Doorway state structure in ^{41}Sc ($^{40}Ca(p,p')^{40}Ca^*$ investigation)

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LETTER TO THE EDITOR

Doorway state structure in ^{41}Sc

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Abstract. Inelastic proton scattering to the 5·609 MeV 4^- state of ^{40}Ca displays a cluster of fine structure resonances with similar angular distributions and with outgoing width modulated according to the expectations for a strongly mixed doorway state of configuration $\{[(1d_{3/2})^{-1}(1f_{7/2})]_4\text{-}(2p_{1/2})\}_{9/2^+}$.

The importance of doorway states to the understanding of compound nucleus formation has been stressed by many authors (Brueckner *et al* 1955, Weisskopf 1961, Block and Feshbach 1963, Kerman *et al* 1963, Lemmer 1965, 1968, Rodberg 1968, Lane 1969). The appearance of doorway state structure has been reported in the excitation of some nuclei (Bolsterli *et al* 1966, Feshbach *et al* 1967, Mittig *et al* 1971); however detailed information on formation, characteristics and properties is rare. Such details can be obtained only through investigation of the fine structure within the intermediate or doorway resonance and determination of the angular distributions and strength functions associated with such fine structure.

The reaction $^{40}Ca(p, p')^{40}Ca^*$ has several advantages as a choice for doorway state investigations. The shell structure is relatively simple and some information is available on the configuration of final states and on single particle and hole energies in this region. The reaction can be studied over a wide range of energies and hence of level densities and the number of open channels is restricted by the Coulomb barrier against alpha emission and by the high threshold for neutron emission.

A metallic calcium target of thickness about 30 keV to the beam was bombarded with protons covering the energy range 7 to 11 MeV in increments of 20 keV. The beam resolution from the Melbourne cyclotron was about 10 keV. Excitation functions were obtained for decay to 14 states of ^{40}Ca from measurements of the associated gamma decay with a Ge(Li) detector. The data reveal strong compound nucleus resonances and intermediate structure, much of which is overlapping. Experimental details and a general discussion of results will appear in a later paper. The purpose of this letter is to draw attention to a particularly clear example of an isolated doorway state at an excitation energy around 9 MeV in ^{41}Sc which gives rise to strong modulation of the fine structure strength in proton decay to the 5·609 MeV 4^- state of ^{40}Ca. The energy region of interest is shown in figure 1. Measurements made with a thinner target showed that the principal fine structure peaks are isolated, except for a later resolved doublet at 8·8 MeV, and that the background is mostly due to weak peaks which are unresolved with this target. The direct interaction cross section appears to be weak at these energies.

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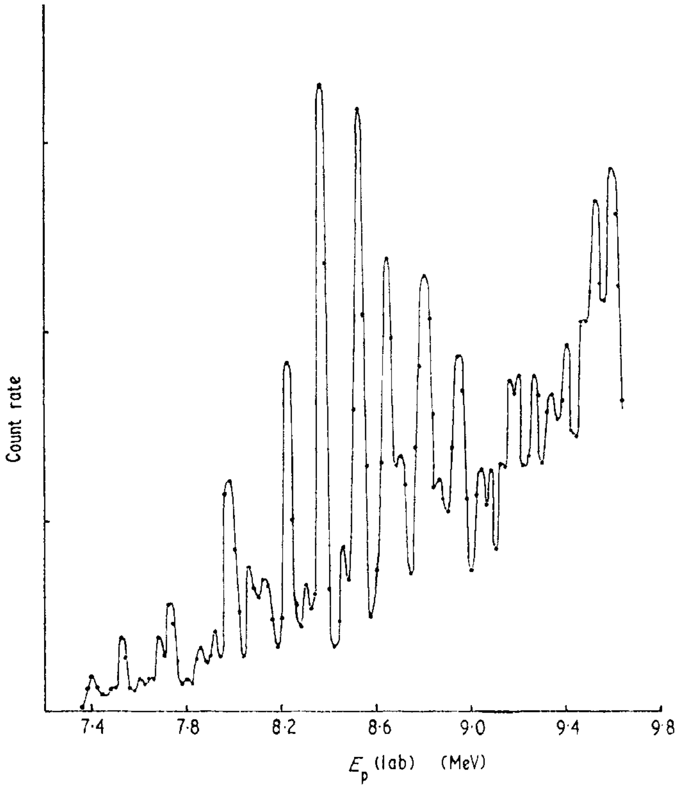

Figure 1. Excitation function of inelastic proton scattering to the 5·609 MeV 4^- state in ^{40}Ca measured by the associated gamma at 90° (lab).

Angular distributions of protons to the above 4^- state for each fine structure resonance were measured with a calcium oxide target which was about 10 keV thick to the beam. A magnetic spectrometer was needed to resolve sufficiently the 5·609 MeV and 5·622 MeV states of ^{40}Ca. The results are shown in figure 2. The near symmetry about 90° for each angular distribution and the large peak to valley ratios in the excitation function suggest that the reaction proceeds mainly via isolated compound nucleus levels with definite spin and parity J^π. Furthermore, the similarity in angular distribution shape for these various ^{41}Sc compound nucleus states suggests that they have the same spin and parity with a common mode of formation and decay dictated by a doorway state. The spin and parity derived for these compound nucleus states is either $J^\pi = \frac{7}{2}^+$ or $\frac{9}{2}^+$ with the ingoing and outgoing orbital angular momenta $l = 4$ and 1 respectively. The slight asymmetry about 90° of each angular distribution is attributed to a small component of direct interaction and agrees well with an estimation of direct interaction cross section by K Amos (1972, private communication).

The (p, p′) data were also used to estimate the total width of each fine structure resonance and the absolute cross section for each resonance integrated over energy and solid angle. These figures are presented in table 1. The relative strengths of the fine structure resonances were similar to the (p, p′) data and the (p, p′γ) data, indicative of similar angular distributions for the gamma de-excitation of each resonance. Advantage was taken of this fact in estimating the integrated cross sections for the first two resonances of table 1, since they were too weak for accurate measurements with the (p, p′) reaction.

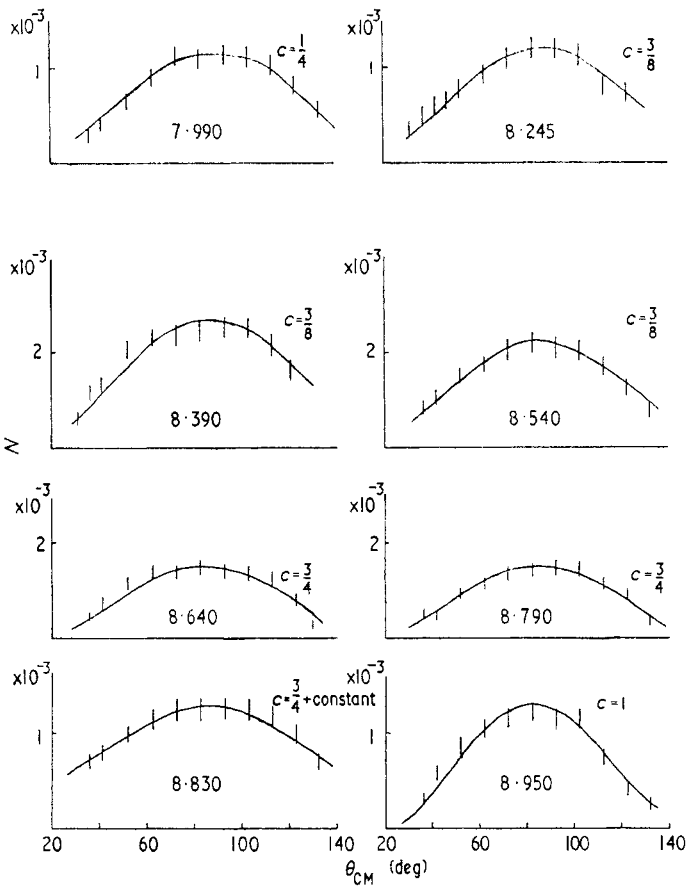

Figure 2. Angular distributions of protons to the 5·609 MeV 4^- state for each fine structure resonance (values of E_p(lab) in MeV are shown on the figure). The parameter c represents a steadily increasing interference component due to a small direct interaction cross section.

Table 1. Strengths and widths of ^{41}Sc resonances decaying strongly to the 5·609 MeV 4^- state of ^{40}Ca. The values for the reduced widths $\gamma_{5\cdot609}{}^2$ correspond to $J^\pi = \frac{9}{2}^+$

E_p (MeV)	$\int\sigma dE$ (mb keV)	Γ (keV)	Γ_0 (keV)	$\Gamma_{5\cdot61}$ (keV)	$\gamma_0{}^2$ (keV)	$\gamma_{5\cdot61}{}^2$ (keV)	E_x (MeV)
7·550	(130)			(0·05)		(5·3)	8·450
7·750	(340)			(0·12)		(6·5)	8·645
7·990	810	8	8	0·32	41	10·1	8·879
8·245	1260	18	17	0·50	75	7·8	9·128
8·390	1880	10	9	0·78	37	8·1	9·269
8·540	1950	11	10	0·85	37	6·8	9·416
8·640	1180	15	14	0·50	49	3·3	9·513
8·790	920	16	16	0·42	53	2·4	9·660
8·830	940	12	12	0·40	39	2·0	9·699
8·950	770	13	13	0·33	39	1·5	9·816

It can be seen in table 1 that the integrated cross section is strongly modulated, as if by some doorway state, but the resonance width Γ is not. Inspection of all other measured channels indicates that they contribute little to the total width of these resonances, for which it may be inferred that $\Gamma_0 + \Gamma_{5\cdot61} \simeq \Gamma$ and that modulation occurs only in the weaker of Γ_0 and $\Gamma_{5\cdot61}$, the stronger contributing most of Γ.

If it is assumed, on the grounds of penetrability, that the elastic channel has the greater width, then the reduced widths of table 1 are obtained. The quantity of greatest interest for each channel is the strength function $\gamma^2/\langle D\rangle$ shown plotted in figure 3. The theoretical level density $\langle D\rangle$ (Gilbert and Cameron 1965), used in

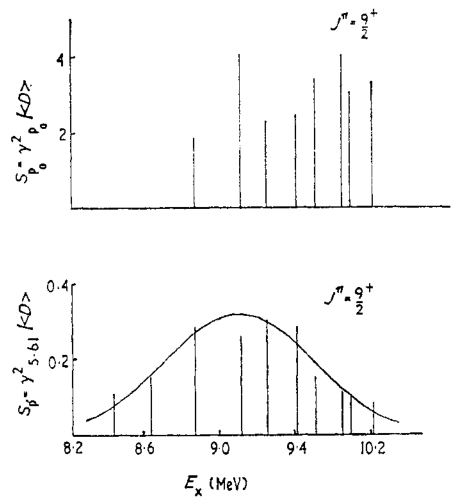

Figure 3. Strength function distributions of the elastic and inelastic channel for thu 9·1 MeV resonance in ^{41}Sc.

order to have a smoothly varying function, agrees well with the measured distribution of strong resonances. Again the doorway state modulation appears only in the exit channel strength function. A lorentzian fit to this strength function gives a value for the mixing or damping width $\Gamma_d\!\downarrow\; \simeq 1\cdot0$ MeV. The total escape width, obtained by summing over all fine structure resonances, is $\Gamma_d\!\uparrow\; = \Sigma\Gamma \simeq 150$ keV. This is then a case of strong mixing, $\Gamma_d\!\downarrow\; \gg (D, \Gamma_d\!\uparrow)$, as described by Lane (1969). The doorway state has spin and parity $\frac{7}{2}^+$ or $\frac{9}{2}^+$ and dominates only one channel. The dominated channel appears to be the exit channel, which explains a poor correlation between fine structure resonances seen in this and other exit channels. The absence of intermediate structure modulation in the entrance channel, despite a large partial width, may be due to overlapping of several doorway states or to strong direct coupling of each fine structure resonance to the entrance channel. Finally, the ingoing g wave proton energy is centred in the region of strong $\frac{9}{2}^+$ excitation and an assumed single particle state (Class *et al* 1959, Payne 1968), explaining the uniformly large entrance channel widths; the outgoing p wave proton energy corresponds exactly to that of a known single particle $2p_{1/2}$ state (Class *et al* 1959, Payne 1968); and the residual 4^- state is known to have the particle hole configuration $[(1d_{3/2})^{-1}(1f_{7/2})]_{4^-}$ (Erskine 1966, Seth *et al* 1967, Forster *et al* 1970, Fuchs *et al* 1969). There is therefore strong reason to believe that a principal component of the doorway state has the 2p1h configuration

$\{[(1d_{3/2})^{-1}(1f_{7/2})]_4\text{-}(1p_{1/2})\}_{9/2^+}$. It should be noted that Mittig *et al* (1970) show evidence for a similar weak coupling of a $1p_{1/2}$ proton to the ^{40}Ca 3^- state at lower excitation.

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