dual resonances. The results are presented in Table I, where it is seen that ground-state radiation widths lying between 2 and 10 eV prevail. For the region near the detector threshold and the region close to the bremsstrahlung tip, entries in Table I have been placed in parentheses.

Using an average level spacing D of 70 keV (27 levels are excited in an interval of 2 MeV), we obtain values for the ground-state $E1$ strength function lying between 2×10^{-5} and 1.5×10^{-4}, with an average value of $\langle\Gamma_{\gamma 0}/D\rangle = 8\times10^{-5}$. Such a value of $\langle\Gamma_{\gamma 0}/D\rangle$ accords well with $E1$ transition strengths in the inverse radiative capture process.[15] A similar value of 9.6×10^{-5} is quoted by Fultz *et al.*[16] for ^{26}Mg, and is also interpreted as representing radiative strength not associated with the giant dipole resonance. Axel[17] has proposed that, in general, the distribution of $E1$ strength near the neutron threshold should reflect the low-energy wing of the giant dipole resonance, and predicts that for a typical heavy nucleus the strength should vary as E^5. The energy dependence for ^{40}Ar is quite different, and suggests that the distribution of $E1$ strength near the photoneutron threshold is reflecting the high-energy wing of a local single-particle resonance.

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Hole-Strength Variations in Neutron Pickup Reactions to Isobaric-Analog States in Mo Isotopes*

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We report a study of isobaric-analog states excited in the (p,d) and (d,t) reactions on ^{92,94,96}Mo and in the reaction ^{98}Mo$(p,d)^{97}$Mo. We observe a large decrease in $l=1$ hole strength with increasing mass number and fluctuations in the ratios $C^2S_n(p,d)/C^2S_n(d,t)$. The first effect is discussed in terms of mixing with the dense spectrum of $T_<$ levels in the region of the isobaric-analog states.

Isobaric-analog states (IAS) in the $A=90$ region have been studied extensively via proton scattering[1] and, more recently, in proton stripping reactions.[2-4] However, no extensive studies of $T_>$ hole states have been reported for this region. In the present work, we studied IAS excited in the (p,d) and (d,t) reactions on ^{92,94,96}Mo and in the reaction ^{98}Mo$(p,d)^{97}$Mo. A comparison of spectroscopic strengths deduced from these two reactions is presented, with further comparisons to the parent-state results of Ohnuma and Yntema,[5] who studied the $(d,{}^3\mathrm{He})$ reaction on the molybdenum isotopes.

Data were taken with 38.6-MeV protons and

40.6-MeV deuterons incident on enriched Mo targets, whose weighed thicknesses ranged from 0.554 to 1.10 mg/cm^2. Two counter telescopes spaced 5° apart were used simultaneously to reduce data acquisition time. An overall resolution of about 50-keV full width at half-maximum was obtained. Normalizations for the targets of different A were checked by measuring proton elastic scattering cross sections. The maximum disagreement among experimental values was $\approx 5\%$ at $\theta_{\text{c.m.}} = 7.8°$, and excellent agreement with optical-model predictions was obtained.

Angular distributions were measured for analogs corresponding to all levels observed in the $(d, {}^3\text{He})$ reaction.[5] Distorted-wave Born-approximation (DWBA) calculations (including local energy approximations for finite range and nonlocality) were performed using optical potentials from the literature.[6-8] The same deuteron and triton parameters were used for all calculations, while the proton parameters were adjusted slightly as a function of target mass and isospin according to the prescription of Ref. 6. A potential of radius $1.23A^{1/3}$ F and diffuseness 0.65 F was used to determine the neutron form factors, with the binding energies equal to the actual separation energies. This geometry reproduces the shape of the proton form factor used by Ref. 5 for the corresponding parent states to within 2% in the nuclear interior for all levels considered here. The normalization constants 2.54[9] and 3.33[10] were used for the (p,d) and (d,t) reactions, respectively. Experimental angular distributions and DWBA curves for the (p,d) and (d,t) reactions to 1g and 2p IAS in ^{93}Mo are shown in Fig. 1.

According to the sum rules for single nucleon transfer reactions,[11] the IAS spectroscopic factors are related to those for proton pickup to the parent states by

$$2TC^2S_n(p,d) = 2TC^2S_n(d,t) = C^2S_p(d, {}^3\text{He}),$$

where $T \equiv T_>$. These quantities are listed in Table I and graphically summarized in Fig. 2. The (p,d) spectroscopic factors for $l_n = 4$ and 1 levels average about 45% larger than those obtained from the (d,t) reaction. A similar effect is obtained for $T_<$ levels in these nuclei[12] and probably reflects the uncertainties in optical potentials and overall DWBA normalizations for these reactions.

The ratios $C^2S_n(p,d)/C^2S_n(d,t)$ (R in Table I), which might be compared for levels of the same J^π, change markedly in some cases (as much as 40%) from nucleus to nucleus. Also, for each nucleus, R for the $\frac{3}{2}^-$ level of lowest energy is consistently lower than for the second $\frac{3}{2}^-$ level. However, the ratio of summed strengths for the (p,d) and (d,t) reactions is constant to within $<10\%$ from nucleus to nucleus (curve d in Fig. 2). Most of these ratios have assigned uncertainties of about ± 15%, which reflects a conservative estimate of possible inconsistencies in normalizing the DWBA curves to the data, and no evidence has been observed for large fluctuations for $T_<$ states in these nuclei.[12] This effect may be related to the discrepancies observed between the $({}^3\text{He}, d)$ and (d,n) reactions to IAS in light nuclei,[13] although at present no clear explanation exists for either phenomenon.

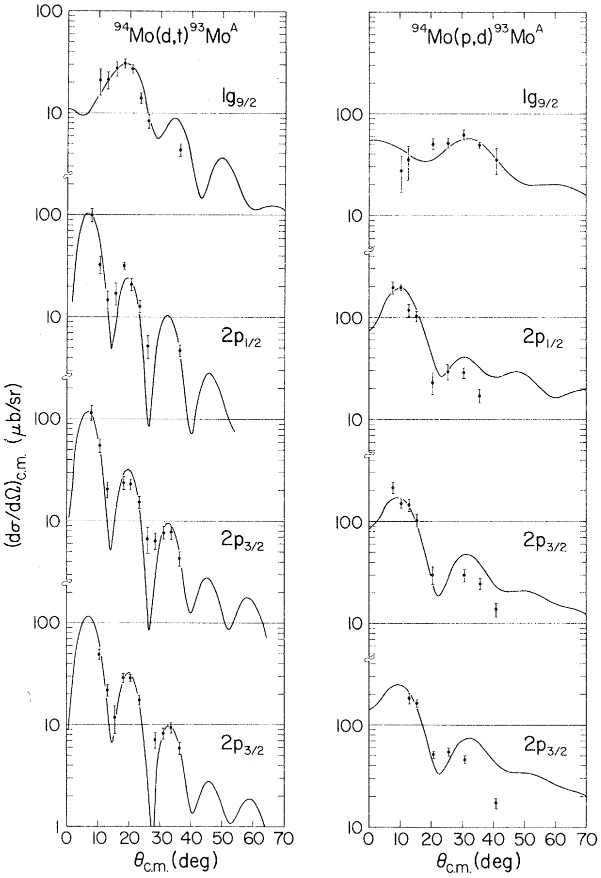

FIG. 1. Angular distributions for (d,t) and (p,d) reactions to IAS in ^{93}Mo. The curves are DWBA predictions.

The $(d, {}^3\text{He})$ spectroscopic factors summed over 1g and 2p orbitals are essentially constant for $A = 91$, 93, and 95 (curve a, Fig. 2), as expected. The value reported in Ref. 5 for ^{97}Nb is somewhat lower. The IAS strength is not constant, however, but decreases with increasing

TABLE I. Spectroscopic factors from (p,d), (d,t), and $(d,{}^3\mathrm{He})$ reactions on Mo targets.

A,T	E_{IAS} [a] (MeV)	J^{π} [b]	$2TC^2S_n$ (p,d)	$2TC^2S_n$ (d,t)	C^2S_p [b] (d, ^{3}He)	R [d]
91,9/2	6.99	$9/2^+$	2.48	1.70	2.3	1.46 ± 0.27
	7.12	$1/2^-$	1.59	1.35	1.2	1.18 ± 0.17
	8.34	$(3/2^-)$	1.37	0.99	1.0	1.38 ± 0.20
	8.66	$(3/2^-)$	3.01	1.75	2.1	1.72 ± 0.24
	8.87	$5/2^-$	3.70	4.38	3.8	0.85 ± 0.19
93,11/2	10.89	$9/2^+$	2.25	2.11	(2.6)	1.06 ± 0.15
	10.94	$1/2^-$	1.17	0.66	(1.4)	1.77 ± 0.25
	11.59	$(3/2^-)$	1.07	0.75	1.0	1.42 ± 0.20
	12.22	$(3/2^-)$	1.73	0.92	(1.6)	1.87 ± 0.26
	12.30	$5/2^-$	2.73	2.83	(2.8)	0.96 ± 0.14
95,13/2	12.10	$9/2^+$	2.25	1.42	2.6	1.58 ± 0.33
	12.36	$1/2^-$	1.13	0.81	1.4	1.39 ± 0.19
	12.94	$(3/2^-)$	1.15	0.87	1.6	1.32 ± 0.28
	13.15	$5/2^-$	1.79	2.74	1.8	0.65 ± 0.18
	13.37	$(3/2^-)$	0.78	0.45	(2.2)	1.72 ± 0.38
	13.43	$(5/2^-)$ [c]	2.40	2.04		1.18 ± 0.21
97,15/2	13.03	$9/2^+$	2.07		1.9	
	13.79	$1/2^-$	1.00		1.0	
	14.30	$(3/2^-)$	1.09		2.3	
	14.34	$(3/2^-)$	0.94			
	14.50	$(5/2^-)$	1.74		2.0	

[a] ±30 keV.

[b] See Ref. 5.

[c] Assigned from present work.

[d] $R \equiv C^2S_n(p,d)/C^2S_n(d,t)$.

neutron number. For both the (p,d) and (d,t) reactions, the total $(1g+2p)$ strength is nearly 45% lower for $A=95$ than $A=91$. Most of this is due to a decrease in $l=1$ strength which, for the (p,d) reaction, is a factor of 2 between $A=91$ and $A=97$ (curve *b*, Fig. 2). The change in (p,d) spectroscopic factors for the $1g_{9/2}$ ground-state analogs is less than 20% (curve *c*). The DWBA calculations are insensitive to slight changes in target mass and, since the binding energies of the transferred neutrons all lie in an interval of 3.5 MeV, it seems unlikely that this effect is due to incorrect Q-dependence. Data were taken for the $({}^3\mathrm{He},\alpha)$ reaction on ^{92}Mo and ^{96}Mo at 35 MeV to check the latter possibility. Even though the DWBA Q dependence for $({}^3\mathrm{He},\alpha)$ is drastically different than that for either (p,d) or (d,t), the relative decrease in $l=1$ strength measured is the same for all three reactions (within 10%). A similar decrease in strength was noted by Sherr *et al.*,[14] who studied $f_{7/2}$ IAS via the (p,d) reaction in the Ni region, but was partially attributed[15] to experimental uncertainties.

The decrease in IAS hole strength might be explained by considering the mechanism that leads to a spreading width for isobaric-analog resonances (IAR).[16] The spreading width is accounted for by the mixing of the IAR with the dense spectrum of $T_<$ states (in the region of the IAR), which are in turn coupled to low-lying configuration states and $t=1$ monopole excitations. The monopole contribution is dominant and consists mainly of particle-hole excitations of the type $[n,l]^{-1}[n+1,l]^1$. For proton single-particle resonances, both $T_<$ and $T_>$ components are likely to decay by proton emission and have comparable

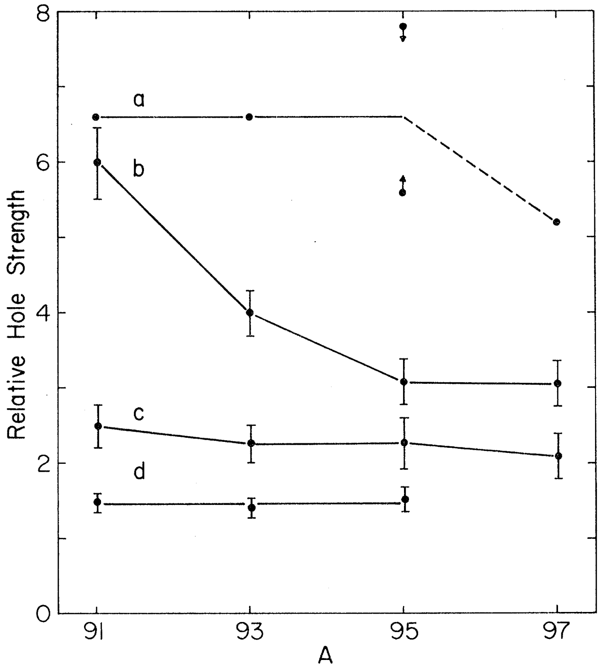

FIG. 2. Spectroscopic strengths and ratios versus mass number. Curve a, summed $(1g+2p)$ proton hole strength measured by Ref. 5. The values for $A=95$ are upper and lower limits, which depend on whether all or none of their unresolved $(\frac{3}{2}^- + \frac{5}{2}^-)$ doublet is assigned $l=1$ (see also Table I). Curve b, $2TC^2S_n(p,d)$, summed over the three $l=1$ IAS observed in each nucleus. Curve c, $2TC^2S_n(p,d)$ for the $g_{9/2}$ IAS. Curve d, $R_s \equiv \sum C^2S_n(p,d)/\sum C^2S_n(d,t)$, where the sums are over the $l=1$ and $l=4$ IAS. The errors for curves b, c, d include possible inconsistencies in normalizing DWBA curves to the data and uncertainties in relative normalizations for targets of different A.

widths. In our case, however, the yield in the region of the IAS is presumably due to hole-state components, which are neutron-bound for $A=91$ and become increasingly unbound for $A \geq 93$. The $T_<$ levels in this region (which could contain some of the IAS strength) may thus decay by neutron emission for $A \geq 93$ and, therefore, could be quite broad and not observable because of the high background. Neutron decay of the IAS is T forbidden, however, so they probably decay by proton emission since that (T-allowed) channel is open, and the observed strength is concentrated in relatively narrow peaks in our spectra ($\Gamma_{\text{peak}} \leq 100$ keV in all cases). Also, the monotonic decrease in observed IAS hole strength is consistent with the IAS moving closer to the monopole with increasing neutron number.[17] Monopole configurations having a particle in a $3p$ orbit should be dominant in the $A=90$ region from shell-model considerations, but it is not clear that the J^π of all such states is the same since the core is not necessarily coupled to zero. The fact that the depletion of spectroscopic strength is concentrated in $l=1$ transitions seems to imply that monopole J^π values of $(\frac{1}{2}, \frac{3}{2}^-)$ may be dominant over $\frac{9}{2}^+$, or that the $\frac{9}{2}^+$ $T_<$ states are relatively narrow and included in our peak yields for the IAS.

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