IPR 7 1966

Study of the Low-Lying Isobaric Analog States of Sr^{89}

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H.C. \$ 1.00 ; MN .50

This work has been supported in part through funds provided by the U. S. Atomic Energy Commission under AEC Contract AT(30-1)-2098.

The analog states of the low-lying levels in Sr^{89} are studied via the (p,p) and (p,p') reactions on Sr^{88} . The information from conventional Breit-Wigner fits to the elastic data is compared with the results of a DWBA analysis of the $\text{Sr}^{88}(\text{d,p})\text{Sr}^{89}$ reaction. In addition, an analysis of the $\text{Sr}^{88}(\text{p,p})$ data is discussed, and preliminary results are given. This involves a solution of the two-coupled channel equations that describe the analog-state excitations.

1. Experimental Results

Figure 1 shows a $\text{Sr}^{88}(\text{p,p})$ excitation curve from 4.9 to 7.5 MeV obtained with the proton beam from the MIT-ONR Van de Graaff accelerator. The target thickness was about $35 \mu\text{g}/\text{cm}^2$, and the scattered protons were detected by surface barrier counters. The first two pronounced and well-separated resonances correspond to analogs of the $d_{5/2}$ ground state and $s_{1/2}$ first excited state of Sr^{89} , and the disturbance at 7.1 MeV is caused by interference between two d-wave resonances. Several energy sweeps have revealed consistent fine deviations from a smooth cross-section curve. One example is the sharp "spike" at the bottom of the 90° s-wave dip.

Figure 2 displays the proton spectrum up to 2.5-MeV excitation from the $\text{Sr}^{88}(\text{d,p})\text{Sr}^{89}$ reaction at 7.0-MeV incident energy. Level Nos. 2, 4 and 5 had not been resolved from level No. 3 by previous investigators. Also shown are the

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angular distributions of the lowest six transitions, as obtained with the MIT multiple-gap spectrograph. The circles are the data, and the curves were calculated by the DWBA code JULIE. The stripping transitions 0, 1, 2, and 3 correspond to the $\text{Sr}^{88}(\text{p},\text{p})$ resonances mentioned above. The nonstripping levels, Nos. 4 and 5 (marked "n.s." in the figure), probably have large collective components orthogonal to $\text{Sr}^{88}(0)$ and therefore did not appear in the elastic data.

Results from inelastic proton scattering to the 1.820-MeV, 2^+ state in Sr^{88} are shown in Fig. 3. In the top of the figure, the arrows indicate the incident energies on and off resonance at which this 2^+ transition was studied; at the bottom of the figure are shown the angular distributions obtained in the multiple-gap spectrograph for this transition. By monitoring the elastic yield near resonance and by narrowing the entrance and exit slits of the analyzing magnet, it was possible to keep the energy drift of the incident beam to less than 1 keV throughout these exposures. Off resonance (E_4), the yield is low, and the angular distribution is flat. On the resonances, the yields are much higher, and the angular distributions seem to deviate from symmetry around 90° . This is particularly true for $E_2 = 5.056$ MeV on the $d_{5/2}^+$ resonance for which the transition shows a pronounced peaking in the back angles. This effect seems to vary rapidly with incident energy, since for E_1 and E_3 , 30 keV to each side of E_2 , it has disappeared. The shapes at E_1 , E_3 , E_5 , and E_6 all suggest a forward-angle bump at about 60° . In the case of $E_6 = 7.120$ MeV, the energy was not precisely at the center of the large 7.10 analog resonance, and therefore a back-angle peaking may have been missed. These behaviors may be due to an interference of the analog-state exciting mechanism and other reaction processes, such as Coulomb excitation.

A (p,p') excitation function for the 2^+ state at 157° has also been recorded on nuclear-track plates, but the data had not been extracted at the time of this meeting.

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II. Analysis of the Results

A.

The $\text{Sr}^{88}(\text{p},\text{p})$ data have been compared with Breit-Wigner shapes using the equations of Blatt and Biedenharn¹ where the adjustable parameters are E_{res} , Γ_p , Γ_{tot} , ℓ , j^n . Figure 4 shows the results of this comparison at 90° . In the $d_{5/2}$ case, this method does not reproduce the asymmetry of the shape at 90° , whereas for the other resonances, the 90° fit is good.

Table 1 compares the information derived from the (p,p) and (d,p) reactions. The (d,p) spectroscopic factor was derived from the relationship

$$d\sigma/d\Omega = 1.48 (2j + 1) S_{\ell_n j}^2 \sigma(\ell_n, Q, E_d, \theta)$$

where σ is calculated from the DWBA code JULIE, and $d\sigma/d\Omega$ is the experimental cross section. The d and p optical-model parameters used were obtained from Perey.²

The equation used to relate θ_n to Γ_p is³

$$\theta_n^2 = (2T_0 + 1) \frac{\Gamma_p}{2P_\ell} \cdot \frac{m R^2}{\hbar^2}$$

where P_ℓ is the penetrability, $T_0 = 1$ spin of target, and R = nuclear radius.

B.

An attempt has been made to generate the analog-state resonances by coupling the proton-plus-target channel $|pT\rangle$ to the neutron-plus-analog state of the target channel $|nA\rangle$. The two coupled equations describing neutron and proton wave functions, u_n and u_p , are

$$\begin{aligned} \left[E - T_p - (V_0 + V_c + \frac{T_0}{2} V_1) \right] u_p &= \sqrt{\frac{T_0}{2}} V_1 u_n \\ \left[E - \Delta - T_n - (V_0 - \frac{T_0 - 1}{2} V_1) \right] u_n &= \sqrt{\frac{T_0}{2}} V_1 u_p \end{aligned}$$

and the resulting ^{exact}_Δ transition matrix for the proton scattering is

$$J = J_p + \frac{T_o}{2} \langle \phi_p^{(-)} | V_1 G V_1 | \phi_p^{(+)} \rangle$$

where J_p gives rise to the potential scattering and the Green's function is

$$G = \frac{1}{(E - \Delta - T_n - V_o + \frac{T_o - 1}{2} V_1 - \frac{T_o}{2} V_1 \frac{1}{E^{(+)} - H_p} V_1)}$$

From this, one sees that the approximate position of the resonance is always at the energy of the bound neutron plus Δ , the Coulomb-energy difference between $|T\rangle$ and $|A\rangle$.

Figure 5 shows a comparison of the experimental data to curves derived from the coupled-channel calculation. Adjusting the shapes with this method was found to be more difficult than with the previous procedure because of their very sensitive dependence on V_o , W , and V_1 . The results are preliminary. To produce the curves shown, well parameters had to be used that seem unacceptable because of their deviation from values derived from optical-model analysis.

References

1. J. M. Blatt and L. C. Biedenharn, Revs. Mod. Phys. 24, 258 (1952)
2. F. G. Perey, Phys. Rev. 131, 745 (1963)
3. D. Robson, Phys. Rev. 137, B535 (1965)

Table 1

Sr ⁸⁸ (p,p) States in Y ⁸⁹							Sr ⁸⁸ (d,p) States in Sr ⁸⁹					
Level No.	E _p (MeV)	E _x (MeV)	l, j ⁿ	Γ _{tot}	Γ _p	Q _n ²	E _x (MeV)	Q (MeV)	(2j+1)S _{l,j}	j ⁿ	S _{l,j}	l _n
0	5.056	0.000	2, 5/2 ⁺	16	8	1.20	0.000	4.133	4.76	5/2 ⁺	0.80	2
1	6.062	1.006	0, 1/2 ⁺	70	46	0.96	1.031	3.102	1.81	1/2 ⁺	0.91	0
2	7.030	1.974	2, (5/2 ⁺ , 3/2 ⁺)	50	11	0.30	1.931	2.202	0.55	{ (5/2 ⁺) (3/2 ⁺)	{ 0.092 0.14	2
3	7.100	2.044	2, 3/2 ⁺	50	23	0.63	2.000	2.133	1.85	{ (5/2 ⁺) (3/2 ⁺)	{ 0.31 0.46	2
4	not seen						2.057	2.076				n.s.
5	not seen						2.071	2.062				n.s.

PROTON RESONANCE FREQUENCY (kc)

FIG. 1

Spectrum from $Sr^{88}(d,p)Sr^{89}$ measured in M.C.T. Multiple Gap Spectrograph

Proton angular distributions from the $Sr^{88}(d,p)Sr^{89}$ reaction

FIG. 2

$\text{Sr}^{88}(\text{p,p})$ - Elastic Scattering at 90°

$\text{Sr}^{88}(\text{p,p})\text{Sr}^{88}(\text{p,p})$ - Angular Distributions from Transitions to the 2^+ State in Sr^{88} at Several Incident Energies

$\text{Sr}^{88}(\text{p},\text{p})$ - BREIT - WIGNER FITS TO ANALOG STATE RESONANCES

FIG. 4

$\text{Sr}^{88}(\text{p},\text{p})$ - COUPLED CHANNEL FITS TO ANALOG STATE
RESONANCES AT 90°

FIG. 5