ANALOGUES OF EXCITED STATES IN ^{91}Zr†

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The level structure in ^{91}Zr has been investigated by Cohen and Chubinsky (1963) with the ^{90}Zr(d, p)^{91}Zr reaction. They noted some 14 levels up to an excitation energy of 3·9 MeV. All these states were found to have positive parity and their structure is fairly well understood in terms of coupling a single-particle neutron to the ground state and the first two excited states of ^{90}Zr (Ramavataram 1964). A study of the isobaric analogues of the ^{91}Zr states with the ^{90}Zr(p, p$_0$)^{90}Zr reaction was carried out by Moore (1964). His results were in agreement with those of Cohen and Chubinsky (1963) except that he did not see the analogue of the 1·48 MeV level in ^{91}Zr.

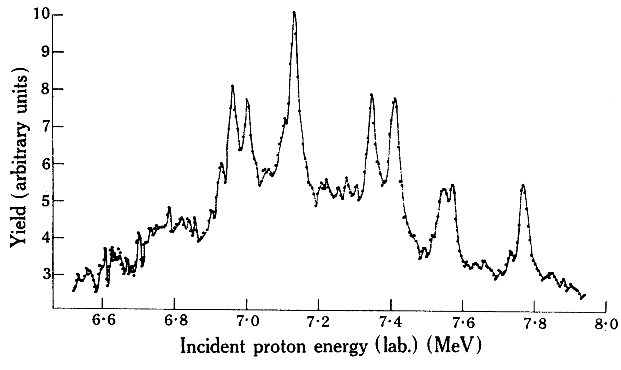

Fig. 1.—Excitation function for the decay of the 5$^-$ isomeric level in ^{90}Zr following the reaction ^{90}Zr(p, p$'$)^{90}Zr*.

It was decided to investigate the inelastic scattering of protons from ^{90}Zr to look for isobaric analogues of states in ^{91}Zr that were not observed in the (d, p) reaction. The method of using the inelastic scattering of protons to locate the analogues of levels not previously known has proved very successful in the case of ^{89}Y(p, p$'$)^{89}Y* (Black *et al.* 1967). Since ^{90}Zr has a 5$^-$ ($\tau_{\frac{1}{2}} = 0·8$ sec) metastable state at 2·23 MeV (Hendrie and Farwell 1964), the technique of measuring the γ-ray decay of this state was used. This method is fully described by Black *et al.* (1967). The yield of this 2·23 MeV γ-ray as a function of the incident proton energy is shown in Figure 1. The absolute energy was determined by measuring the elastic proton scattering at several of the known elastic scattering resonances. Table 1 shows a comparison of the resonance energies with the elastic scattering data of Moore (1964) and with the excitation energies of levels in ^{91}Zr measured by Cohen and Chubinsky (1963).

† Manuscript received February 19, 1969.

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TABLE 1

RESONANCE ENERGIES FROM $^{90}Zr + p$ REACTION COMPARED WITH OTHER DATA

All energy measurements are ± 10 keV

C.M. Proton Energy (MeV)		Energy Levels in ^{91}Zr from $^{90}Zr(d, p)^{91}Zr$ (MeV)†	C.M. Proton Energy (MeV)		Energy Levels in ^{91}Zr from $^{90}Zr(d, p)^{91}Zr$ (MeV)†
5^- (Isomeric)	Elastic Scattering*		5^- (Isomeric)	Elastic Scattering*	
	4·69	4·69	7·26		
	5·87	5·90	7·33		
		6·17	7·46		
	6·58	6·58	7·49		
	6·73	6·75		7·55	7·57
6·88	6·88	6·90	7·68		
6·92				7·74	7·80
	6·99	7·04		7·98	7·99
7·05				8·16	8·18
	7·21	7·27		8·38	8·39

* Moore (1964). † Cohen and Chubinsky (1963).

TABLE 2

STATES OF DOUBLE EXCITATION IN ^{91}Zr AND EXPECTED ENERGIES FOR OUTGOING CHANNEL RESONANCES (5^-, 4^-)

Columns 1 and 2 give the configurations of the last two protons and the last neutron in ^{91}Zr, column 3 the expected excitation energy in ^{91}Zr, column 4 the proton energy (c.m.) at which the analogues of these states are expected, column 5 the possible spins and parities of the states, and column 6 the states for which the incoming proton has $l \leqslant 4$. Higher l values are expected to be inhibited by the angular momentum barrier

(1) Proton Configuration	(2) Neutron Configuration	(3) Excitation Energy (MeV)	(4) Proton Energy of Analogue State (MeV)	(5) J	(6) J ($l_p \leqslant 4$)
$(2p_{1/2}\,1g_{9/2})\,5^-$	$2d_{5/2}$	2·3	6·9	$\frac{5}{2}^-, \ldots, \frac{15}{2}^-$	$\frac{5}{2}^-, \frac{7}{2}^-, \frac{9}{2}^-$
$(2p_{1/2}\,1g_{9/2})\,4^-$	$2d_{5/2}$	2·7	7·3	$\frac{3}{2}^-, \ldots, \frac{13}{2}^-$	$\frac{3}{2}^-, \frac{5}{2}^-, \frac{7}{2}^-, \frac{9}{2}^-$
$(2p_{1/2}\,1g_{9/2})\,5^-$	$3s_{1/2}$	3·5	8·1	$\frac{9}{2}^-, \frac{11}{2}^-$	$\frac{9}{2}^-$
$(2p_{1/2}\,1g_{9/2})\,4^-$	$3s_{1/2}$	3·9	8·5	$\frac{7}{2}^-, \frac{9}{2}^-$	$\frac{7}{2}^-, \frac{9}{2}^-$

It is clear that except for the resonance at 6·88 MeV (analogue of the 2·21 MeV level in ^{91}Zr) the resonances seen in the decay of the isomeric level are not analogues of the known positive parity states in ^{91}Zr. Since the 5^- level in ^{90}Zr can be populated by γ-rays from higher excited states, the interpretation of the results is uncertain. The inelastic scattering of protons to the 4^- level at 2·75 MeV, and possibly the 3^- level also at 2·75 MeV, may contribute to the yield of the 2·23 MeV γ-ray as at least one of these levels is known to decay via the 5^- level.

There is little doubt that these resonances are analogues of levels in ^{91}Zr and that these levels have a structure more complex than single-particle excitations.

Since the resonances decay through the 5^-, 4^-, and (3^-) states in ^{90}Zr an obvious choice is that the levels are formed by a single-particle neutron coupled to a ^{90}Zr core that is excited to these states. From our knowledge of the energies of the single-particle states in ^{91}Zr (Ramavataram 1964) and the energies of the 5^-, 4^-, and 3^- levels in ^{90}Zr (Hendrie and Farwell 1964) it is easy to predict the approximate positions of such levels in ^{91}Zr. The results of the calculations are given in Table 2. It can be seen that three states are expected around 7 MeV proton energy and four states at about 7·4 MeV, which is in agreement with the experimental results. It is interesting to note that all the predicted levels are of negative parity.

The good agreement between experimental evidence and the simple predictions strongly suggests that the resonances seen in the decay of the 5^- isomeric level in ^{90}Zr are analogues of low-lying negative parity states in ^{91}Zr. Unfortunately due to background problems it was not possible to extend the measurements beyond 8 MeV to check whether there are resonances around 8·2 and 8·6 MeV. It would also be of interest to know which resonances decay to the 5^- level directly and which decay to the 4^- and 3^- levels in ^{90}Zr. This knowledge would enable more reliance to be placed on the interpretation of the data. Work is in progress to measure the inelastic scattering of protons to various ^{90}Zr states to determine this information.

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