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$Ru^{103,\,105}$ States Observed in the Reactions $Ru^{102,\,104}(d,p)$†

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The (d,p) reaction on Ru^{102} and Ru^{104} has been studied at an incident deuteron energy of 14 MeV. Proton spectra were recorded in a broad-range magnetic spectrograph. Transferred l values and spectroscopic factors were obtained by comparing the measured angular distributions with distorted-wave Born-approximation predictions. The low-lying levels of Ru^{103} are in good agreement with the results of a recent (d,t) study; information on higher levels of Ru^{103} and on all levels in Ru^{105} is new. There is good correspondence between strongly excited levels in the two isotopes, although there is evidence of a higher level density in Ru^{105}. The summed spectroscopic factors give information on the extent of filling of the neutron orbitals in the targets, and these results are in reasonable agreement with results from the (d,t) reaction and for other nuclei in this region.

I. INTRODUCTION

It has been suggested[1] that stable quadrupole deformations may occur in nuclei with $40 < Z < 50$ and with $N > 60$. This includes the region of neutron-rich Mo, Ru, and Pd isotopes. Support for this suggestion comes from the fact that the energies of the first excited 2^+ states in such even-even isotopes decrease appreciably as neutrons are added; this feature is most pronounced in the Ru isotopes. Further support comes from the mass dependence of delayed γ-ray yields from fission fragments[2]; again the heavy Ru isotopes appear to be the most likely region in which to find nuclei with low-lying deformed states.

Almost all of the experimental evidence on deformation involves the study of complex γ-ray transitions, and rarely can the level structure be uniquely determined from such data alone. A particularly complex spectrum was observed[3] in the decay of Tc^{105} to Ru^{105}. In order to gain spectroscopic information on the level structure of nuclei in this region, we have studied (d,p) reactions on the most neutron-rich stable Ru^{102} and Ru^{104} targets. Of special interest was the comparison between the level structures of the two nuclei in an effort to obtain evidence for or against a change in character between Ru^{103} and Ru^{105}.

Also of interest is the comparison between the results for these Ru isotopes and the corresponding results for neighboring nuclei having a similar number of neutrons. In particular, the (d, p) reaction on Pd^{106} and Pd^{108} has been studied in detail.[4] A recently reported[5] study of the (d, t) reaction on Pd^{110}, Pd^{108}, and Ru^{104} complements the (d, p) spectroscopic studies. A preliminary report[6] of the present work was referred to in the (d, t) study; the present paper extends and completes the (d, p) study.

The analogs of several of the low-lying states in Ru^{103} and Ru^{105} have recently been reported by Friedman *et al.*[7] Spectroscopic strengths were extracted for three of the strong $l = 2$ states and may be compared with the corresponding values from the (d, p) reaction.

II. EXPERIMENTAL PROCEDURE

Angular distributions and absolute cross sections for the (d, p) reactions on the Ru targets were measured with 14-MeV deuterons obtained from the Argonne FN tandem Van de Graaff accelerator. The emitted protons were detected with photographic emulsions in the focal plane of a Browne-Buechner magnetic spectrograph. The total number of incident deuterons was determined by a current integrator which measured the charge collected in a Faraday cup. A monitor counter placed at forward angles (~30°) provided an independent check of the normalization.

The targets were isotopically enriched foils of Ru^{102} and Ru^{104}, made by evaporating onto thin carbon (≤20 $\mu g/cm^2$) backings. The thicknesses of Ru used were 25–50 $\mu g/cm^2$. Such thin targets permitted the safe use of beam currents up to ~2 μA.

The target thicknesses were determined by taking spectra of deuterons elastically scattered by the target at a number of forward angles. These elastic scattering data were then compared with the predictions from the deuteron optical-model parameters used in the distorted-wave calculations. This method was supplemented by further elastic scattering measurements at 4 MeV, at which energy the cross section at forward angles

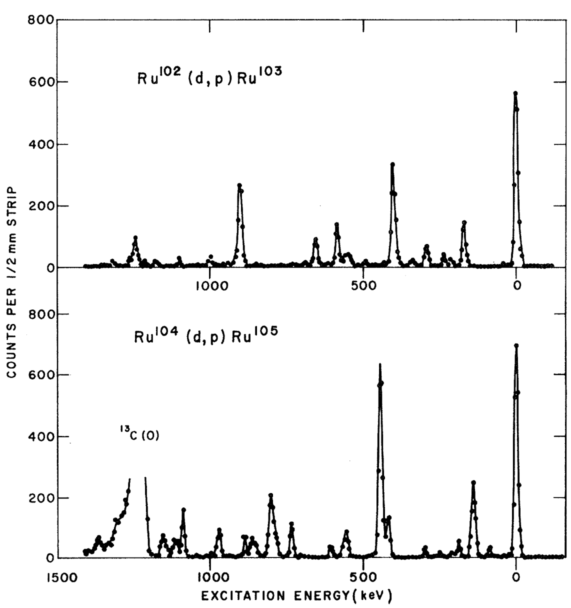

FIG. 1. Proton spectrum from the $Ru^{102}(d,p)Ru^{103}$ and $Ru^{104}(d,p)Ru^{105}$ reactions at $\theta_L = 20°$ and an incident deuteron energy of 14.0 MeV.

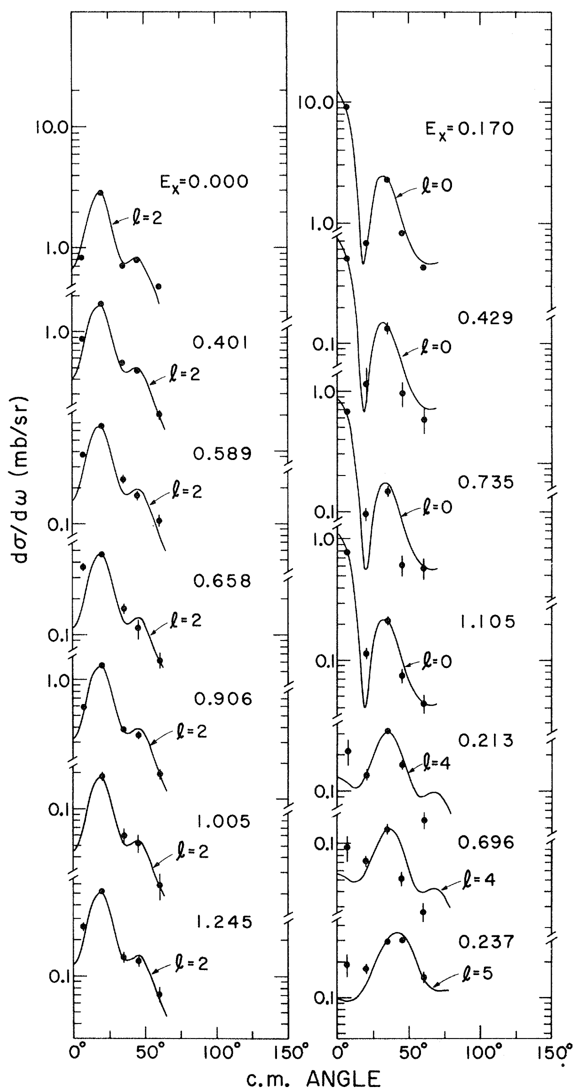

FIG. 2. Measured angular distributions of the Ru^{102}-$(d,p)Ru^{103}$ reaction, grouped to show $l = 0$, 2, 4, and 5 angular momentum transfers. The points represent the data and the curves represent the results of DWBA calculations as described in the text. The excitation energies are in MeV.

is well described by Rutherford scattering. The target thicknesses obtained by the two methods were in good agreement. The over-all accuracy in the determination of the absolute cross section is estimated to be better than 15%.

III. RESULTS

Proton spectra were recorded at five lab angles (7, 20, 35, 45, and 60°) chosen so as to distinguish $l=0$, 2, and 4 angular distributions. Spectra obtained at 20° for both Ru^{102} and Ru^{104} targets are shown in Fig. 1. The energy resolution width achieved in the work was approximately 12 keV. A consistent energy calibration was achieved by using the protons from the $C^{12}(d,p)C^{13}$ and $O^{16}(d,p)$-O^{17} impurity reactions. The Q values of the ground-state transitions were determined to be 4.005 ± 0.015 MeV for the $Ru^{102}(d,p)Ru^{103}$ reaction and 3.663 ± 0.015 MeV for $Ru^{104}(d,p)Ru^{105}$ reaction.

Angular distributions were extracted for the levels below about 1.3-MeV excitation energy in both nuclei and are shown in Figs. 2–4. The errors in the relative cross sections contain both the statistical contributions and an estimate of the uncertainties in background subtraction; in the case of closely spaced levels, an error for the peak-shape fitting procedure was also included. Analysis was limited to states whose peak cross section was greater than about 0.1 mb/sr, although there are indications of weaker states in the spectra from both targets. At higher excitation energies the density of levels increases and the strength of individual levels decreases. Only a few strong states between 1.3 and 2 MeV could be analyzed.

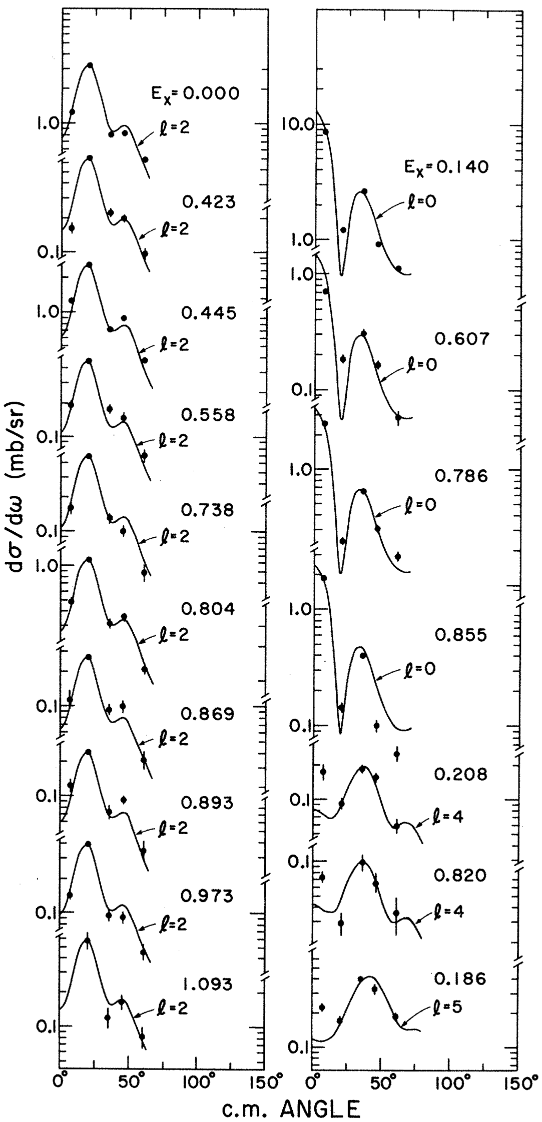

FIG. 3. Measured angular distributions of the Ru^{104}-$(d,p)Ru^{105}$ reaction. The details are as described for Fig. 2.

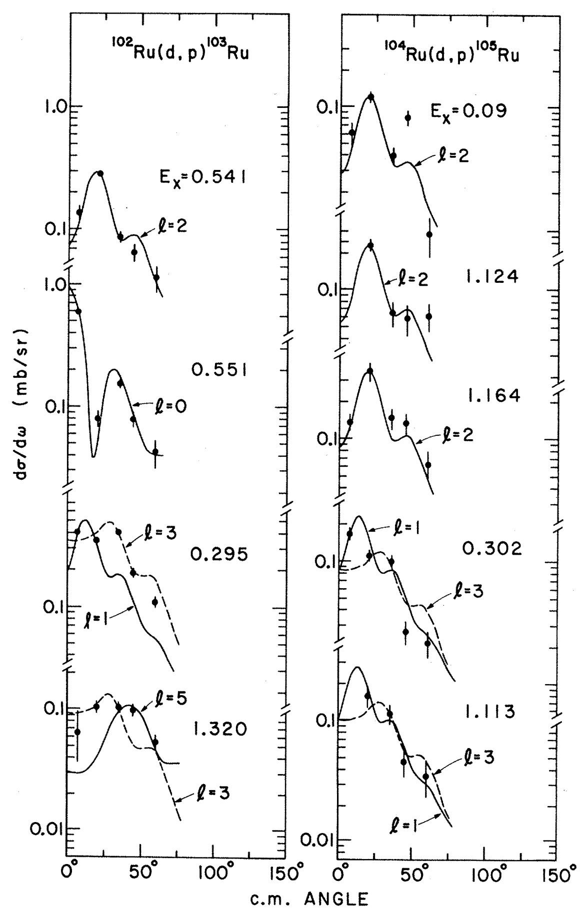

FIG. 4. Measured angular distributions for states weakly populated in the $Ru^{102,104}(d,p)Ru^{103,105}$ reactions. The details are as described for Fig. 2. The two angular distributions plotted at the bottom for each reaction do not permit an unambiguous determination of l.

IV. ANALYSIS

The angular distributions were analyzed by means of the local zero-range form of the distorted-wave Born-Approximation (DWBA) formalism.[8] These calculations were done with the code JULIE.[9] Values of orbital angular momentum transfer l and spectroscopic factors S were obtained by comparing the experimental angular distribution with the results of the DWBA calculations by use of the expression

$$\sigma_{\text{exp}}(\theta) = 1.65(2J_f + 1)S_{lj}\sigma_{lj}(\theta) .$$

The optical-model parameters used in the DWBA calculations for the deuteron[10] and proton[11] channels were taken from earlier work in this mass region. The bound-state form factor for the transferred neutron was taken to be the wave function of a neutron in a Woods-Saxon well, with a binding energy given by the neutron separation energy for the state in question. A spin-orbit interaction was included for the bound-state and proton channels, but not for the deuteron channel. The parameters used in the DWBA calculations are listed in Table I.

The angular distributions calculated with the parameters in Table I do not fit the experimental data unless the contribution from the nuclear interior is eliminated by using a lower cutoff on the radial integrals. This situation also holds in the Ba isotopes,[12] for which it was found that partial damping of the nuclear interior by including finite-range and nonlocal effects was inadequate. It is possible that some combination of deuteron and proton optical parameters would eliminate this problem. However, since the present emphasis is on comparing the structure of Ru^{105} with that of Ru^{103}, the necessary parameter search was not done. The resulting absolute spectroscopic factors may, therefore, be uncertain by as much as ±50%.

The calculated angular distributions obtained by using a lower cutoff radius equal to 6.0 F are compared with experiment in Figs. 2–4. Figures 2 and 3 contain the majority of cases in Ru^{103} and Ru^{105}, respectively; the observation of $l = 0$, 2, 4, and 5 is consistent with the shell-model orbitals for $50 < N < 82$. Good fits are obtained for $l = 0$ and 2. The fits for $l = 4$ and 5 are somewhat poorer at forward angles, although the shift in the first maximum is reasonably well predicted, and hence the two l values can be distinguished with reasonable confidence. Additional angular distributions for weakly populated states in both nuclei are plotted in Fig. 4. These lead to unambiguous l-value assignments except for the two bottom plots for each reaction.

Tables II and III summarize the energies (±5 keV) and spectroscopic strengths determined in the present work for Ru^{103} and Ru^{105}, respectively. The results of the $Ru^{104}(d,t)$ reaction study[5] are also included for comparison in Table II. Some additional states that are only weakly populated in the (d,p) reaction are observed in the (d,t) reaction. These states are included in Table II, and limits on the (d,p) spectroscopic factors are given. Results on the few strong states observed between 1.3 and 2.0 MeV in both nuclei are also included for completeness.

V. DISCUSSION

Table II shows that the $Ru^{102}(d,p)$ and $Ru^{104}(d,t)$ reactions agree well on the energies and l values assigned to the levels in Ru^{103}. In particular, the agreement for $l = 4$ and 5 transitions gives confidence in the distinction made in the present (d,p) study. Only two discrepancies are revealed in Table II. The 0.545-MeV state assigned $l = 1$ in the (d,t) study appears as an $l = 0$, 2 doublet in the (d,p) study. A peak-shape fitting procedure achieved the separate angular distributions shown in Fig. 4. Excitation energies of 0.551 MeV for the $l = 0$ state and 0.541 MeV for the $l = 2$ state were extracted from the energy spectra observed at 7° ($l = 0$ maximum) and 20° ($l = 2$ maximum, $l = 0$ minimum), respectively. A further discrepancy occurs for the 0.295-MeV state; $l = 0$ is inferred from the (d,t) work whereas $l = 3$ is favored in the (d,p) reaction. However, it appears that the (d,t) angular distribution of the state does not exclude the possibility of $l > 0$.

It is not possible to distinguish between $j = l \pm \frac{1}{2}$ from the (d,p) data alone. From shell-model systematics in the mass region, the low-lying $l = 4$ and $l = 5$ transitions are expected to correspond to

TABLE I. Potential parameters used in analysis of the $Ru^{102,104}(d,p)Ru^{103,105}$ reactions. The notation is that of Refs. 10 and 11.

Particle	V_s (MeV)	r_{0s} (F)	a_s (F)	W_D (MeV)	r_{0I} (F)	a_I (F)	r_C (F)	V_{so} (MeV)
n	Adjusted	1.25	0.65	···	···	···	1.25	($\lambda = 25$)
d	71.3	1.146	0.911	16.16	1.383	0.70	1.30	0
p	57.66	1.150	0.687	8.21	1.263	0.738	1.25	8.16

TABLE II. Energies and spectroscopic factors for states observed in the $Ru^{102}(d,p)Ru^{103}$ and $Ru^{104}(d,t)Ru^{103}$ reactions.

$Ru^{102}(d,p)Ru^{103}$			$Ru^{104}(d,t)Ru^{103}$ [b]			
E_x [a] (MeV)	l	$(2J_f+1)S_{dp}$	E_x (MeV)	l	S_{dt}	$\frac{S_{dt}}{(2J_f+1)S_{dp}}$
0.0	2	1.40	0.0	2	1.973	1.4
0.139	(2)	(≤0.01)	0.133	2	(0.14)(0.11)	~10
0.170	0	0.85	0.171	0	0.431	
0.213	4	2.35	0.210	4	2.36	
0.237	5	3.25	0.235	5	1.92	
0.295	(1)(3)	(0.17)(1.5)	0.294	(0)	0.080	
0.339	(2)	(≤0.06)	0.343	2	0.164	~3
0.401	2	0.85	0.402	2	0.621	0.73
0.429	0	0.055	0.428	0	0.118	
0.499	(2)	(≤0.05)	0.497	2	0.257	~5
0.541	2	0.14	0.545	1	0.068	
0.551	0	0.06				
0.589	2	0.33	0.587	2	0.377	1.15
0.658	2	0.24	0.658	(2)	0.036	0.15
0.696	4	1.00	0.693	4	0.47	
0.735	0	0.064	0.731	0	0.146	
0.906	2	0.67	0.902	2	0.088	0.13
1.005	2	0.09				
1.105	0	0.076				
1.245	2	0.26				
1.320	(3)(5)	(0.4)(1.0)				
1.55	(2)	(0.15)				
1.805	(0)	(0.07)				
1.96	(2)	(0.35)				

[a] The error in most cases is ±5 keV.

[b] See Ref. 5.

transfer of a $1g_{7/2}$ and $1h_{11/2}$ neutron, respectively. However, for $l=2$ transitions, both $2d_{5/2}$ and $2d_{3/2}$ transfers are possible—although the former assignment should be favored for low-lying $l=2$ states. In particular, the ground-state spins of both Ru^{103} and Ru^{105} are most likely to be $J^\pi=\frac{5}{2}^+$. A previous study[13] of the β decay of Ru^{105} has suggested that the ground state is $\frac{3}{2}^+$ and arises from a $(d_{5/2})^n$ configuration of seniority 3. The large spectroscopic strength observed in the (d,p) reaction would appear to refute this suggestion.

TABLE III. Energies and spectroscopic factors for states observed in the $Ru^{104}(d,p)Ru^{105}$ reaction.

E_x [a] (MeV)	l	$(2J_f+1)S$	E_x [a] (MeV)	l	$(2J_f+1)S$
0.0	2	1.34	0.804	2	0.46
0.09	(2)	(0.05)	0.820	4	0.61
0.140	0	0.79	0.855	0	0.14
0.186	5	3.36	0.869	2	0.11
0.208	4	1.25	0.893	2	0.11
0.302	(1) (3)	(0.07)(0.37)	0.973	2	0.15
0.423	2	0.28	1.093	2	0.24
0.445	2	1.09	1.113	(1)(3)	(0.08)(0.37)
0.558	2	0.19	1.124	2	0.10
0.607	0	0.09	1.164 [b]	2	0.15
0.738	2	0.19	1.56	(2)	(0.15)
0.786	0	0.20	1.91	(2)	(0.20)

[a] The error in most cases is ±5 keV.

[b] Possible doublet.

Strictly speaking, the DWBA cross section (and hence the spectroscopic strengths listed in Tables II and III) are slightly spin dependent. This is mainly due to the effect of the spin-orbit potential on the normalization of the tail of the bound-state wave function. For $l=4$ and $l=5$ the spectroscopic strengths were calculated for spins $\frac{7}{2}$ and $\frac{11}{2}$, respectively, as expected from the shell model. The $l=2$ calculations were all done for spin $\frac{5}{2}$. For $l=2$ states with spin $\frac{3}{2}$, therefore, the spectroscopic strengths listed in Tables II and III should be increased about 16%.

In their recent paper, Diehl *et al.*[5] attempted to infer the spin of the $l=2$ transfers in this mass region from the ratio of the spectroscopic factor for the (d,t) reaction to that for the (d,p) reaction; this ratio should be appreciably larger for $j=\frac{5}{2}$ than for $j=\frac{3}{2}$, since the $2d_{5/2}$ orbit is much fuller than the $2d_{3/2}$ orbit. They found for Ru^{103} that the ratios were not appreciably different. However, this unexpected result appears to have been due to a misinterpretation of the (d,p) cross sections. The actual ratios are given in Table II; the (d,p) spectroscopic strength $(2J_f+1)S$ was used in the computation.

The five states that are seen strongly in the (d, p) reaction below 1 MeV mainly separate according to the ratio: The states at 0.0 and 0.589 MeV have a ratio characteristic of $J=\frac{5}{2}^+$, while the states at 0.658 and 0.906 MeV have a ratio characteristic of $J=\frac{3}{2}^+$. However, the 0.401-MeV state has an intermediate value of this ratio. The method also appears to break down for the states at 0.139, 0.339, and 0.499 MeV—which are very weakly excited in the (d, p) reaction and for which the ratio is very large. Since such states may correspond to more complicated configurations than are excited in single-nucleon transfer reactions, the validity of this method appears doubtful. The results for $Ru^{104}(d, p)$ are new and no (d, t) data exist for comparison.

It is found that the states strongly populated in the (d, p) reaction on each target occur at similar excitation energies and are excited with very similar spectroscopic strengths; and in each case the strongest state has the lowest excitation energy. This is apparent from a comparison of Figs. 5 and 6, in which the spectroscopic strengths for $l=0$, 2, 4, and 5 transfers are displayed against excitation energy in Ru^{103} and Ru^{105}, respectively. Both nuclei have $l=2$ ground states; and if the spin of Ru^{105} is also $\frac{5}{2}^+$, the spectroscopic factors are equal to within 4%. Higher-lying $l=2$ transitions also show close similarities. Both nuclei are found to have a strong low-lying $\frac{1}{2}^+$ state with very similar spectroscopic factors and additional but much weaker $l=0$ strength to higher excited states. And in both nuclei the positions and relative strengths of the $l=4$ and 5 transitions are similar. The only obvious difference between the two spectra is that in Ru^{105} the levels are more compressed in excitation energy and the $l=2$ transitions appear more fragmented than are those in Ru^{103}.

It may also be noted that the changes apparent in going from Ru^{103} to Ru^{105} are also reflected[4] in going to Pd^{107} and to Pd^{109} ($N=61$ for Ru^{105} and Pd^{107}). Moreover the strengths and positions of the strong transitions observed in the $Ru(d, p)$ study closely resemble those observed in the $Pd^{106,108}(d, p)$ reactions. And similar ratios of (d, p) and (d, t) spectroscopic factors are observed for the corresponding states in Ru^{103}, Pd^{107}, and Pd^{109}.

In addition to the levels discussed above, we observed a few weak levels for which the l-value assignment is uncertain. These occur at 0.295 and 1.320 MeV in Ru^{103} and at 0.302 and 1.113 MeV in Ru^{105}. The experimental angular distributions and possible theoretical fits are shown in Fig. 4. The fit to the 0.295-MeV states in Ru^{103} favors an $l=3$ assignment, whereas the fit to the (corresponding?) level at 0.302 MeV in Ru^{105} is indicative of $l=1$. If these levels are indeed characterized by angular momentum $l=1$ or 3, then they must correspond to configurations outside the $50 \leq N \leq 82$ shell. The possibility that such states occur at low excitation energy in both nuclei appears somewhat surprising. In the case of Pd^{107} and Pd^{109}, the first negative-parity states (both $l=1$) are observed[5] at 0.781

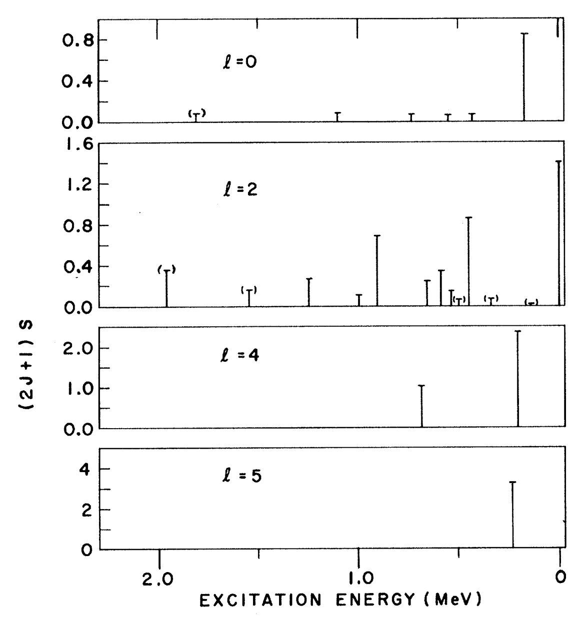

FIG. 5. Distribution of spectroscopic strength for $l=0$, 2, 4, and 5 angular momentum transfers in the Ru^{102}-$(d,p)Ru^{103}$ reaction.

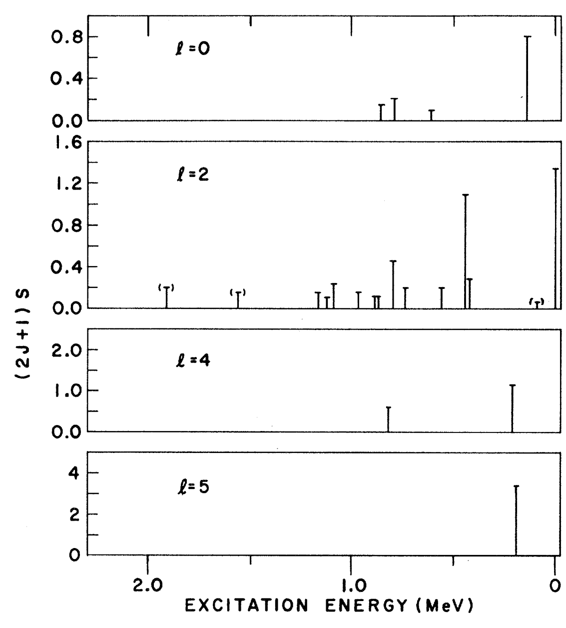

FIG. 6. Distribution of spectroscopic strength for $l=0$, 2, 4, and 5 angular momentum transfers in the Ru^{104}-$(d,p)Ru^{105}$ reaction.

and 0.671 MeV, respectively. The angular distributions of the two remaining states do not permit l-value determinations.

The present (d,p) results in Ru^{103} suggest a reinterpretation of the results obtained from previous studies of the decay scheme.[14] From the observation of 0.135-, 0.21-, and 0.35-MeV γ rays following the β decay of Tc^{103}, levels at 0.135 and 0.35 MeV were inferred in Ru^{103}. However, if the ground-state spin of Tc^{103} is $\frac{9}{2}^+$ (as is the case for Tc^{101}), then (as is the case for Tc^{101}) the most reasonable β decay is to the $\frac{7}{2}^+$ levels at 0.696 and 0.213 MeV in Ru^{103}. Deexcitation of these levels, with the upper proceeding via the intermediate levels at 0.339 and 0.213 or 0.139 MeV, could then account for the observed γ rays. The decay of the $\frac{11}{2}^-$ state at 0.237 MeV in Ru^{103} should give rise to an isomeric transition (as is observed in Ru^{101}); such a transition, with a half-life of 1.7 msec, may have been observed in a recent $Ru^{104}(\gamma,n)$ experiment.[15] The observed γ-ray energy ($E_\gamma = 0.209 \pm 0.0005$ MeV) appears to correspond to the deexcitation of the $\frac{7}{2}^+$ state at 0.213 MeV, and implies that the isomeric decay is mainly to this intermediate state rather than directly to the $\frac{5}{2}^+$ ground state.

The summed strengths for the various l values are listed in Table IV. The additional $l=2$ strength in levels that lie between 1.3- and 2.3-MeV excitation energy and that are too weak to analyze is estimated to be at most 0.3 for each nucleus. If it is assumed that all $l=0$ and 2 strength is then accounted for, the summed strength determines the distribution of neutrons in the single-particle orbits above $N=50$ (assumed closed). The results given in Table IV imply that 0.82 and 0.78 neutrons are present in the $3s_{1/2}$ orbital and ≤ 5.4 and ≤ 5.2 neutrons are present in the combined $2d_{5/2}$ and $2d_{3/2}$ orbitals in Ru^{102} and Ru^{104}, respectively. Thus the neutron occupations of these orbitals are very similar; the remaining 1.8 and 4 neutrons in Ru^{102} ($N=58$) and Ru^{104} ($N=60$), respectively, are distributed between the $1g_{7/2}$ and $1h_{11/2}$ orbitals. Table IV shows that the total strength to these orbitals is less in Ru^{105} than in Ru^{103}, which is consistent with this result; nevertheless, the actual values imply that a considerable fraction of their strength has not been observed in the (d,p) reaction. Our analysis was limited to a peak cross section ≥ 0.1 mb/sr. Since this value corresponds to spectroscopic strengths of 0.6 and 1.0 for $l=4$ and 5 transitions, respectively, fragmentation of the $l=4$ and 5 strength at higher excitation energies can explain the missing strength.

TABLE IV. Sum of the observed strengths for the $Ru^{102}(d,p)Ru^{103}$ and $Ru^{104}(d,p)Ru^{105}$ reactions.

	$\sum (2J_f+1)S$	
l	Ru^{103}	Ru^{105}
0	1.18	1.22
2	4.60	4.80
4	3.35	1.86
5	3.25	3.36

The results for the $Ru^{104}(d,p)$ reaction may also be directly compared with those from the $Ru^{104}(d,t)$ reaction. The (d,t) study finds 0.78 neutrons in the $3s_{1/2}$ orbit and 3.63 neutrons in the combined $2d_{3/2}$ and $2d_{5/2}$ orbits. This is in very good agreement with the (d,p) results, particularly when it is noted that the $Ru^{102}(d,p)$ reaction reveals $l=2$ strength beyond 1-MeV excitation energy – the upper limit for the (d,t) study. The (d,t) study gives directly a neutron occupation of 4.7 for the $1g_{7/2}$ and $1h_{11/2}$ orbitals in Ru^{104}, a number which is again consistent with that inferred from the (d,p) results.

As mentioned in the Introduction, the isobaric analogs of several of the low-lying states of Ru^{103} and Ru^{105} have been observed as resonances in elastic proton scattering.[7] Spectroscopic factors were determined (on the assumption that $J^\pi = \frac{5}{2}^+$) for three of the observed $l=2$ resonances, namely, the two ground-state resonances and a resonance corresponding to an excitation energy of 0.435 MeV in Ru^{105}. Comparison with the (d,p) spectroscopic factors shows poor agreement not only in absolute magnitude but also in the ratios of spectroscopic factors. The reason for the discrepancy between the two determinations is not known.

VI. CONCLUSIONS

As discussed in the Introduction, the initial motivation of this work was an attempt to obtain evidence for or against the existence of a stable deformation in Ru^{105}. The present results give no indication of any deformation, and indeed the positions and spins of states in Ru^{105} bear a close resemblance to those in Ru^{103} and to other neighboring nuclei. Almost all of the present results can be interpreted by assuming a distribution of neutrons over the known single-particle orbits between the major shell bounded by $N=50$ and 82. There is evidence of a possible low-lying level, both in Ru^{105} and in Ru^{103}, with a configuration outside this major shell. However, these states are very weak and the angular distributions are ambiguous.

Of course the shell-model states are those that should be preferentially populated in a single-nucleon-transfer reaction. If the deformation of Ru^{105} is different from that of the Ru^{104} ground state, this deformation should give rise to states only weakly excited in the (d, p) reaction. However, the present data are again inconclusive, since weakly excited states are observed in both final nuclei (Ru^{105} and Ru^{103}). The only remaining prospect for deformation is that even with the present extensive data on levels in Ru^{105}, it appears that (in contrast to the situation in Ru^{103}) the γ rays observed in Ru^{105} following the decay of Tc^{105} cannot be fitted into a consistent level scheme.[3] This result may be not inconsistent with the recent (t, p) study[16] on Ru^{104}, which finds evidence that Ru^{106} has a transitional character between a vibrational and rotational nucleus.

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Lifetimes of Ground-Band States in $^{148,150,152}Sm$†

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The lifetimes of a number of ground-band states in $^{148,150,152}Sm$ have been measured by the recoil-distance Doppler-shift method following Coulomb excitation by backscattered ^{40}Ar projectiles. The measured $B(E2)$ values for ^{152}Sm are larger than the rigid-rotor values; in terms of the mixing or stretching parameter α the present experiments yield $\alpha = (+2.2 \pm 0.7) \times 10^{-3}$. For $^{148,150}Sm$ the measured $B(E2)$ values are near those expected for vibrational nuclei.

INTRODUCTION

The stable samarium isotopes are well suited for the testing of current nuclear models and ideas, as they span the region from vibrators to rotors, and include soft nuclei as well as rigid ones. Much of the information on the nature of the ground band has come from studies of the energy-level spacings. The lifetimes, or $B(E2)$ values, of the excited states in the ground band constitute another source of information on the changes occuring in these levels as the spin increases.

The recoil-distance Doppler-shift method,[1] when combined with high-resolution Ge detectors and heavy-ion beams, seems ideal for determining half-lives in the 10^{-9}–10^{-12}-sec range.[2-7] However, an earlier study involving recoils from (^{40}Ar, $4n$) reactions indicated that the accuracy ob-