PHYSICAL REVIEW C VOLUME 8, NUMBER 4 OCTOBER 1973

Mass and β Decay of the New Isotope ^{29}Mg: Systematics of Masses of $T_z = \frac{5}{2}$ Nuclides in the $2s$-$1d$ Shell*

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(Received 30 May 1973)

Measurements of the mass, half-life, and β decay of the new isotope ^{29}Mg are reported. Produced by the ^{18}O(^{13}C, $2p$)^{29}Mg reaction, this activity was periodically transferred to remotely located Ge(Li) and NE 102 detectors. γ-ray energies (in keV) and relative intensities for the ^{29}Al daughter transitions are 960.3 ± 0.4 (52 ± 18), 1397.7 ± 0.4 (64^{+30}_{-20}), 1430 ± 1.5 (34 ± 17), 1753.8 ± 0.4 (22 ± 5), and 2223.7 ± 0.4 (100 ± 6). The ^{29}Al excitation energies (in keV) and relative β branching intensities are 1397.7 ± 0.4 (64^{+35}_{-28}), 1753.8 ± 0.4 (<10), 2223.8 ± 0.4 (55 ± 22), and 3184.0 ± 0.6 (100 ± 35). Upper limits on other possible transitions are given. ^{29}Mg decays with a half-life of 1.20 ± 0.13 sec, measured by the decay of the prominent 2224-keV γ ray. The decay of ^{29}Mg is discussed in terms of the Nilsson model. By measuring the spectrum of pulses in the NE 102 detector coincident with 2224-keV γ rays, the mass excess for ^{29}Mg has been determined to be $-10\,590 \pm 400$ keV, disagreeing by 1.7 ± 0.5 MeV from a previous report. The present mass for ^{29}Mg is combined with all other information concerning masses of $T_z = \frac{5}{2}$ nuclides in the $2s$-$1d$ shell, and the results are compared with predictions based upon measured masses closer to stability using the transverse relationship of Garvey. When the differences between the measured and predicted values are plotted against atomic weight, systematic effects are evident.

I. INTRODUCTION

Nuclei far from the valley of stability are important to study because they not only provide masses to test various predictions, but also lend insight, via β-decay matrix elements, to the structure of very high isospin ground states.

This article is a continuation of a program to search for neutron-rich species in the $2s$-$1d$ shell and to measure their masses. Previous work in this region has been summarized by Goosman and Alburger,[1] and Alburger, Goosman, and Davids.[2]

^{29}Mg was shown to be nucleon stable by Artukh *et al.*,[3] who showed that this nuclide lived at least 10^{-7} sec, after having been produced by bombardment of ^{232}Th with 290-MeV ^{40}Ar ions. No information on the decay scheme or half-life of ^{29}Mg has been published. However, a report by Scott *et al.*,[4] who sought the mass of ^{29}Mg via the ^{26}Mg(^{11}B, ^{8}B)-^{29}Mg reaction, indicates from their highest-energy ^{8}B peak a possible mass excess for ^{29}Mg of -12.33 ± 0.16 MeV.

In the present work, ^{29}Mg has been produced in the ^{13}C(^{18}O, $2p$)^{29}Mg reaction, and has been identified via the β-delayed γ-ray transitions in ^{29}Al. The half-life and mass have been measured, and the latter differs by 1.7 ± 0.5 MeV from the value suggested in Ref. 4.

II. METHOD AND RESULTS

A. γ-Ray and β-Ray Intensities

As explained in detail in Ref. 1, new activities are sought by looking for γ-ray transitions in the daughter nucleus following the β decay of the parent nuclide at a remotely located counting station. The experimental equipment and electronics were almost identical to that described in Ref. 1, except that a beam of 100 nA (electrical) of the +4 charge state of 35-MeV ^{13}C ions was used to bombard a target of Ta_2O_5 enriched to 99% in ^{18}O. The ^{18}O weight was 3 mg/cm^2 on each side of the thick Ta strip. An on-line computer stored β-ray spectra in an NE 102 scintillator coincident with digital gates set on the γ-ray spectrum as well as storing singles γ rays in four successive 0.9-sec bins, and γ-ray spectra coincident with pulses in the NE 102 detector above about 2.5 MeV. The latter spectra were taken in order to enhance weak γ rays coincident with high-energy β rays that would otherwise be swamped by γ rays coincident with low-energy β rays. Another improvement over the system described in Ref. 1 is that the time required to pump out the target shuttle system just prior to bombardment was shortened to 2 sec, allowing for a more efficient cycle.

Preliminary results showed the presence of a weak 2224-keV γ ray which could not be attributed to any known activity. It decayed with a half-life indistinguishable from that of ^{26}Na (1.087 sec)[2], which is made copiously in this experiment via the ^{18}O(^{13}C, αp)^{26}Na reaction. In order to be certain that the 2224-keV line was not simply a previously unobserved ^{26}Na line, a separate experiment was carried out. By bombarding ^{10}B pellets in the shuttle system with an ^{18}O beam, ^{26}Na was made in the ^{10}B(^{18}O, $2p$)^{26}Na reaction free of any possible ^{29}Mg activity. No 2224-keV γ ray was seen in the latter experiment, and it was clear from relative intensity considerations that the 2224-keV γ ray could not belong to the decay of ^{26}Na.

Since the excitation energies of the ^{29}Al daughter were known[5,6] only with accuracies of about ±6 keV, another experiment was carried out to measure transition energies in ^{29}Al. A thick target of aluminum was bombarded with 3-MeV tritons from the 3.5-MeV Van de Graaff accelerator. Singles prompt γ rays were observed with a Ge(Li) detector placed 33 cm away and accurately located at 90° to the beam to avoid Doppler shifts. Runs were taken with two different detectors located independently in order to check the possibility of systematic errors in the γ-ray energies due to mislocation of either detector. The results from the two detectors agreed within errors and the weighted averages are shown in Table I, along with the energies of the strongest delayed γ-ray transitions in ^{29}Al as observed by bombarding ^{18}O with ^{13}C. The close correspondence definitely establishes the new activity as ^{29}Mg.

A 30-h run was taken with ^{13}C on ^{18}O, and the selected regions of interest in the delayed γ-ray spectra are shown in Figs. 1 and 2. For each γ ray, singles spectra and spectra coincident with pulses in the NE 102 detector above about 2.5 MeV

TABLE I. Comparison of level and transition energies in ^{29}Al. All energies are in keV.

E_x [a]	E_x [b]	E_γ ^{27}Al($t,p\gamma$)^{29}Al [c]	E_γ ^{29}Mg β decay [c]	E_x adopted
1405±10	1406	1397.7±0.4	1398.1±0.8	1397.7±0.4
1759±6	1762	1753.7±0.5	1753.9±0.7	1753.8±0.4
2228±6	2334 [d]	2223.5±0.7	2223.7±0.4	2223.8±0.4
2873±6	2875		(2865±1)	2873±6
3069±6	3071			3069±6
3193±6	3191	960.2±0.5	960.3±0.5 1430.0±1.5	3184.0±0.6 [e]

[a] Reference 5.

[b] Reference 6. No uncertainties for ^{29}Al are quoted in Ref. 6; however, three other experiments described in Ref. 6 have quoted uncertainties which would make ±10 keV a reasonable uncertainty for ^{29}Al excitation energies in this column.

[c] Present work.

[d] As pointed out by Ref. 5, this is apparently a misprint.

[e] This adopted value is discussed in the text.

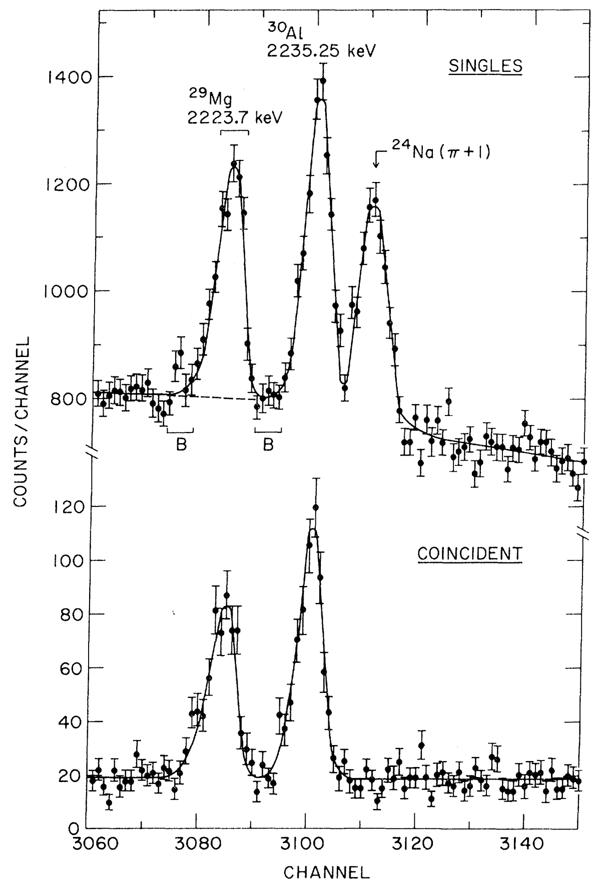

FIG. 1. Part of the delayed γ-ray spectra showing the strongest ^{29}Mg line at 2224 keV. The dispersion is 0.74 keV/channel. The upper spectrum was taken in singles and the lower in coincidence with pulses in the NE 102 detector above 2.5 MeV. β-ray spectra in the NE 102 were recorded in coincidence with γ-ray counts in channels 3083-3087 and in the sum of channels 3074-3078 and 3090-3094. The two high points in channels 3075 and 3076 are due to a weak ^{25}Na line and are discussed in Sec. II B 2. This spectrum represents counts accumulated for 1.8 sec starting 0.5 sec after irradiation, accumulated over about 19 000 cycles of bombardment and counting. The cross section for producing the 2224-keV γ ray, energy averaged between 16- and 35-MeV lab beam energy, is within a factor of 2 of 26 μb.

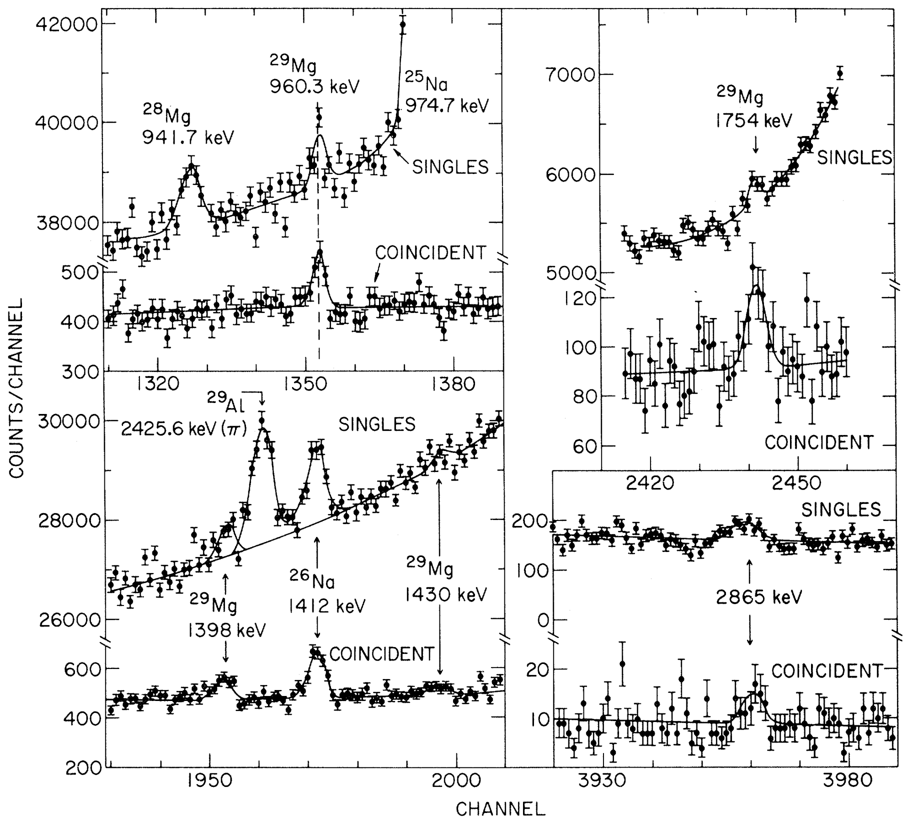

FIG. 2. Other regions of the delayed γ-ray spectrum shown in singles and coincidence. The 2865-keV line is not definitely ascribed to the decay of ^{29}Mg.

are shown for comparison. In several instances the energy of the γ ray is more precisely obtained from the coincidence spectra, because of the major reduction in background due to the coincidence requirement. Comparison of intense background lines in both singles and coincidence showed that there was no perceptible gain shift between the two.

The half-life of ^{29}Mg was measured to be 1.20 $\pm$0.13 sec from the yield of the top five channels of the 2224-keV line in each of four 0.9-sec time bins. Figure 3 shows the decay curve. The yield of the 1779-keV line from the decay of ^{28}Al, corrected for its own decay, provided a measure of the total system dead time in each bin. ^{28}Mg lines in the spectrum were negligible, and therefore contributed essentially no feeding of ^{28}Al which would otherwise invalidate the dead-time correction procedure used.

As shown in Table I, we assign the 960-keV γ ray to be a transition between the "3193 $\pm$ 6"-keV level of Ref. 5 and the 2224-keV level, because the 960-keV line is seen in the $^{27}Al + t$ work. Also, the 3193-keV level is known[7] to branch 59 $\pm$ 2% to the 2224-keV level and 32 $\pm$ 2% to the 1754-keV

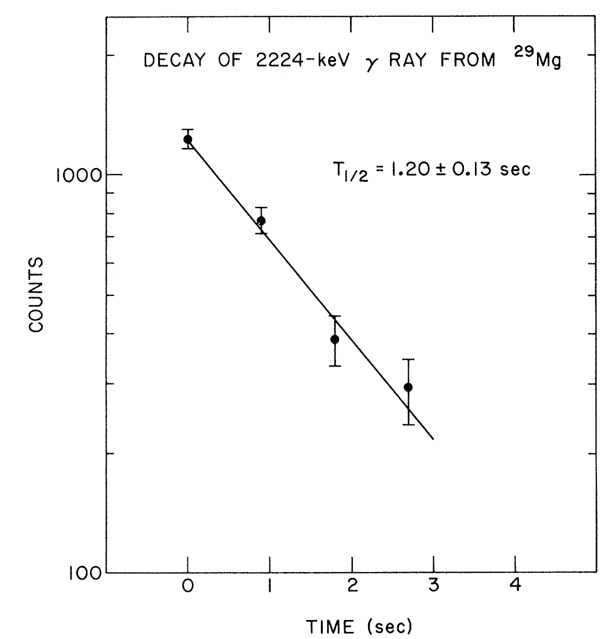

FIG. 3. The decay of the 2224-keV γ ray, using the ^{28}Al activity as a measure of the total system dead time.

level. This means if the assignment is correct there should also be a 1430-keV line. In fact, Fig. 2 shows that there is a barely statistically significant peak in both singles and coincidence spectra at this energy with an intensity consistent with expectation. In the (t, p) spectra, the background near 1430 keV made the observation of this γ ray impossible. Also the decay of the 960-keV line is consistent with 1.2 sec.

The 2865-keV line in Fig. 2 cannot be ascribed definitely to a transition in ^{29}Al since we were unable to produce it directly with the ^{27}Al$(t, p\gamma)$ reaction. It does have a half-life consistent with 1.2 sec, and we tentatively assign it as being a ground-state transition from the 2873 ± 6-keV level of Ref. 5.

A rough measure of the energy of the β ray preceding each delayed γ ray shown in Figs. 1 and 2 can be obtained by comparing the ratio of coincident counts to singles counts: the larger the ratio, the higher the β-ray energy. This is strictly valid only if the γ ray originates from the terminal level of the β ray and the γ ray terminates on the ^{29}Al ground state. Otherwise the pulse-height spectrum in the NE 102 scintillator contains events due to one or more β rays, β rays summing with γ rays, and γ rays alone. For several strong lines in the delayed spectrum, this validity requirement is met, and Fig. 4 has been constructed from observed ratios of coincident-to-singles yields. The ^{26}Na point has been corrected for a 12% strength of lower-energy β rays.[2] This curve saturates at a ratio of 0.40, which is the measured solid angle of the β-ray detector.

The adopted excitation energies for ^{29}Al are shown in Fig. 5, as well as weighted averages of all published branching ratios as presented by Ref. 7. We have used these branching ratios in deducing relative β branches to ^{29}Al, as summarized in Table II. Summing corrections were made for the relative γ-ray intensities, which were all taken from the singles spectra of Figs. 1 and 2. In deducing the β branches to the first three excited states, consideration has been given to possible feeding from higher states to which only upper limits on the β-ray strength have been given. In several cases the limits on the relative β-ray branches would be considerably smaller if the excitation energy of the state were known more accurately. For example, the branch to the 3439 ± 10-keV level is limited to <28, because of a nearby background peak. If the excitation energy of this level is >3432 keV, the limit would be 3 times smaller. The asymmetric uncertainties in the relative β branches to the lower states shown in Table II reflect consideration of possible higher-feeding effects. No branch can be ascribed to the 1754-keV level, since all of the observed 1754-

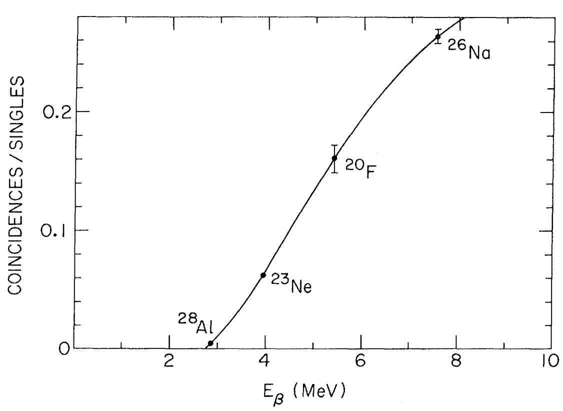

FIG. 4. The ratio of γ-ray counts in coincidence with β rays above 2.5 MeV to counts in singles, for four activities with known β-ray end points. This curve was used to establish consistency between the β-ray branches derived in the text with the observed ratio of coincidence-to-singles counts.

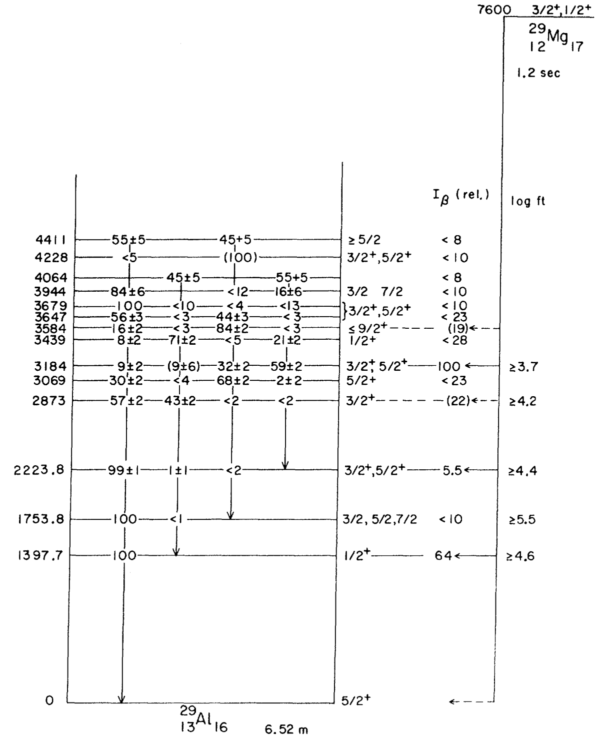

FIG. 5. The β decay of ^{29}Mg to levels of ^{29}Al. References for the excitation energies are given in Tables I and II. The γ-ray branching ratios are those averaged and adopted by Ref. 7. The spin and parity assignments for ^{29}Al are from Ref. 7, except that the assignments for the 3184- and 2224-keV levels are from the present work. A large ground-state β-ray branch is expected for ^{29}Mg, but there was no way to measure this branch in the present work.

keV γ rays can be accounted for from feeding from the 3184-keV level.

B. β-Ray Spectra and the Mass of ^{29}Mg

The on-line computer used for data storage simultaneously recorded the spectra in the NE 102 detector coincident with digital gates set on singles γ-ray photopeaks and backgrounds. Figure 1 shows a gate set on the top five channels of the 2224-keV peak as well as two background regions above and below this peak. Gates on the peaks and backgrounds for the 1779-keV line following the decay of ^{28}Al, the 440-keV line from ^{23}Ne, the 1634-keV line from ^{20}F, and the 1809-keV line from ^{26}Na were also stored simultaneously with the ^{29}Mg spectra.

1. ^{23}Ne Calibration Spectrum

Figure 6 shows the spectrum for a β-ray end point of 3939 keV from the decay of ^{23}Ne, obtained in coincidence with the 440-keV β-delayed γ ray. ^{23}Ne also decays[8] with a minor branch to the 2076-keV level in ^{23}Na, and the data shown in Fig. 6 have been corrected for this inner β-ray branch in the following manner. For each 440-keV γ ray detected in the Ge(Li) counter, there is a 97.1% chance that a β ray from a 3939-keV end-point spectrum is the only radiation coincident with it. There is a 2.9% chance that one or more events due to a β-ray feeding the 2076-keV ^{23}Na level is coincident. Thus, the raw spectrum coincident with the 440-keV line must be corrected in order to generate the desired spectrum of a 3939-keV β-ray end point. One can deduce that the raw spectrum corresponds to the sum of four spectra, namely $0.967\beta(3939)+0.025\beta(2303)+0.004G(1636)+0.0027\beta G(2303,1636)$, where the first term is the desired β spectrum, the second is the spectrum due only to the 2303-keV β ray feeding the 2076-keV ^{23}Na state, $G(1636)$ is the response function of the NE 102 detector to the 1636-keV (=2076-440 keV) γ ray, and the last term is the spectrum in the NE 102 due to the summing of the 2303-keV β spectrum with the 1636-keV γ-ray spectrum. The coefficients multiplying each term reflect the relative β-ray branches for the decay of ^{23}Ne and the chance that the appropriate radiations interact in the NE 102 detector,

TABLE II. β decay of ^{29}Mg to levels of ^{29}Al. All limits are at the 85% confidence level.

^{29}Al level E_x (keV)	I_β (rel)	E_γ (keV)	I_γ (rel)	log ft limit
0	...	...	...	...
1397.7 ± 0.4 [a]	64^{+35}_{-28}	1397.7 ± 0.4	64^{+30}_{-20}	≥4.6
1753.8 ± 0.4 [a]	<10	1753.8 ± 0.4	22 ± 5	≥5.5
2223.8 ± 0.4 [a]	55 ± 22	2223.7 ± 0.4	100 ± 6	≥4.4
$\{(2865\pm1)$, $2873\pm6\}$ [a]	(22 ± 5)	(2865 ± 1) [b]	(11.3 ± 2.4)	≥4.2
3069 ± 6 [a]	<23	1315 ± 6	<14	
3184.0 ± 0.6 [a]	100 ± 35	960.3 ± 0.4	52 ± 18	≥3.7
		1430 ± 1.5	34 ± 17	
3439 ± 10 [c]	<28 [d]	2041 ± 10	<18	
(3574 ± 1) [e]	(19 ± 6)	(1820 ± 1) [b]	(14 ± 3)	
3584 ± 10 [c]				
3647 ± 10 [c]	<23	3647 ± 10	<11	
3679 ± 10 [c]	<10	3679 ± 10	<8	
3944 ± 10 [c]	<10	3944 ± 10	<7	
$4064\pm(10)$ [f]	<8	$2666\pm(10)$	<3	
$4228\pm(10)$ [f]	<10	$2474\pm(10)$	<9	
$4411\pm(10)$ [f]	<8	$2657\pm(10)$	<3	

[a] See Table I.

[b] This γ ray cannot definitely be assigned to ^{29}Mg decay.

[c] Reference 5.

[d] See the discussion in the text regarding this limit.

[e] Based upon the assignment of the 1820-keV γ ray.

[f] Reference 6; see footnote a of Table I.

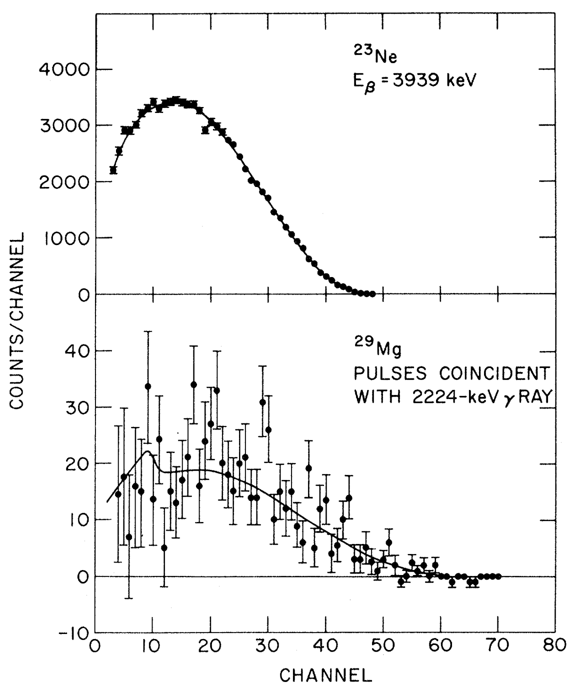

FIG. 6. The upper curve is the spectrum of pulses in the NE 102 detector coincident with the 440-keV γ ray from the decay of ^{23}Ne, with the contributions due to a weak branch to the 2076-keV level of ^{23}Na removed, so as to represent the spectrum of a β ray with a 3939-keV end-point energy. The dispersion is 89 keV/channel. The solid curve guides the eye. The lower portion is the spectrum of pulses coincident with the 2224-keV γ ray from the decay of ^{29}Mg. The solid curve was generated from the ^{23}Ne curve above so as to represent the best fit to the data using the sum of the four spectral distributions mentioned in the text. See Sec. II B 2. The peak in the solid curve near channel 9 represents events in the scintillator due to the 960-keV γ ray interacting alone without the coincident β ray.

and that the 1636-keV γ ray does not interact in the Ge(Li) detector. Since the corrections are small, the raw spectrum was compressed in order to generate $\beta(2303)$, and an observed response function to the 1836-keV γ ray from the decay of ^{88}Y was compressed to generate $G(1636)$, and then $\beta G(2303, 1636)$ was computed numerically. The three terms were then subtracted from the observed raw spectrum to yield the data shown in the top of Fig. 6. The solid curve is a smoothed shape drawn through the data points.

2. Spectrum Coincident with the 2224-keV γ Ray

From Table II and Fig. 5 it can be seen that the spectrum in the NE 102 detector coincident with the 2224-keV γ ray ray is due to β rays feeding the 2224-keV level as well as ones feeding the 3184-keV level. In addition there are events due to the 960-keV γ-ray transition between the 3184- and 2224-keV levels, as well as $\beta\gamma$ summing effects similar to that discussed above for ^{23}Ne. For this reason, a Kurie plot of the data is meaningless, and a different technique was used. First it is to be noted in Fig. 1 that in channels 3075 and 3076 in the singles spectrum for the 2224-keV peak there is an excess of counts due to the 2216-keV γ ray following the β decay of ^{25}Na. This was confirmed by the intensity of this peak relative to the prominent 974.7-keV ^{25}Na line. This peak was situated in the lower background region, and one half of the spectrum in the NE 102 coincident with it was subtracted from the spectrum coincident with channels 3083-3087 during the data analysis. Fortunately, the radiations coincident with the weak 2216-keV line are low in energy: a 1.03-MeV β ray and a 585-keV γ ray. Using a method similar to that described for ^{23}Ne, the appropriate corrections were computed and added into the spectrum coincident with 2224-keV γ ray in order to yield the data shown in the lower half of Fig. 6. This correction amounted to only 20 counts, all of which were distributed into channels 3 through 10.

The data shown at the bottom of Fig. 6 represent the following spectrum: $(0.48 \pm 0.19)\beta(E) + (0.52 \pm 0.19)[0.837\beta(E-960) + 0.17G(960) + 0.11\beta G(E-960, 960)]$, where the symbols mean the same as before and E is the endpoint energy of the β ray directly feeding the 2224-keV level in ^{29}Al. The response functions were generated numerically by stretching the ^{23}Ne spectrum, and the solid curve drawn through the ^{29}Mg data represents the best fit to the data, using a function of the form shown above. The value of E thus determined was 5400 ± 400 keV, where the major source of the uncertainty arises from statistics, while uncertainty in the ratio of intensities of the 960- and 2224-keV γ rays contributes only 150 keV to the over-all uncertainty. Uncertainty in the linearity of the stretching technique are negligible. This corresponds to a Q_β, defined as the maximum possible β-ray energy between the ground states of ^{29}Mg and ^{29}Al of 7624 ± 400 keV. This value is 1.74 ± 0.43 MeV different from the value calculated on the basis of the mass excess for ^{29}Mg suggested in Ref. 4. The coincidence-to-singles ratio for the 2865-keV γ ray, tentatively assigned to ^{29}Mg decay, is 0.12 ± 0.06, consistent with the value of 0.12 ± 0.03 predicted by Fig. 4 for the direct β-ray feeding to this level.

III. INTERPRETATION OF THE DECAY SCHEME

The β branch of ^{29}Mg to the 1398-keV level with $J^\pi = \frac{1}{2}^+$ establishes the spin of the parent as $\frac{1}{2}^+$ or $\frac{3}{2}^+$ if the decay is of the allowed nature, and $\frac{1}{2}^-$, $\frac{3}{2}^-$, or $\frac{5}{2}^-$ if it is first forbidden. It has been our experience that heavy-ion compound reactions emitting two protons from a compound nucleus that is already neutron rich have very low cross sections, and it is very unlikely that our spectra would be sensitive enough under such conditions to see for-

TABLE III. Masses of $T_z = \frac{5}{2}$ Nuclei in the $2s$-$1d$ Shell.

Nuclide	$(M-A)$ expt (keV)	Ref.	$(M-A)$ expt−prediction (keV)
^{21}O	9300^{+300}_{-700}	a	362^{+300}_{-700}
^{23}F	...		...
^{25}Ne	-1960 ± 300	b	-562 ± 300
	-2180 ± 100	c	-782 ± 100
^{27}Na	-5650 ± 180	d	388 ± 180
	-5880 ± 140	e	158 ± 140
^{29}Mg	$-10\,590 \pm 400$	f	930 ± 400
	$-12\,330 \pm 160$	g	-810 ± 160
^{31}Al	$-15\,010 \pm 100$	h	676 ± 100
^{33}Si	$-20\,569 \pm 50$	i	421 ± 67
^{35}P	$-24\,936 \pm 75$	j	-162 ± 87

[a] A. G. Artukh, V. V. Avdeichikov, G. F. Gridnev, V. V. Volkov, and J. Wilczynski, Nucl. Phys. A192, 170 (1972).

[b] D. R. Goosman, D. E. Alburger, and J. C. Hardy, Phys. Rev. C 7, 1133 (1973).

[c] K. H. Wilcox, N. A. Jelley, G. J. Wozniak, R. B. Weisenmiller, H. L. Harney, and J. Cerny, Phys. Rev. Lett. 30, 866 (1973).

[d] Reference 2.

[e] Reference 13.

[f] Present work.

[g] Reference 4.

[h] Reference 1.

[i] Reference 12.

[j] D. R. Goosman and D. E. Alburger, Phys. Rev. C 6, 820 (1972).

bidden transitions. The spherical shell model would predict $J^\pi = \frac{3}{2}^+$ for ^{29}Mg, and there is every reason to expect a large ground-state β branch corresponding to a $d_{3/2}$ to $d_{5/2}$ transition. A measure of the ground-state β branch would establish the spin as $\frac{3}{2}^+$ if the logft values to both the ground and first excited states were in the allowed range. Since we cannot measure the ground-state branch (the observed buildup of the ^{29}Al daughter activity only limits this branch to $\leq 99.9\%$ of all β rays), we can quote only lower limits on the logft values to the states as shown in Table II and Fig. 5. With about 90% confidence we assign to ^{29}Mg a spin of $\frac{1}{2}^+$ or $\frac{3}{2}^+$, and with the same reservation the 2224-keV level in ^{29}Al, which is known[7] to be $\frac{3}{2}$, $\frac{5}{2}$, or $\frac{7}{2}$, can thus be assigned $\frac{3}{2}^+$ or $\frac{5}{2}^+$, and the 3184-keV level, known[7] to be $\frac{3}{2}$ or $\frac{5}{2}$, is assigned positive parity.

An interpretation of the levels of ^{29}Al in terms of the Nilsson model has been given by several authors,[7, 9, 10] and in particular by Ref. 7. These authors discuss evidence suggesting that the ground state is the band head of a $K = \frac{5}{2}$ band formed on Nilsson orbit No. 5, whose $\frac{7}{2}^+$ member is the 1754-keV level, (see Fig. 4 of Ref. 7) using a level ordering compatible with a deformation η between 0 and 3.5. They also suggest a $K = \frac{1}{2}$ band built upon a proton excited to orbit No. 9 whose $\frac{1}{2}^+$ and $\frac{3}{2}^+$ members are the states at 1398 and 2873 keV. A third band is suggested with $K = \frac{3}{2}$ constructed by transferring a proton from orbit 7 to orbit 5, whose $\frac{3}{2}^+$ and $\frac{5}{2}^+$ members are the 2224- and 3069-keV levels. One can examine these suggestions in terms of the ^{29}Mg β decay. For $-4.5 < \eta < 0$, the model without band mixing predicts $J^\pi = \frac{3}{2}^+ = K$ for ^{29}Mg. For $0 < \eta < 3.5$, it predicts $J^\pi = \frac{3}{2}^+$, but with $K = \frac{1}{2}$, and for $3.5 < \eta < 5$, the result is $J^\pi = \frac{1}{2}^+ = K$.

An examination of the appropriate orbitals shows that in order to be compatible with experiment and the suggestions of Ref. 7, ^{29}Mg must have positive deformation. Also the experimentally observed lack of β-decay strength to the 1754-keV level is consistent with its suggested assignment[7] of $K = \frac{5}{2}$, $J^\pi = \frac{7}{2}^+$. The ^{29}Mg configurations for $0 < \eta < 5$ can decay to the $K = \frac{1}{2}$ band members suggested in ^{29}Al. However, the observed decay to the 2224-keV level is totally inconsistent with this picture of ^{29}Al. There is no way that the ^{29}Mg configurations suggested above could β decay to a $K = \frac{3}{2}$ band built upon a hole in orbit No. 7, because the Gamow-Teller operator is only a one-body operator, and the rearrangement of more than one nucleon is required to effect this transition.

It is hoped that increasing experimental information will stimulate detailed shell-model calculations of this β decay.

IV. SYSTEMATICS OF MASSES OF $T_z = \frac{5}{2}$ NUCLIDES IN THE $2s$-$1d$ SHELL

Over the course of the past year the masses of seven of the eight $T_z = \frac{5}{2}$ nuclides in the $2s$-$1d$ shell have been measured at several laboratories. Table III shows the results of all published measurements. The differences between the experimental and predicted masses are also shown. The predictions were in all cases derived simply from the measured masses of nuclei closer to stability in conjunction with the transverse relationship of Garvey *et al.*[11] For example:

$$M(^{33}\mathrm{Si}) = M(^{34}\mathrm{P}) + M(^{32}\mathrm{Si}) + M(^{33}\mathrm{S}) - M(^{34}\mathrm{S}) - M(^{32}\mathrm{P}).$$

The masses of all the relevant $T_z < \frac{5}{2}$ nuclides are very accurately known, except for ^{34}P, for which we have used the recent measurement by Goosman, Davids, and Alburger[12] of $(M-A)^{34}\mathrm{P} = -24\,546 \pm 45$ keV. The predictions were calculated by this simple relationship rather than being taken from least-squares-fitted predictions, because the latter technique tends to average out effects that are being considered here. The results of Table III are also shown in Fig. 7 except for the ^{29}Mg point based on Ref. 4. A systematic trend in the differences is very clear, at least for $A \geq 25$. This trend was not evident before the present measurement of the ^{29}Mg mass was completed, since it differs by 1.7 ± 0.5 MeV from the value previously suggested.[4] On the average, the nuclei

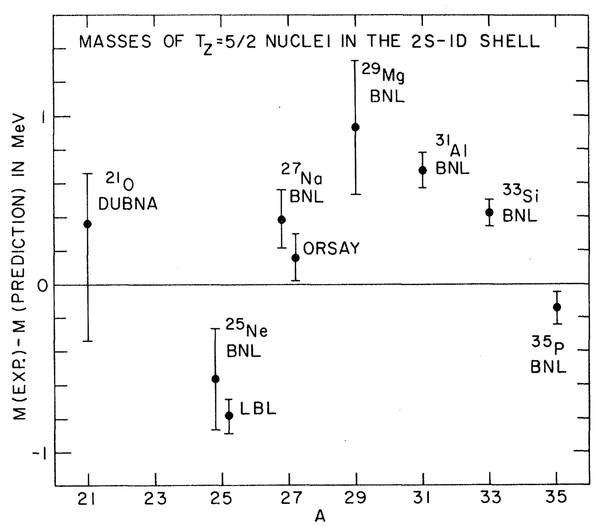

FIG. 7. The differences between the measured masses and predictions based upon the transverse relationship of Ref. 11 for the $T_z = \frac{5}{2}$ nuclei in the $2s$-$1d$ shell. Two measurements for ^{27}Na and ^{25}Ne are shown. The value based on the ^{29}Mg mass given in Ref. 4 has not been included in this figure because of the discrepancy with the present result. A rather systematic trend in the mass differences is evident.

shown in Fig. 7 are less tightly bound than the t relation of Ref. 11 would predict. This effect has also been shown to hold for very neutron-rich isotopes of sodium, as recently demonstrated by Klapisch *et al.*[13]

Attempts to understand the systematics of Fig. 7 are being undertaken: It is hoped that an understanding of this figure will help generate more refined mass relationships in the future. It is curious to note that in Fig. 7 the differences are closest to zero at masses 27 and 35, which is where the $s_{1/2}$ and $d_{3/2}$ neutron shell closures occur, respectively. The $d_{5/2}$ neutron shell closure occurs at mass 23, but to date our attempts to produce and measure the mass of ^{23}F have been unsuccessful. Efforts to refine the measurement of the ^{21}O mass are underway, using the $^{10}Be(^{13}C, 2p)$ reaction. In the future complete $2s$-$1d$ shell-model calculations of these masses will be possible.[14]

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

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