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**Note**

# The Single Particle Resonances and the Intermediate Resonances of $p+{}^{40}$Ca System

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The aim of the present work is to investigate the mechanism of an intermediate resonance, in which only a few degrees of freedom of the target nucleus are exicted. The analysis of the elastic and inelastic nucleon scattering by $^{12}$C<sup></sup>1) has recently shown that the coupled channel method is very useful for interpretation of the resonant scattering in which the incident nucleon is couped to the target core excited state. From the similar point of view, the resonant scattering of protons by $^{40}$Ca has been measured. Though being a double magic nucleus, $^{40}$Ca has collective excited states at low excitation energy. Therefore, the existence of the coupled states to the excited core may be expected.

In the present experiment, the proton beam from the Kyoto Univ. tandem accelerator was incident on a natural Ca target, and the excitation functions of elastic scattering were measured in the bombarding energy range between $E_p=2.3$ MeV and 4.0 MeV. The inelastic channels for the $^{40}$Ca* ($0_1^+$, 3.35 MeV) and $^{40}$Ca* ($3_1^-$, 3.74 MeV) states are energetically open but the inelastically scattered protons have so low energy that the elastically scattered protons were only measured. The excitation functions were measured at intervals of 12.5 keV at the angles of 90°, 125°, and 140° to the incident beam (Fig. 1). These excitation functions showed that 13 members of the known levels in $^{41}$Sc were strongly excited. In Fig. 1, $J^\pi$-assignment was followed to the previous work (unpublished.)2)

The angular distributions of the elastically scattered protons were also measured at four energies of 2.60, 2.85, 3.35, and 3.75 MeV in the off-resonance region and analyzed by the optical potential3) which has no imaginary part because of few open channels (Fig. 2). The optical potential parameters which are all consistent for four energies were used to calculate the excitation functions. As the calculated curves for the excitation functions show, the $P_{1/2}$-potential resonance occurs at $E_p=2.45$ MeV and so the observed resonance at $E_p=2.445$ MeV ($J^\pi=1/2^-$) is considered to be the single particle resonance. This fact is also able to be confirmed by comparing the polarization data4) with the prediction due to the same optical potential (Fig. 3). Not being shown in the figure, $P_{3/2}$-potential resonance occurs at $E_p=0.60$ MeV and this corresponds to the 1-st excited state of $^{41}$Sc($E_x=1.729$ MeV, $J^\pi=3/2^-$). The general trend of the observed excitation functions is well reproduced and each resonance seems

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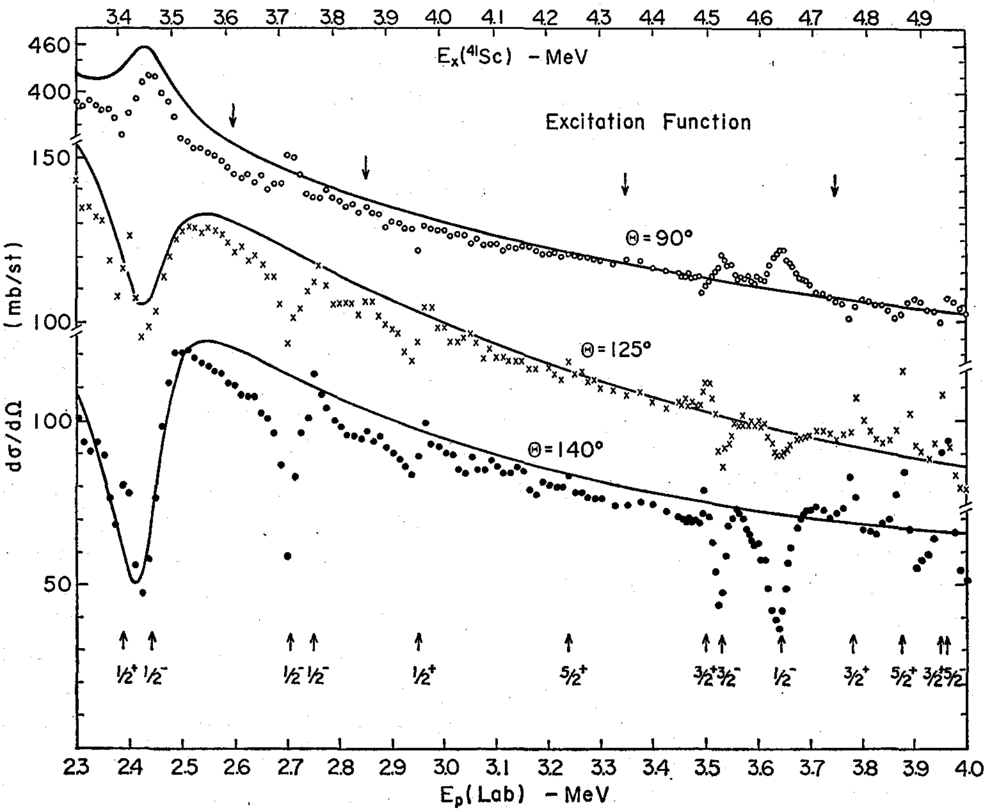

Fig. 1. The measured excitation functions and the calculated excitation functions (at $\theta_{CM}=90°$ (○), $\theta_{CM}=125°$ ($x$), $\theta_{CM}=140°$ (●). The optical potential parameters used are $V_c=55.5-0.55$ E MeV, $V_{so}=6.4$ MeV, $r_c=r_0=1.25$ fm, $r_{so}=1.04$ fm, $a_0=a_{so}=0.65$ fm. The arrows mark resonances with $J^\pi$assignment.

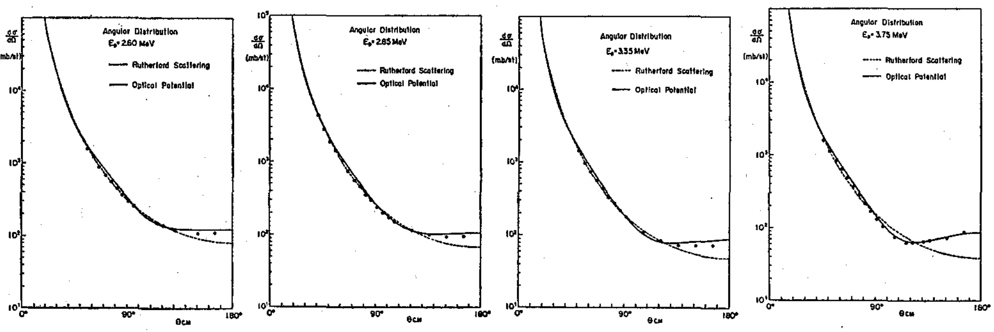

Fig. 2. The measured angular distributions at Ep (Lab) = 2.60, 2.85, 3.35, and 3.75 MeV. The solid lines show the optical potential fit of which parameters used are the same as those of Fig. 1. The dotted lines represent Rutherford scattering cross section.

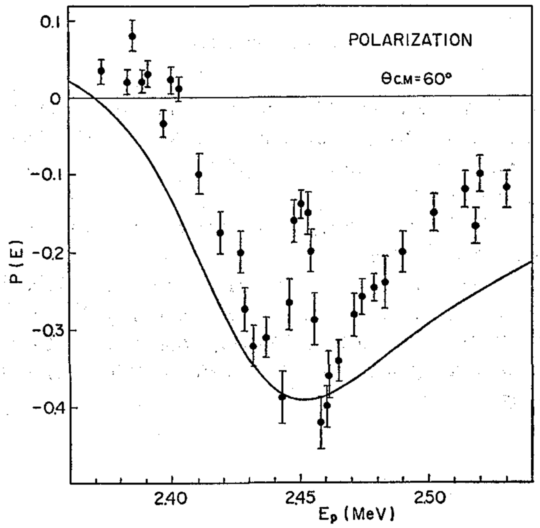

Fig. 3. The comparison of the polarization data with the optical potential fit around the 2.45 MeV resonance.

to be fluctuations from the calculated excitation functions. But the observed excitation functions suggest that the $P_{1/2}$-single particle strength is splitted to the $E_p=2.714$ MeV and 2.755 MeV resonances (each has $J^\pi=1/2^-$). The $^{40}$Ca(d, p)$^{41}$Ca reaction$^{5)}$ showed that the $P_{1/2}$-single particle strength is also splitted in $^{41}$Ca. It must be noted that the lowest 1/2-state in $^{41}$Ca does not have the main component of the $P_{1/2}$-single particle strength, but the lowest $1/2^-$ state in $^{41}$Sc does. In fact the 2-nd $1/2^-$ state in $^{41}$Ca ($E_x=3.954$ MeV) has the largest spectroscopic factor of $P_{1/2}$ ((2J+1)Sn =1.45).

The $^{40}$Ca(d, n)$^{41}$Sc$^{6)}$ and $^{40}$Ca(d, p)$^{41}$Ca reactions showed that the $P_{3/2}$-single particle strength is also splitted to two levels. These splitting and the other resonances demand to take into account the $^{40}$Ca-core excitation mode. The broad odd parity resonances, in particular at $E_p=3.537$ MeV ($J^\pi=3/2^-$) and $E_p=3.647$ MeV ($J^\pi=1/2^-$), are considered to be the doorway state formed from an fp-shell single particle coupled to the $^{40}$Ca* ($0^+_1$, 3.352 MeV) and $^{40}$Ca* ($2^+_1$, 3.903 MeV) excited states. These even parity exicted states of $^{40}$Ca are considered to be admixture of the spherical shell model states and the deformed rotational band.$^{7)}$ The broad even parity resonances, in particular at $E_p=3.785$ MeV ($J^\pi=3/2^+$), $E_p=3.877$ MeV ($J^\pi=5/2^+$) and $E_p=3.959$ MeV ($J^\pi=3/2^+$) are considered to be formed from an fp-shell single particle coupled to the $^{40}$Ca* ($3^-_1$, 3.734 MeV) octupole phonon state. Thus it is certainly worthwhile to examine to what extent the coupled channel method can reproduce the measured excitation function, assuming these schematic model.

The authors dedicate this paper to the memory of the late Prof. Yoshiaki Uemura. The construction of the Kyoto University tandem Van de Graaff which was used in the present work are much owing to him.

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