transition probability between these two states. In addition the comparison of the experimental transition probability with the theoretical $B(E2)$ value determined from the Nilsson wave functions is a consistency check on the application of this model to Ne^{23}. Similar comparisons[8] have been made in Mg^{25}, Al^{25}, and Al^{27}, which also are odd-mass nuclei with N or Z equal to 13. Thus, the purpose of this experiment is to obtain an accurate value for the transition probability between these states in Ne^{23} by measuring the lifetime of the $\frac{1}{2}^+$ 1.02-MeV level. A particle-gamma coincidence technique[9] was used in the present measurement.

II. EXPERIMENTAL TECHNIQUE

The lifetime of the 1.02-MeV state in Ne^{23} was obtained from the logarithmic slope of the distribution of time delays between the formation and the decay of this state. The experimental technique used was similar to that described previously.[9] The time of formation of the 1.02-MeV level in Ne^{23} was determined by the detection of a proton from the $Ne^{22}(d,p)Ne^{23}$ reaction in a solid-state detector, while the time of decay was marked by the detection of a gamma ray in a plastic scintillator. The time-delay pulses were produced in a fast time-to-height converter in the usual fast-slow coincidence arrangement. The advantages of this technique have been discussed.[9] A schematic diagram of the experimental apparatus is shown in Fig. 1.

In this experiment, deuterons from the Van de Graaff accelerator bombarded a 1-cm-thick gas target equipped with 0.002-mm Havar windows at 0°, 90°, and 180°. A Ne^{22} gas pressure of about 25-cm Hg was used. The elemental purity of the gas was 99.85%, and the isotopic purity was 99.70%. The solid-state detector was positioned at 90° with appropriate collimation to minimize transit-time variations and kinematic energy spreads for the particles. The axis of the plastic scintillator was placed perpendicular to the reaction plane defined by the deuteron beam and the proton detector.

The solid-state detector was a 500-Ω cm silicon surface-barrier type of 100-μ thickness and 25-mm² area. To minimize the rise time, the solid-state detector was totally depleted. By means of a pick-off circuit,[10] fast pulses for timing purpose and the normal energy pulses were obtained; the detector energy resolution was about 50 keV.

---

[1] J. M. Freeman, Phys. Rev. **120**, 1436 (1960).

[2] H. B. Burrows, T. S. Green, S. Hinds, and R. Middleton, Proc. Phys. Soc. (London) **A69**, 310 (1956).

[3] A. J. Howard and D. A. Bromley, Bull. Am. Phys. Soc. **9**, 439 (1964).

[4] C. L. McClelland, J. Lowe, and A. J. Howard, Bull. Am. Phys. Soc. **8**, 49 (1963).

[5] H. E. Gove, in *Proceedings of the International Conference on Nuclear Structure at Kingston, Ontario*, edited by E. Vogt and D. A. Bromley (The University of Toronto, Toronto Press, 1960); A. E. Litherland, H. McManus, E. B. Paul, D. A. Bromley, and H. E. Gove, Can. J. Phys. **36**, 378 (1958); E. Almqvist, D. A. Bromley, H. E. Gove, and A. E. Litherland, Nucl. Phys. **19**, 1 (1960); S. Hinds and R. Middleton, Proc. Phys. Soc. **73**, 727 (1959).

[6] K. H. Bhatt, Nucl. Phys. **39**, 375 (1962).

[7] S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat. Fys. Medd. **29**, No. 16 (1955); B. R. Mottelson and S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat. Fys. Skrifter **1**, No. 8 (1959).

[8] A. G. T. Ferguson, M. A. Grace, and J. O. Newton, Nucl. Phys. **17**, 1 (1960); *Nuclear Data Sheets*, compiled by K. Way *et al.* (National Academy of Sciences–National Research Council, Washington, D. C., 1959), NRC 59-6-43.

[9] R. E. McDonald, D. B. Fossan, L. F. Chase, Jr., and J. A. Becker, Phys. Rev. **140**, 1198 (1965).

[10] Oak Ridge Technical Enterprises Corporation, Oak Ridge, Tennessee. Similar to that described by C. W. Williams and J. A. Biggerstaff, Nucl. Instr. Methods **25**, 370 (1964).

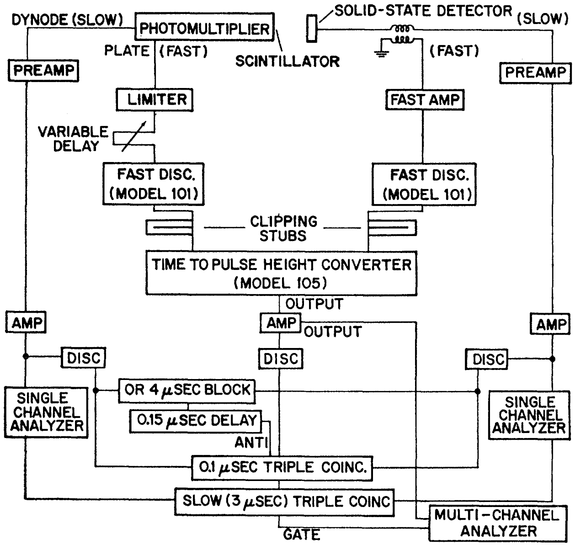

FIG. 1. A schematic diagram of the experimental apparatus.

The gamma rays were detected in a 5-cm-diam by 5-cm-long NE102 plastic scintillator mounted on a RCA 7264A phototube. Fast timing pulses were obtained from a limiter on the anode while the energy pulses were taken from a dynode.

The time-delay spectra were obtained from a time-to-height converter[11] with the usual multicoincidence requirements for the slow pulses, and recorded in a pulse-height analyzer. This system was capable of achieving a time resolution of 450 psec full width at half-maximum (FWHM) for 1-MeV gamma rays with a corresponding minimum half-life slope of 70 psec. Time calibration of the time-to-height converter was made with air-dielectric lines.

III. EXPERIMENTAL MEASUREMENT

For the lifetime measurement of the 1.02-MeV level in Ne^{23}, the slow coincidence conditions of the solid-state detector were adjusted to accept the narrow group of protons which correspond to the population of the 1.02-MeV level from the $Ne^{22}(d,p)Ne^{23}$ reaction. The deuteron bombarding energy was 2.3 MeV. To prevent the protons that populate the 1.02-MeV level from going through the detector, a 10-mg/cm² Al absorber was needed to reduce the proton energy to about 3 MeV. This absorber stopped α particles from the $Ne^{22}(d,\alpha)F^{20}$ reaction and most particles that could be related to possible contaminants. In order to make positive identification of the proton group, coincident NaI pulses from gamma rays and proton pulses from the solid-state detector were observed with a (64×64) 2-dimensional analyzer.

For the plastic scintillator, the upper 15% of the Compton edge of the 1.02-MeV gamma ray was accepted in the pulse-height window. The deuteron beam current was kept at about 20 nA to prevent excessive counting rates in the gamma-ray detector. Also, a 10-cm Pb shield was placed around the plastic scintillator to reduce the background.

The observed time-delay spectrum is shown by the filled circles in Fig. 2. From several least-squares fits to different portions of the logarithmic slope, the half-life of the 1.02-MeV level in Ne^{23} is $t_{1/2} = (178 \pm 10)$ psec. These error limits include statistical and time-calibration uncertainties. A slight amount of broadening was observed at the edges of the decay curve; this results from the fairly high gamma counting rates. This slight broadening was accepted to avoid the possibility of long-term time shifts. The data for the decay curve in Fig. 2 were taken over about 40 h of accelerator operation.

To obtain a prompt resolution function for comparison purposes under similar operating conditions, naturally abundant Ne was put into the gas cell. A strong proton group from the $Ne^{20}(d,p)Ne^{21}$ reaction[1] with only slightly less energy was accepted in the solid-state detector window. This proton group populated the 2.79-MeV level in Ne^{21} which decays predominantly by gamma rays to the ground state. The unchanged gamma-ray window observed a portion of the Compton spectrum of this gamma ray. Since the lifetime of 2.79-MeV level in Ne^{21} is expected to be small relative to the lifetime of the 1.02-MeV level in Ne^{23}, the observed time-delay spectrum should represent a prompt resolution function. The result of this measurement yielded a slope corresponding to a half-life of less than 100 psec. The observed FWHM, however, was slightly larger than that

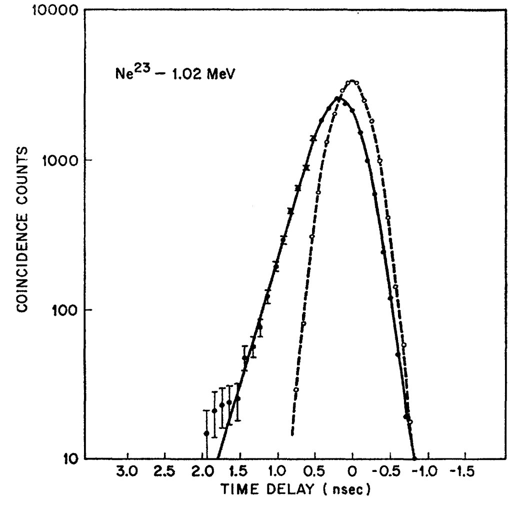

FIG. 2. The experimental decay curve for the 1.02-MeV state in Ne^{23} as shown with filled circles and the solid line. Open circles and the dashed line represent the prompt resolution function. The left slope of the decay curve corresponds to a half-life, $t_{1/2} = (178 \pm 10)$ psec. An arbitrary zero time is used.

---

[11] Cronetics Inc., Yonkers, New York. Similar to that described by R. Sugarman *et al.*, Brookhaven National Laboratory Report No. BNL 711 (T-248), 1962 (unpublished).

TABLE I. Theoretical and experimental $B(E2, \frac{5}{2} \rightarrow \frac{1}{2})$ comparisons for nuclei with an odd 13th particle. Theoretical values contain the effective charge $(1+Z/A)e$ for an odd proton and Ze/A for an odd neutron.

Nucleus	$B(E2, \frac{5}{2} \rightarrow \frac{1}{2}) \times [10^{-53} e^2\ \mathrm{cm}^4]$ Theory	Experiment
$_{10}\mathrm{Ne}_{13}{}^{23}$	5	9.5[b]
$_{12}\mathrm{Mg}_{13}{}^{25}$	6[a]	8[c]
$_{13}\mathrm{Al}_{12}{}^{25}$	50[a]	57[c]
$_{13}\mathrm{Al}_{14}{}^{27}$	60[a]	210[d]

[a] K. H. Bhatt, Nucl. Phys. **39**, 375 (1962).
[b] Present experiment.
[c] A. T. G. Ferguson, M. A. Grace, and J. O. Newton, Nucl. Phys. **17**, 1 (1960).
[d] *Nuclear Data Sheets*, compiled by K. Way *et al.* (National Academy of Sciences–National Research Council, Washington, D. C., 1959), NRC 59-6-43.

expected from previous prompt measurements.[9] Higher energy protons which populated the 1.75-MeV level in Ne^{21} passed through the solid-state detector and a few of the associated pulses folded back into the pulse-height window; this along with the coincident gamma rays from the 1.75-MeV level which fell into the gamma-ray window resulted in an additional weak prompt peak. This peak was displaced slightly from the desired prompt resolution function because of a different transit time for the higher energy protons; the resulting FWHM was about a channel broader than that of the expected experimental resolution function. To obtain a closer approximation to the resolution function, a prompt peak from the 1.47-MeV level in O^{19} was measured with O^{18} in the gas target using the $\mathrm{O}^{18}(d,p)\mathrm{O}^{19}$ reaction. The half-life of this state has been measured to be less than 75 psec.[9] For this measurement the pulse-height windows were similar to those in the lifetime measurement; however, the lower Q value for this reaction required the removal of the Al absorber. The resulting prompt resolution function is shown by open circles and a dashed line in Fig. 2; the left slope corresponds to a half-life of about 85 psec and the FWHM is about 500 psec. A comparison of the decay curve and the resolution function indicates the region of the decay curve which can be used for the lifetime determination.

IV. DISCUSSION AND CONCLUSIONS

In this experiment, the half-life of the $\frac{1}{2}^+$ 1.02-MeV level of Ne^{23} has been measured to be $t_{1/2} = (178 \pm 10)$ psec, which is in agreement with the upper limit placed on the lifetime by McClelland *et al.*[4] The transition between this state and the ground state is either an $M1$-$E2$ mixture or $E2$ depending on whether the ground state is $\frac{3}{2}^+$ or $\frac{5}{2}^+$, respectively; these are the two allowed spin assignments for the ground state from the $\mathrm{Ne}^{22}(d,p)\mathrm{Ne}^{23}$ stripping angular distributions.[2] The experimental half-life is a factor of 10^4 longer than the Moszkowski estimate for an $M1$ transition but comparable to the Weisskopf $E2$ estimate; thus the $\frac{3}{2}^+$ assignment possibility for the ground state is very unlikely, which implies a $\frac{5}{2}^+$ assignment and therefore an $E2$ transition. The experimental reduced transition probability deduced from this lifetime measurement is $B(E2, \frac{5}{2} \rightarrow \frac{1}{2}) = 9.5 \times 10^{-53} e^2\ \mathrm{cm}^4$.

Although the level structure[1] of Ne^{23} resembles that of Mg^{25}-Al^{25}, there is not sufficient information available to determine the various parameters for the Nilsson model. There are reasons to expect, however, that parameters similar to those for other odd-mass nuclei with N or Z equal to 13 are applicable.[5] Bhatt[6] has made the theoretical $B(E2, \frac{5}{2} \rightarrow \frac{1}{2})$ calculations for Mg^{25}, Al^{25}, and Al^{27} using a deformation $\eta = 3$ and appropriate values for the other Nilsson parameters. The two lowest Nilsson orbits, $\frac{5}{2}^+$ No. 5 and $\frac{1}{2}^+$ No. 9, do not interact directly through the Coriolis force, and since the $\frac{3}{2}^+$ No. 8 orbit is well separated, the $B(E2, \frac{5}{2} \rightarrow \frac{1}{2})$ depends predominantly on the motion of the single odd particle. Aside from the effective charge that was used, $(1+Z/A)e$ for an odd proton and Ze/A for an odd neutron, the reduced transition probabilities are essentially the same. Assuming that similar Nilsson parameters describe Ne^{23} and using the appropriate effective charge, the expected $B(E2, \frac{5}{2} \rightarrow \frac{1}{2})$ for Ne^{23} from the Nilsson model is $5 \times 10^{-53} e^2\ \mathrm{cm}^4$. This value is in fair agreement with that obtained from the experimental lifetime.

To summarize the experimental and theoretical $B(E2, \frac{5}{2} \rightarrow \frac{1}{2})$ in odd-mass nuclei with N or Z equal to 13, the theoretical results of Bhatt and that for Ne^{23} are compared with the various experimental values in Table I. A reasonable agreement is seen between theory and experiment for Ne^{23}, Mg^{25}, and Al^{25}; however, for Al^{27} the theoretical value is more than a factor of 3 smaller than the experimental result. This difference has been explained by Bhatt as being a result of the different deformations that exist in Al^{27} for the two Nilsson orbits involved in this transition. There is no experimental information for this transition in Si^{27}.

In conclusion, the present lifetime measurement of the $\frac{1}{2}^+$ 1.02-MeV state in Ne^{23} implies a $\frac{5}{2}^+$ spin assignment for the Ne^{23} ground state and the deduced $B(E2)$ transition probability is consistent with the Nilsson model.