Mean Life of the 1.61-Mev Level of Mg^{25}

V. K. RASMUSSEN, F. R. METZGER, AND C. P. SWANN
Bartol Research Foundation of the Franklin Institute, Swarthmore, Pennsylvania*

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Nuclear resonance fluorescence techniques have been used to measure the mean life of the 1.61-Mev level of Mg^{25} and the 1.83-Mev level of Mg^{26}. The exciting γ radiation was obtained by bombarding metallic Mg^{25} and Mg^{26} targets with 4.0- and 4.4-Mev protons. For the Mg^{25} level, assumed to be $\frac{7}{2}^+$, the self-absorption of the resonance radiation gives $\tau=(2.5_{-0.4}^{+0.6})\times10^{-14}$ sec. The angular distribution for the resonance scattering was found to be $1+(0.42\pm0.03)P_2(\cos\theta)+(0.03\pm0.003)P_4(\cos\theta)$, where the errors given are statistical only. For other reasons it is believed that the correct coefficient of the P_4 term is approximately zero. For the Mg^{26} level, the apparent resonance scattering cross section combined with some previous estimates of slowing-down times for the excited nuclei gives $\tau=(7\pm3)\times10^{-13}$ sec. Further evidence as to the collective nature of these nuclei and of Al^{27} is discussed. Support is given to the suggestion of the Chalk River group that the 1.61-Mev Mg^{25} and the 2.21-Mev Al^{27} levels are the $\frac{7}{2}^+$ second members of $K=\frac{5}{2}^+$ rotational bands based on the ground states. For the Mg^{25} level, spin and parity $\frac{7}{2}^+$ is required to obtain agreement between the quadrupole transition probability from these measurements and that found by Coulomb excitation.

I. INTRODUCTION

At the 1960 International Conference on Nuclear Structure, Gove reviewed the evidence for the appearance of collective effects in the $2s-1d$ shell.[1] Among other things, he pointed out that the nuclei for which the odd particle number is 13—${}_{10}Ne_{13}$, ${}_{12}Mg_{13}$, ${}_{13}Al_{12}$, ${}_{13}Al_{14}$, and ${}_{14}Si_{13}$—show a striking similarity of level structure. In particular, it is attractive to regard the lower-lying levels as belonging to either a $K=\frac{5}{2}$ rotational band, based on the ground state, or a $K=\frac{1}{2}$ band based on the first excited state, although the evidence is still far from complete. In a recent paper,[2] we gave a preliminary value for the lifetime of the second member of the ground-state band of Mg^{25}. This paper is a report of further work on this level, and a brief discussion of further information as to its characteristics and those of the possibly related level in Al^{27} that can be obtained from our present results and from reference 2.

An experimentally related measurement of the mean life of the first excited state of Mg^{26} is also described.

II. EXPERIMENTAL DETAILS

The experimental procedures in measuring a lifetime by nuclear resonance fluorescence when the γ rays are produced in a nuclear reaction have been discussed in several publications.[2–6] We mention the basic principle, that the resonance scattering cross section is proportional to the level width, and then confine the following description of experimental details to points of particular importance for the present measurements.

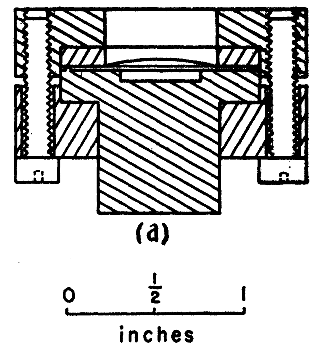
A. Source of γ Radiation

As noted previously,[2] inelastic scattering of a few microamperes of 4-Mev protons from natural magnesium targets gives a good yield of both the 1.61-Mev γ ray from Mg^{25} and the 1.83-Mev γ ray from Mg^{26}. However, the simpler γ-ray spectra and the increased yield expected from isotopically enriched targets indicated that their use would be desirable. Fifty mg each of 97.5% Mg^{25} and 99% Mg^{26} were obtained from the Stable Isotopes Division of the Oak Ridge National Laboratory. These were converted to metallic flakes by Oak Ridge. They contained enough impurities (of unknown nature) to require that targets be made from them by what may be described as a crude sort of vacuum distillation, as described in the caption of Fig. 1(a). The targets thus obtained were almost entirely metallic magnesium tightly bonded to the 0.010-in. thick tantalum backing. They were approximately circular, around 3 mm in diameter, and of nominal, but very nonuniform, thickness around 150 mg/cm^2.

These targets, when placed in the water-cooled assembly shown in Fig. 1(b) stood up quite well under bombardment by 10–12 μa of 4-Mev protons from the Bartol-ONR Van de Graaff generator, as long as the beam was spread out to a diameter of about 3 mm. The yield of 1.61-Mev γ radiation from the Mg^{25} targets increased smoothly as the proton energy varied from 3.0 to 4.8 Mev. The yield of neutrons from target impurities, etc., increased more rapidly, and 4.00 Mev was selected as the most suitable bombarding energy.

As previously noted, the calculation of a γ-ray width from a resonance scattering experiment requires a knowledge of $N(E_R,\beta)$, the number of photons per unit energy interval at the resonance energy as a function of a coordinate β which describes the scatterer location.

* This research was supported by the U. S. Office of Naval Research.
[1] H. E. Gove, in *Proceedings of the International Conference on Nuclear Structure, Kingston, Canada*, edited by D. A. Bromley and E. W. Vogt (University of Toronto Press, Toronto, and North-Holland Publishing Company, Amsterdam, 1960), Chap. 5.4.
[2] F. R. Metzger, C. P. Swann, and V. K. Rasmussen, Nuclear Phys. **16**, 568 (1960).
[3] F. R. Metzger, in *Progress in Nuclear Physics*, edited by O. R. Frisch (Pergamon Press, New York, 1959), Vol. 7, Chap. 2.
[4] C. P. Swann, V. K. Rasmussen, and F. R. Metzger, Phys. Rev. **114**, 862 (1959).
[5] V. K. Rasmussen, F. R. Metzger, and C. P. Swann, Nuclear Phys. **13**, 95 (1959).
[6] C. P. Swann and F. R. Metzger, Phys. Rev. **108**, 982 (1957); V. K. Rasmussen, F. R. Metzger, and C. P. Swann, *ibid.* **110**, 154 (1958); F. R. Metzger, C. P. Swann, and V. K. Rasmussen, *ibid.* **110**, 906 (1958); C. P. Swann, V. K. Rasmussen, and F. R. Metzger, *ibid.* **121**, 242 (1961).



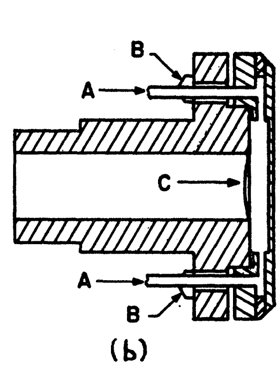


FIG. 1. (a) "Vacuum still" used in preparing magnesium targets from small metallic flakes of the separated isotopes. The construction was entirely of stainless steel (including the six screws), except for the 0.010-in. thick tantalum disk on which the targets were deposited. The flakes were placed in the central cavity and the tantalum disk sealed on in vacuum, the seal being made by a knife edge around the outer circumference. The assembly, with the tantalum up, was heated in vacuum by rf induction to somewhat above the melting point of magnesium. Disassembly required some judicious machining where the tantalum and steel fused together at the knife-edge seal. (This is why the construction is somewhat more complicated than would appear to be necessary.) The metallic magnesium was then found in the fastest-cooling region, the center of the tantalum disk, well bonded to it, and separated from most of the impurities which, fortunately, were of much higher melting point than magnesium. Three or four meltings were required to obtain satisfactory purity. It was possible to scrape most of the magnesium off the tantalum for remelting. (b) Water-cooled target holder. *A* denotes the tubes used for water inlet and outlet, *B* two of the screws used to hold the assembly together, and *C* the target on the 0.010-in. thick tantalum. The vacuum seal to the tantalum was by a circumferential knife edge, of smaller diameter than that for (a). The material used was stainless steel. Especially for angles with the incoming proton beam greater than 65° absorption of γ radiation was appreciable. The correction factor used for these larger angles was essentially empirical. The "dishing" of the tantalum, a result of the heating described in the caption of (a) does reverse in direction as shown in (b) because of the subsequent application of external pressure—i.e., the magnesium is on the inside of the curved surface in (a), and on the outside in (b).

Calculation of this function requires a knowledge of the proton-recoil nucleus and recoil nucleus-photon correlations. However, in the present case, the measurements of Sec. IIB showed that there was appreciable scattering and/or slowing down of the excited nuclei within the level lifetime. A knowledge of the angular correlations is then of questionable value[2–4] and no such measurements were made.

For the 1.83-Mev γ ray from Mg^{26}, the optimum proton energy was found to be 4.4 Mev. It turned out in this case that slowing-down was virtually completed during the radiation lifetime, so that again no angular correlation measurements were made.

B. Scattering and Self-Absorption of the 1.61-Mev γ Ray

The experimental arrangement used for the scattering and self-absorption measurements is shown in Fig. 2. The magnesium (Dow metal) and comparison aluminum scatterers have been described previously.[2] The magnesium absorber (made from 99% pure magnesium) was 3-in. o.d. by $1\frac{1}{2}$-in. i.d. and the comparison aluminum absorber was 3-in. o.d. by 2-in. i.d., the inner diameter being made larger to match the electronic absorption of the magnesium absorber. The data obtained are shown in Fig. 3. From examination of Fig. 10 of reference 2 and consideration of the large change in the Mg^{25}/Mg^{24} ratio (≈ 500) between those data and the present data, it is clear that no interference by the 1.37-Mev radiation from Mg^{24} is expected. As to higher-energy γ radiation, a small (1% of that at 1.61-Mev) Mg scatterer–Al scatterer difference is found at 1.96-Mev, the location of the next higher energy γ ray from Mg^{25}. Some difference is also seen

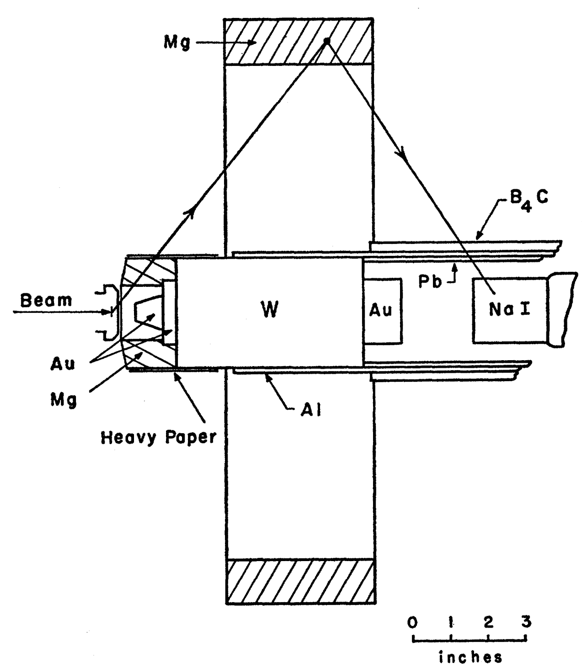


FIG. 2. "Ring" geometry used for the scattering and self-absorption measurements. The absorber and scatterer are cross hatched.

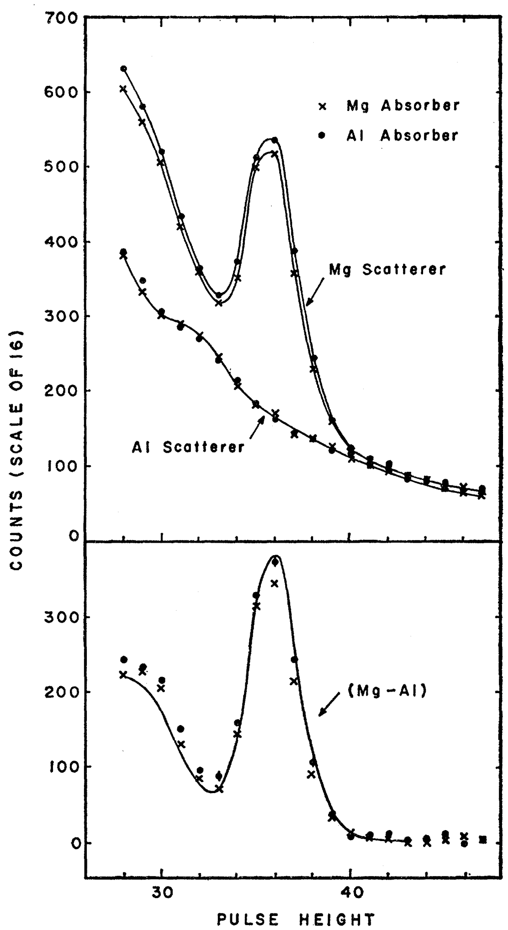


FIG. 3. Resonant scattering of the 1.61-Mev γ ray from Mg^{25}. The upper curves give the original data for the scatterer-absorber combinations noted. Statistical errors can be estimated from the left-hand scale which gives the total number of counts for each point. Magnesium scatterer-aluminum scatterer differences are shown in the lower plot, where the solid curve drawn is the shape found for an isolated 1.61-Mev γ ray from a radioactive source and is normalized to the aluminum absorber data. The sum of the counts for pulse heights 34 to 37 was taken to represent the resonance effect.

for pulse heights greater than those plotted in Fig. 3, possibly as a result of neutron effects. It is felt that any contribution of these higher-energy γ rays to the counting rate at 1.61 Mev should be small compared to other errors.

When the γ radiation for a resonance experiment results from inelastic proton scattering, as is the case here, the source distribution function, $N(E_R,\beta)$, is, in principle, zero in a forward and a backward cone since photons of the correct energy are emitted only at $\approx 90°$ to the direction of motion of the excited recoiling nuclei, and these nuclei are confined to a forward cone. Observation of resonant-energy γ rays in the forbidden region is then an indication that there has been scattering and/or slowing down of the nuclei within the level lifetime. A measurement to obtain a relative value of $N(E_R,\beta)$, where β is here the angle the scatterer makes with the incident proton beam, was made using an arrangement similar to that of Fig. 2, with scatterers of the same diameters, but only 1 in. long rather than 4 in. long. The results, expressed as relative values of the source distribution function, are shown in Fig. 4. The horizontal bar indicates the region over which resonant radiation is expected. Slowing-down effects are clearly indicated.

C. Angular Distribution for Scattering from the 1.61-Mev Mg^{25} Level

The angular distribution for the resonant scattering of the 1.61-Mev radiation was measured using an arrangement similar to that of Fig. 2 except that the small value of $N(E_R,\beta)$ at forward angles with the beam, where the scatterer would normally be placed to reach large scattering angles, suggested that the attenuator-scatterer-detector assembly be rotated around the target until its axis was at $\approx 90°$ to the beam direction (see also Fig. 7 of reference 2). Measurements were

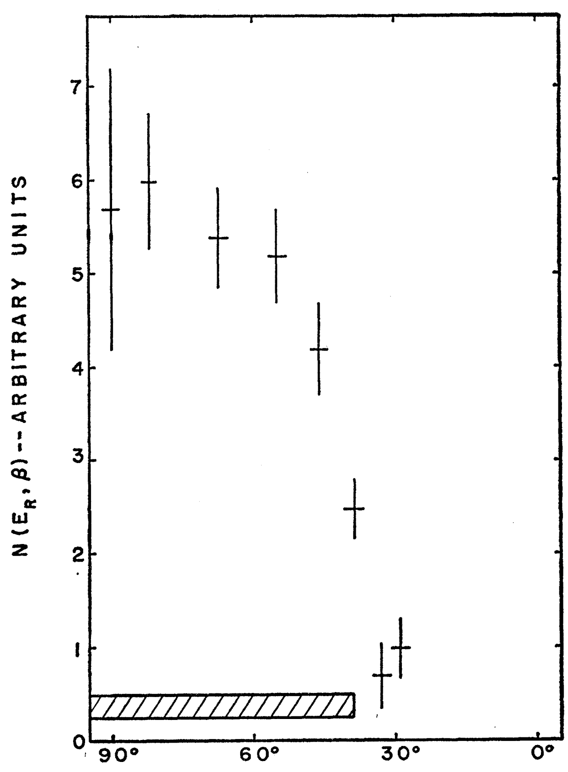


FIG. 4. Relative number of 1.61-Mev photons of the resonance energy as a function of the angle with the incident proton beam, measured as described in Sec. IIB. The angular resolution at 30° is about equal to the separation of the experimental points. The shaded horizontal bar indicates the angular range (for the angles covered in the figure) to which resonant photons would be limited by the kinematics of the $Mg^{25}(p,p')$ reaction at $E_p=4.0$ Mev and the Doppler shift necessary to compensate for the recoil energy in photon emission and absorption. The points at 29° and 33° are definitely outside this range.

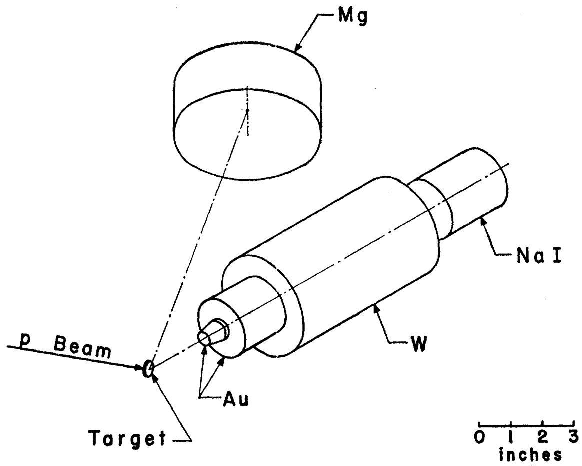


FIG. 5. "Point" geometry used in investigation of possible polarization effects. The orientation shown is for the measurement of J_0 (see text), with the detector in the plane defined by the beam and the scatterer.

made for scattering angles of 95°, 125°, and 142°. To evaluate the data it was also necessary to know how the relative intensity of the incident, resonant-energy radiation varied over the scatterer. This was determined by placing the 1-in. long scatterer in successive positions that scanned out the longer scatterer. The detector was also moved by amounts sufficient to keep the scattering angle constant.

As has been previously pointed out,[2] there exists a possibility that the resonant-energy radiation from the nuclear reaction is partially linearly polarized. This is of considerable concern, since it would add some of the (different) polarization-direction correlation to the direction-direction correlation of interest. Some preliminary measurements were made using the resonance scattering as a polarimeter whose calibration is not known but where the readings obtained are directly related to possible distortions of the desired direction-direction correlation. The "point" geometry shown in Fig. 5, with a disk scatterer at 65° to the proton beam, was used. For a resonance scattering angle of 90°, the change in counting rate as the counter was rotated around the target-scatterer axis was measured. The ratio $(J_0-J_{90})/(J_0+J_{90})$ was found to be less than ±0.03.[7] It is felt that although this does not completely rule out the possibility of polarization effects, it does indicate that they will not be large. Further measurements of this type are not planned because it has since been realized that if the angular distribution of the scattering is measured with the proper "point" geometry any polarization of the incident radiation can be corrected for. It is intended to make measurements of this latter type for both the 1.61-Mev Mg^{25} and the 2.21-Mev Al^{27} levels.

[7] Similar results were obtained for the 2.21-Mev level in Al^{27}.

D. Scattering and Self-Absorption—1.83-Mev Level in Mg^{26}

Scattering and self-absorption measurements for the 1.83-Mev γ ray from a Mg^{26} target were performed with the arrangement of Fig. 2, and the data obtained are shown in Fig. 6. Relative values of $N(E_R,\beta)$ were obtained by scanning with the 1 in. scatterer the volume occupied by the 4-in. scatterer.

Since this level is taken[8] as the usual 2^+ first excited state of an even-even nucleus, the transition is pure $E2$ with no possibility of mixing so that there is no particular interest in the angular distribution, and none was measured. Future measurements are planned, however, in connection with using the calculable polarization in the scattering to calibrate a polarimeter.

III. RESULTS—1.61-Mev LEVEL IN Mg^{25}

The self-absorption of the resonance radiation in the Mg absorber was found to be $(7.7\pm1.6)\%$, where the

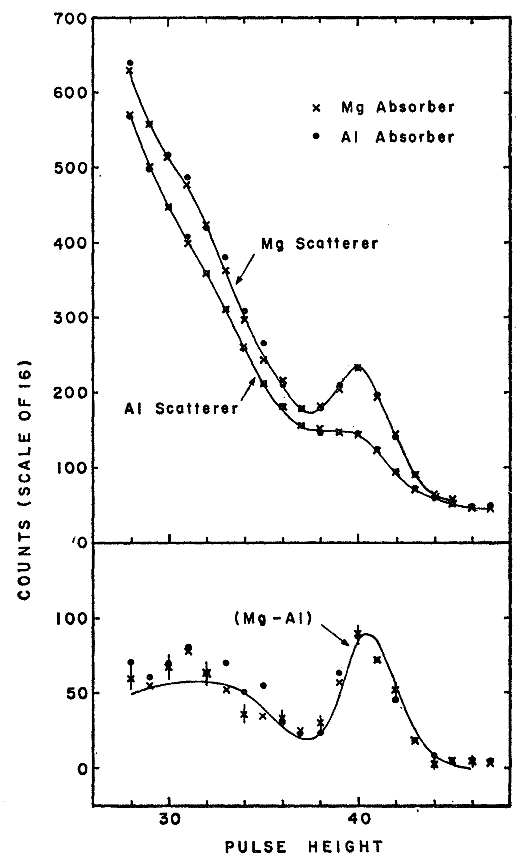


FIG. 6. Resonant scattering of the 1.83-Mev γ ray from Mg^{26}. The upper curves give the original data for the scatterer-absorber combinations noted. Statistical errors can be estimated from the left-hand scale which gives the total number of counts for each point. Mg scatterer–Al scatterer differences are shown in the lower plots, where the solid curve is that obtained when the counter is exposed to direct radiation from the target. The sum of counts for pulse heights 39 to 42 was taken to represent the resonance effect.

TABLE I. Quadrupole enhancements for lower-lying levels in Mg^{25} and Al^{27}. The data for the first two excited states are from Gove's review in reference 1. Values of the spin previously considered unlikely are enclosed in parentheses. Values of the $E2/M1$ amplitude ratio, δ, and the reduced quadrupole matrix element for Coulomb excitation, $B(E2)$, follow from the angular distributions and lifetimes from the present work and from Metzger *et al.* [Nuclear Phys. **16**, 568 (1960)]. The last column gives $B(E2)/B(E2)_{sp}$ as obtained from Coulomb excitation, the values for Mg^{25} being from I. Kh. Lemberg in a private communication to H. E. Gove, and those for Al^{27} being from Gove's review.

Nucleus	Level energy (Mev)	J^π, K	δ	$B(E2)$ ($e^2\times10^{-48}$ cm^4) (from lifetime)	$B(E2)/B(E2)_{sp}$	$B(E2)/B(E2)_{sp}$ (from Coulomb excitation)
Mg^{25}	0	$\frac{5}{2}+, \frac{5}{2}$				
	0.58	$\frac{1}{2}+, \frac{1}{2}$				0.025
	0.98	$\frac{3}{2}+, \frac{1}{2}$				0.13
	1.61	$\frac{7}{2}+, \frac{5}{2}$	$+0.64 \pm0.03$[a]	0.117	53	5
			-0.19 ± 0.02	0.013	6.1	
		$(\frac{5}{2}+, -)$	$+0.29 \pm0.05$	0.030	14	
			$+0.93 \pm0.08$[a]	0.19	84	
		$(\frac{3}{2}+, -)$	$+0.53 \pm0.03$	0.088	40	
Al^{27}	0	$\frac{5}{2}+, \frac{5}{2}$				
	0.842	$\frac{1}{2}+, \frac{1}{2}$				0.7
	1.013	$\frac{3}{2}+, \frac{1}{2}$				1.2
	2.208	$\frac{7}{2}+, \frac{5}{2}$	$+0.47 \pm0.03$	0.010	4.3	
			-0.083 ± 0.017	0.00039	0.16	
		$\frac{5}{2}+, -$	$+0.053\pm0.03$	0.00016	0.065	
		$\frac{3}{2}+, -$	$+0.33 \pm0.03$	0.0056	2.3	

[a] These are the only values consistent with the dubious $P_4(\cos\theta)$ term in the angular distribution.

rather large statistical error reflects the low abundance of the mass 25 isotope in natural magnesium. Using the favored value[1,9] of the spin and parity, $\frac{7}{2}^+$, a Debye temperature of 318°, [3,10] and assuming that the decay is entirely to the ground state (Gove *et al.*[9] find <4% branching), we calculate a mean life for the level of $\tau=(2.5_{-0.4}^{+0.6})\times10^{-14}$ sec, in agreement with the preliminary value of reference 2.

The apparent scattering cross section, on the other hand, corresponds to the somewhat smaller value of $\tau=1.7\times10^{-14}$ sec. However, it is known that some slowing-down correction is required, and it is probable that a correction for angular correlations in the inelastic scattering reaction is necessary, so that the uncertainties in the scattering lifetime are large.

The angular distribution for the resonance scattering was fitted by $1+A_2P_2(\cos\theta)+A_4P_4(\cos\theta)$, giving $A_2=0.42\pm0.03$ and $A_4=0.03\pm0.003$. Fitting to $1+A_2P_2$ gives $A_2=0.41\pm0.02$. The errors given are purely statistical and do not reflect the full uncertainty in the values. In particular, appreciably more experimental work would be required to establish definitely that A_4 is not zero. It might also be mentioned that the nonzero A_4 could be a spurious effect of polarization of the resonant-energy radiation as it is produced in the nuclear reaction—i.e., it might be that the appropriate function to fit the present data is $1+A_2P_2+A_2'P_2^2$, where the associated Legendre polynomial is a polarization term.

The distribution obtained is in agreement with the conclusion of Gove *et al.*[9] from the Na^{25} decay that the spin of the level is $\leq 7/2$, since spin 9/2 would require the distribution $1+0.19P_2+0.07P_4$ (the transition would also be very fast for an $E2$). On the other hand, spin $\frac{3}{2}$ and $\frac{5}{2}$, which previous work has not definitely ruled out, are consistent with the observed distribution (except for the P_4 term). The resultant mixing ratios and quadrupole enhancements are discussed in Sec. IV and listed in Table I.

IV. DISCUSSION—LOWER-LYING LEVELS OF Mg^{25} AND Al^{27}

Table I gives some pertinent information about the 1.61-Mev level of Mg^{25}, the 2.21-Mev level of Al^{27}, and the lower-lying levels of these two nuclei. Values of K, the rotational quantum number, are given where they might be appropriate, and several possible values of the spin are given where there still is some doubt as to the correct value. All values of δ, the $E2/M1$ amplitude ratio, allowed by our experimental angular distributions and also within the range $-1<\delta<1$ are given, although the resulting quadrupole matrix elements are sometimes rather large.

In discussing certain regions of the periodic table, comparison with previously published information seems to be simpler if transition probabilities are given in terms of $B(E2)$, the reduced transition probability for Coulomb excitation, rather than as a level width, decay rate, etc. In obtaining values of $B(E2)$ from our measured lifetimes we use Eq. (IV.3) of Alder, Bohr, Huus, Mottelson, and Winther.[11] For single-particle values we use $B(E2)_{sp}=3\times10^{-5}A^{4/3}e^2\times10^{-48}$ cm^4, which is Eq. (V.1) of the same article, and where it should

[8] *Nuclear Data Sheets*, edited by K. Way, F. Everling, G. H. Fuller, N. B. Gove, C. L. McGinnis, and R. Nakasima (Printing and Publishing Office, National Academy of Sciences—National Research Council, Washington, D. C., 1960).

[9] H. E. Gove, E. B. Paul, G. A. Bartholomew, and A. E. Litherland, Nuclear Phys. **2**, 132 (1956/57).

[10] Jules deLaunay, in *Solid-State Physics*, edited by F. Seitz and D. Turnbull (Academic Press, Inc., New York, 1956), Vol. 2, p. 233.

[11] K. Alder, A. Bohr, T. Huus, B. Mottelson, and A. Winther, Revs. Modern Phys. **28**, 432 (1956).

TABLE II. Mg^{25} 1.61-Mev and Al^{27} 2.21-Mev transitions interpreted on the rotational model with $K=\frac{5}{2}$. The intrinsic quadrupole moment obtained from the $E2$ transition probability is given in column 3, and that from the ground-state quadrupole moment is given in column 4.

Nuc.	δ	Q_0 (barns)	Q_0 (barns)	β	g_K-g_R	g_K	g_R
Mg^{25}	-0.19	0.54	$+0.42$	$+0.48$	-1.27	-0.71	0.56
Al^{27}	$+0.47$	0.52	$+0.42$	$+0.41$	1.28	1.82	0.54

be noted that the statistical factor used is, to quote Alder *et al.* ". . . somewhat arbitrary—it is the factor appropriate to a two-proton excitation of the type $(j^2)_{J=0}\rightarrow(j^2)_{J=2}$ in the limit of large j."

The application of the rotational model to the mirror pair $Al^{25}-Mg^{25}$ has been discussed by the Chalk River group, especially Litherland *et al.*[12] From Table I, it is seen that the present work supports this—the quadrupole part of the ground state–1.61-Mev state transition is strongly enhanced, especially when compared to transitions to the lower-lying levels, which implies, in the first instance, collective effects and, in the second, a lack of such effects. Also, for the model-indicated spin of $\frac{7}{2}$ (and $\delta=-0.19$) the measured enhancement is the same as that found in Coulomb excitation. For other values of the spin and mixing ratio the disagreement is marked.

For Al^{27}, the applicability of the model is not as well established, although it is regarded as an attractive possibility.[1,13] The evidence as to the spin and parity of the level at 2.21 Mev has been discussed previously by Metzger *et al.*[2] To summarize briefly: Work on the $Mg^{26}(p,\gamma)Al^{27}$ reaction seems to require spin $\frac{3}{2}$ or $\frac{5}{2}$, but the small branching ($<4\%$) then poses a problem most easily solved by assuming spin $\frac{7}{2}$. The possibility of negative parity we somewhat arbitrarily ignore. From Table I it is seen that the spin $\frac{7}{2}$ assumption does lead to an $E2$ enhancement consistent with a collective model, although there is as yet no compelling reason to rule out the other spins.

It is of interest to consider further examples of the internal consistency found when these nuclei are treated as rotational. Table II gives certain quantities defined[11] in the framework of the rotational model as calculated under the assumption that the 1.61-Mev Mg^{25} and 2.21-Mev Al^{27} levels are the $J=\frac{7}{2}+$ second member of a $K=\frac{5}{2}+$ band based on the ground state. The intrinsic quadrupole moment of the band, Q_0, is related by constants and angular momentum-dependent factors (see Sec. V.B.2 of reference 11) to both the quadrupole matrix element for transitions within the band and to the static quadrupole moment of the ground state of these odd-A nuclei. The deformation parameter β follows directly from the quadrupole moment and the assumption of a spheroidal nuclear deformation. The gyromagnetic ratios g_K and g_R refer, respectively, to the intrinsic and rotational motion, and determine both the static magnetic moment and the $M1$ matrix element for transitions within a band. In addition, the sign of the amplitude ratio, δ, is the same as the sign of $Q_0/(g_K-g_R)$. Values of δ which are considered are limited to those consistent with the model. The Nuclear Data Sheets[8,14] give $+0.15\times10^{-24}$ cm^2 for the ground-state quadrupole moments of both Mg^{25} and Al^{27}, and -0.855 and $+3.64$ nm for the magnetic moments.

The calculated values in Table II are all quite reasonable. The values of β are similar to those for neighboring nuclei,[1] the values of g_R are close to the expected value $Z/A=0.48$, and the change in both the sign and magnitude of g_K is expected since the odd particle in Mg^{25} is a neutron, that in Al^{27} a proton. Also, Eqs. (13) and (14) of Gove's review[1] yield for Mg^{25} a theoretical value of $g_K=-0.77$ in agreement with the experimental value of -0.71. Comparison of the theoretical g_K for Al^{25} of 1.92 with our experimental value for Al^{27} of 1.82 supports Gove's subsequent assumption that the magnetic moments of Al^{25} and Al^{27} are equal.

In conclusion, we note that the agreement with the predictions of the rotational model for these two levels is quite expected in view of previous evidence, especially strong for Mg^{25}, that the model describes many other features of these nuclei quite well. It would seem to be difficult to doubt that the Mg^{25} level is correctly described as $\frac{7}{2}+$, particularly since any other value gives disagreement by a factor of 3 or more between $B(E2)$ from the lifetime measurement and that from Coulomb excitation. For the Al^{27} level one might perhaps say that it would be surprising if it were not $\frac{7}{2}+$. In both cases, a definitive spin measurement is desirable.

V. RESULTS AND DISCUSSION—1.83-Mev LEVEL IN Mg^{26}

The measured self-absorption of the resonance radiation is $-(1.6\pm4.7)\%$. The nominal maximum value allowed, 3.1%, corresponds to a mean life $\tau=1.9\times10^{-13}$ sec. The apparent scattering cross section—i.e., one calculated without any attempt to correct for slowing down of the excited nuclei—corresponds to $\tau=4.1\times10^{-13}$ sec, with a negligible statistical error. The problem of correcting for slowing-down effects has been discussed previously by Metzger *et al.*[2] for cases closely related to the present one, except that the lifetimes were somewhat longer, both being greater than 10^{-12} sec. For these cases it was shown that a simple calculation based on a rudimentary range-velocity curve could give a reasonable value for F/F_0, where F is the number

[12] A. E. Litherland, H. McManus, E. B. Paul, D. A. Bromley, and H. E. Gove, Can. J. Phys. **36**, 378 (1958).

[13] E. Almqvist, D. A. Bromley, H. E. Gove, and A. E. Litherland, Nuclear Phys. **19**, 1 (1960).

[14] See also A. Lurio, Bull. Am. Phys. Soc. **4**, 419 (1959) and D. Strominger, J. M. Hollander, and G. T. Seaborg, Revs. Modern Phys. **30**, 585 (1958).

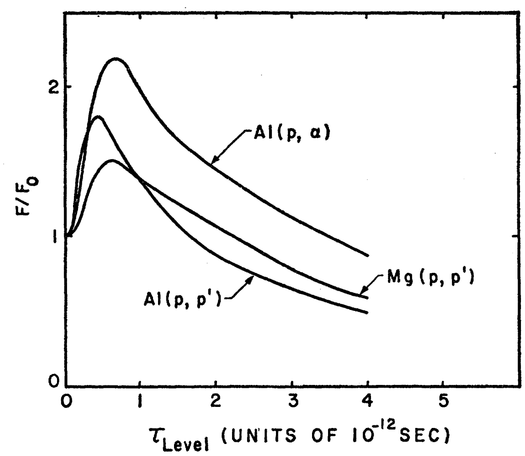


FIG. 7. Calculated "slowing down" curves from Metzger *et al.*, Nuclear Phys. **16**, 568 (1960). F is the number of photons per ev at the resonance energy divided by the total number of photons, and F_0 is the same quantity assuming no slowing down. The curves labeled "Al(p,α)" and "Mg(p,p')" are for excitation of the 1.37-Mev Mg^{24} level, and that labeled "Al(p,p')" for the 1.01-Mev Al^{27} level.

of photons per unit energy interval at the resonant energy divided by the total number of photons, and F_0 is the same quantity when there is no slowing down. Metzger's curves for F/F_0 vs τ_{level} are redrawn in Fig. 7. The curve labeled Mg(p,p') was drawn for the 1.37-Mev level in Mg^{24}, but that for the 1.83-Mev level in Mg^{26} would differ only slightly. Our uncorrected value for τ falls at the peak of the curve. The only evidence as to the validity of the curves in this region is from measurements[5] on the first excited state of Na^{23}, where the experimental value of F/F_0 is 6.5, which is somewhat larger than can be obtained from the simple calculation.[15] Noting also that $\tau=10^{-12}$ sec, where one feels that these curves should be reasonably valid, corresponds to an enhancement of only 1.3, suitable limits would seem to be $4\times10^{-13}<\tau<10^{-12}$ sec. We give $(7\pm3)\times10^{-13}$ sec as our value for this mean life.

Collective effects are also indicated for Mg^{26}, since our value of the mean life corresponds to $B(E2)/B(E2)_{\text{sp}}$ of 12. This may be compared to 30 and 19 for the same transition in the nearby nuclei Mg^{24} and Si^{28}.[16] The intrinsic quadrupole moment is $Q_0=0.53$ barns, to be compared to 0.81 and 0.68 for Mg^{24} and Si^{28}. One should note also, as pointed out by Gove,[1] that the 2^+ spin of the second excited state of Mg^{26} and its pure $E2$ decay to the first excited state suggest a vibrational model for this nucleus, whereas Mg^{24} and Si^{28} are probably rotational.

VI. SUMMARY

The mean life of the 1.61-Mev level of Mg^{25} has been measured as $(2.5_{-0.4}^{+0.6})\times10^{-14}$ sec, assuming spin $\frac{7}{2}$ and that for the 1.83-Mev level of Mg^{26} has been measured as $(7\pm3)\times10^{-13}$ sec.

Further evidence as to the collective nature of these nuclei and Al^{27} is discussed. As pointed out by the Chalk River group, a rotational description of Mg^{25} and Al^{27} seems to be particularly appropriate. The 1.61-Mev Mg^{25} and the 2.21-Mev Al^{27} levels are then $\frac{7}{2}^+$. Our results support this spin assignment although a direct measurement of the spin would be desirable.

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[15] Note that the time scale for the slowing-down varies inversely with the density.

[16] D. S. Andreyev, A. P. Grinberg, K. I. Erokhina, and I. Kh. Lemberg, Nuclear Phys. **19**, 400 (1960).