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EXCITATION OF FORBIDDEN ISOBARIC ANALOGUE RESONANCES

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Analyses of neutron scattering data from ^{118}Sn and ^{120}Sn isotopes indicate the excitation of states ^{119}Sn and ^{121}Sn, respectively, which are the isobaric analogues of the first and second excited states in ^{119}In and ^{121}In, respectively.

I. INTRODUCTION

The phenomenon of isobaric analogue (IA) resonance was first revealed via (p,n) reaction [1] and later through the study of the (p,p) and (p,p') reactions [2]. However, the excitation of IA resonances via (n,p) or (n,n) reactions is forbidden by the conservation of isospin. The former is forbidden in the entrance channel and the latter is forbidden in both the entrance and exit channels. Isospin forbidden resonances via (p,n) and (α,n) reactions have been observed [3,4], but the amount of spectroscopic information obtained from them was limited. Nonetheless, they support the expectation, base on the reciprocity theorem of nuclear reactions, that analogue resonances should occur in the inverse (n,p) and (n,α) reactions, and it is quite possible that isospin mixing will allow analogue states to be excited by neutrons.

Over the past several years many attempts were made to search for IA resonances via (n,p), (n,n), and (n,n') reactions. Long and coworkers [5] made a search for IA states of levels in ^{209}Tl via the $^{208}Pb(n,p)^{208}Tl$ reaction; however, no evidence was found for the existence of such resonances. Benetskii et al. [6] reported the observation of resonance in the neutron total cross sections on ^{207}Pb, which was attributed to the excitation of IA in the ^{208}Pb system. Also, Hicks et al. [7] reported that resonant structure was observed in the neutron total cross sections on ^{90}Zr and in the $^{90}Zr(n,p)$ excitation function. It was interpreted as being due to states in ^{91}Zr, which are IA of the low lying states in ^{91}Y. Weigman et al. [8] studied the resonance interaction of neutrons with stable isotopes of magnesium. They concluded that the $^{24}Mg+n$ data served to assess the isospin impurities in ^{25}Mg. These states were previously observed by charged particle reaction [9,10] and this was the first time that analogue states have been observed in neutron induced reactions. Finally, a paper by Cierjacks and coworkers [11] reported that resonance parameters for four resonances in ^{28}Si were obtained by analyzing measured neutron scattering differential cross sections combined with the neutron total cross sections in the energy range 1.05 – 1.40 MeV. The resonance at 1.254 MeV was identified as the analogue resonance in ^{29}Si.

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In the present work, data of neutron scattering excitation functions and total cross sections from $^{118,120}Sn$ in the energy range of 8.7–10.6 MeV, are analyzed. The data were collected in an attempt to excite states in ^{119}Sn and ^{121}Sn, which are the IA to the ground state and the first two excited states in $^{119,121}In$.

II. THE EXCITATION ENERGY OF AN ISOBARIC ANALOGUE STATE

The excitation energy of an isobaric analogue state is given by the equation [12]

$$E_x = E_{\beta\pm} + (\delta E_C - \delta M), \qquad (1)$$

where $E_{\beta\pm}$ is the ground state transition energy between the Z and $Z \pm 1$ nuclei, δE_C is the Coulomb energy difference between the Z and $Z \pm 1$ nuclei, and δM is the mass difference between the hydrogen atom and the neutron.

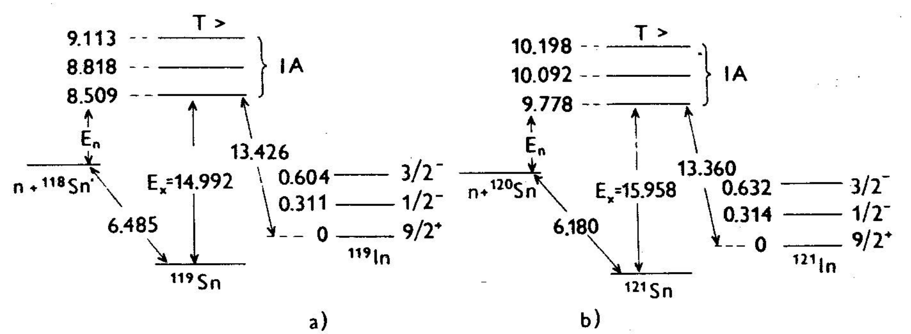

Fig. 1. a)The relative position of the $n + {}^{118}Sn$ system with respect to the $T >$ in the ^{119}Sn, and the first three levels in ^{119}In. b) The same as in a) for the ^{120}Sn, ^{121}Sn, and ^{121}In systems. All energies are in the center of mass system.

The excitation energies of the $T >$ states in $^{119,121}Sn$ isotopes (i.e. the IA of the ground states and the first two excited states in $^{119,121}In$, respectively, (see Figure 1) were calculated by using Equation 1. Table 1 gives a break up of the different components of this equation for each isotope and the neutron lab energy

Table 1
The different components of Eq. (1) and the incident neutron energies needed to excite the IA of the ground state and the first two excited states in ^{119}In and ^{121}In. δE_C = (13426 ± 30) keV, $E_{\beta\pm}$ = (2348 ± 38) keV for sample 118, δE_C = (13360 ± 30) keV, $E_{\beta\pm}$ = (3380 ± 40) keV for sample 120, respectively.

Sample (A)	δM (keV)	E_x (keV)	$E_{(n+A)}$ (keV)	E_n(C.M.) (keV)	$E_n^{g.s}$(Lab) (keV)	$E_n^{1/2^-}$ (Lab) (keV)	$E_n^{3/2^-}$ (Lab) (keV)
118	782	14992 ± 68	6485	8507 ± 68	8579 ± 68	8893 ± 68	9189 ± 68
120	782	15958 ± 70	6180	9778 ± 70	9859 ± 70	10175 ± 70	10486 ± 70

required to excite the $T >$ states in the compound system, which are IA's of the ground state and the first two excited states in $^{119,121}In$.

These excitation energies are checked against the values obtained by M. Schiguchi , et al. [13] and found to be in excellent agreement with them.

III. EXPERIMENTAL PROCEDURE

The neutron differential scattering excitation functions and total cross sections were measured at the Ohio University 11 MeV Tandem Van de Graaff Accelerator Laboratory. All experimental details can be found in references [14] and [15]. The neutron differential cross section excitation functions were measured using a standard Time-of Flight (TOF) technique [14,15] with a flight path of 6.6 m at one laboratory angle chosen such that the elastic scattering differential cross section is at a minimum in order that any small angular differences will not result in large changes in the excitation functions. By use of the computer code DWUCK [16] it was found that the best angle would be 82.5°, where the elastic differential cross section is at a minimum but with large values, and at the same time still in the forward direction, which does not require long accumulation time. The neutron beam energy dispersion during the excitation functions measurements was kept less than 80 keV (FWHM), and the time resolution of the T.O.F system was < 1 ns.

The total neutron scattering cross sections were measured by means of a transmission experiment [17]. The neutron source, the sample, and the detector were located such that the sample completely overshadowed the detector at a distance of 350 cm, and at a distance of 60 cm from the neutron source. The neutron beam energy dispersion for the total cross section measurements was less than 30 keV (FWHM) and the time resolution of the T.O.F spectrometer system was < 1 ns.

Typical TOF spectra of the differential scattering cross section measurements and of the total neutron scattering cross section are shown in figures 2 (a & b). They show the sample-in and sample-out spectra in both measurements. Accurate determination of incident neutron energy was critical in these measurements.

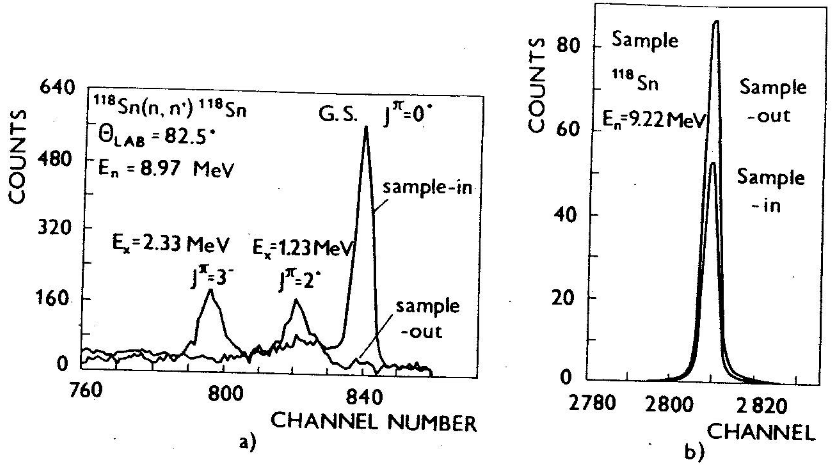

Fig. 2. a) A typical TOF spectrum of the differential cross section excitation function measurement. b) A typical TOF spectrum of the total cross section measurement.

Therefore, the absolute value of the neutron energy and its energy spread were checked by measuring the energy dependence of the neutron total cross section on 14C around the sharp resonance at E_n = 6.297 MeV. The present work is in excellent agreement with the results of Foster and Glasgow [18]. The major contribution to the relative uncertainty in the differential cross section measurements arises from statistics in the detector yields. It varied from 3% to 5% for the elastic data, while it varied from 5% to 8% for the inelastic scattering from the 3- state and from 6% to 20% for the inelastic scattering from the 2+ state. Unfortunately, the uncertainties in the inelastic scattering differential cross sections' excitation functions were higher than expected, therefore, they were not considered in the analyses. The statistical uncertainty in the total cross section data was 1–2%.

IV. RESULTS AND DISCUSSION

A. The differential cross section excitation functions

The elastic scattering excitation functions for the $^{118}Sn(n,n)$ and $^{120}Sn(n,n)$ reactions are shown in Figures 3 and 4.

The excitation of the isobaric analogue of the ground state in ^{119}In or ^{121}In (at E_n(lab) = 8.579 MeV, for the former, and at E_n(lab) = 9.859 MeV, for the latter), in the resent work is very difficult, because it requires the transfer of large orbital angular momenta (J^π (ground state) = $9/2^+$ for ^{119}In and ^{121}In), which is

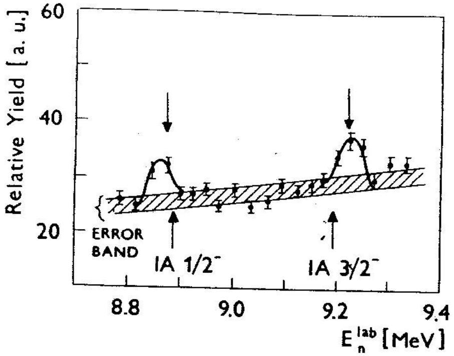

Fig. 3. The relative yield of the $^{118}Sn(n,n)^{118}Sn$ reaction. The lower arrows indicate the incident neutron energies, where IA resonances are expected to be. Downward arrows indicate the positions of the centroids of the observed peaks. The drawn curves are a help to the eye and do not represent mathematical fits. All energies are in the laboratory system.

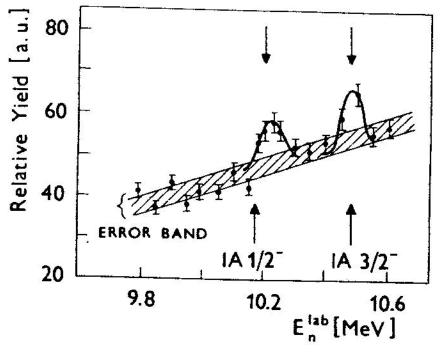

Fig. 4. The same as in Figure 3 but for the $^{120}Sn(n,n)^{120}Sn$ reaction.

not available to the incident neutrons. Therefore, no resonances were expected at these positions. However, as far as the excitation of the IA of the first and second excited states of ^{119}In and ^{121}In (at E_n(lab) = 8.893 MeV for the $1/2^-$ and E_n(lab) = 9.189 MeV for the $3/2^-$states in ^{119}In, and at E_n(lab) = 10.175 MeV for the $1/2^-$ and E_n(lab) = 10.486 MeV for the $3/2^-$ states in ^{121}In), Figures 3 & 4 show two peaks in each (marked by downward arrows). The centroids of these peaks lie within the range of the incident neutron energy, where the IA of these states are supposed to be. In spite of the fact that the large error bars make the identification of the resonance peaks with confidence rather difficult, yet they are located where they are supposed to be and each peak overcomes the width of the error band in the two regions where IA states are expected to be. This observation leads one to conclude that the resonances are most likely not due to statistical fluctuations.

B. The Total Cross Section Data

The total neutron scattering cross sections from ^{118}Sn, and ^{120}Sn are plotted in figures 5 and 6, respectively. It can be seen from these figures that there is resonance structure in the energy range 8.2–9.4 MeV in the ^{118}Sn data at the neutron energies where IA are expected to be. Also, resonance structure can be seen in the energy range 9.4–10.4 MeV in the ^{120}Sn data, where IA are supposed to

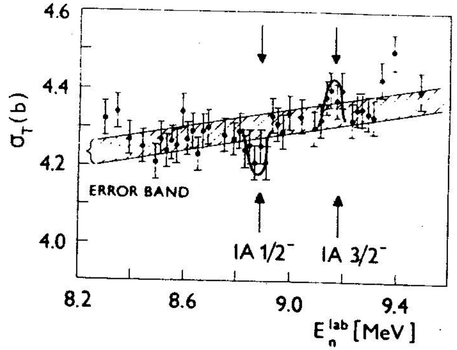

Fig. 5. The neutron total cross section on ^{118}Sn. The arrows are explained in the caption of Figure 3.

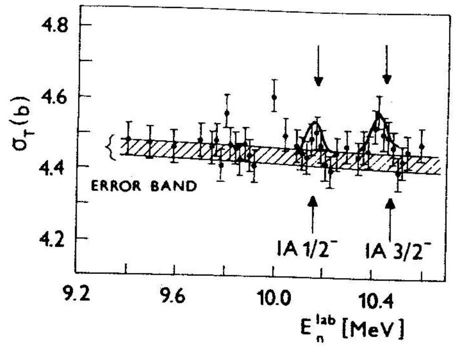

Fig. 6. The same as Figure 5 but for ^{120}Sn.

be. These observations support the claim that IA resonances are excited. However, in order to make a better judgment, and following G.C.Hicks et al. [7] the ratio of the total cross sections on ^{118}Sn to that on natural tin were calculated and plotted in Figure 7. Such a procedure is justified because any variations in the cross

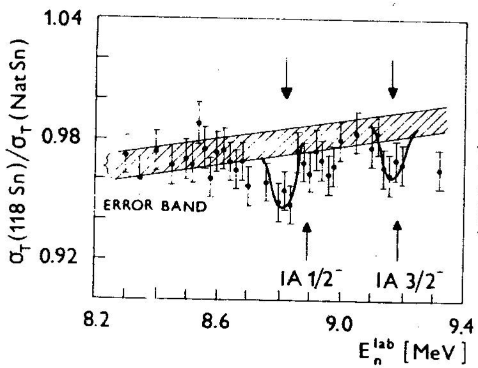

Fig. 7. The ratio of the neutron total cross section from ^{118}Sn to that from ^{NAT}Sn in the energy range 8.2–9.5 MeV.

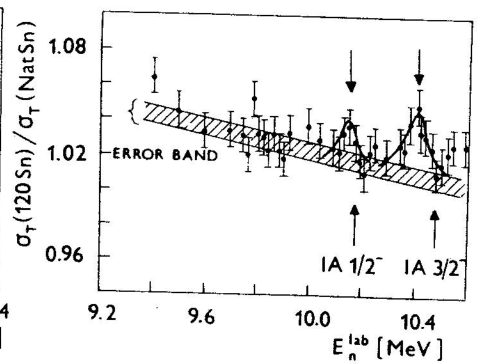

Fig. 8. The ratio of the neutron total cross section from ^{120}Sn to that from ^{NAT}Sn in the energy range 9.4–10.6 MeV.

sections which are due to the experimental set up and data reduction, as well as statistical fluctuations, should cancel out. Also, this ratio should, in theory, cancel out resonances that could be attributed to any other neutron inducing reactions than the excitations of the IA states. In Figure 7, we can see two peaks at the positions where IA are expected to be, which support our earlier conclusion drawn from the excitation function data. Similarly, we took the ratio of the total cross section data from ^{120}Sn to that from ^{NAT}Sn. The result is shown in Figure 8. In spite of the fact that the ^{120}Sn total cross section data in the energy range 9.4–10.6 MeV were not as smooth as they were hoped to be, resonant structures do exist near the expected positions in the ratio of the total cross sections on ^{120}Sn to that on ^{NAT}Sn. In both sets of total cross section data on ^{118}Sn, the locations of the peaks are consistent with those found in the differential cross section which means that they are not to statistical fluctuations.

V. CONCLUSIONS

The neutron scattering differential cross section excitation functions on ^{118}Sn and ^{120}Sn isotopes reveal to some extent the excitation of isobaric analogue resonances which are doubly forbidden in the entrance and exit channels. The positions of the resonances correspond to the excitation energies of the IA states of the first and second excited states in ^{119,121}In. The neutron total cross sections on ^{118}Sn and ^{120}Sn show resonant structures near the expected positions of the IA states, which support the reached conclusion from the excitation functions data. The agreement in the locations of the resonances in both the differential and total cross section data means that they could not be due to statistical fluctuations. However, the large error bars of the measured differential and total cross sections make a confident decision rather difficult to be drawn from these data alone. A more definite conclusion and full theoretical analysis of such data should be made after repeating some of the measurements of the differential scattering excitation functions, in order to obtain a better accuracy in the elastic and the inelastic data. Also, (n,p) reaction measurements are needed for the confirmation of the excitation of forbidden isobaric analogue resonances.

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ВОЗБУЖДЕНИЕ ЗАПРЕЩЕННЫХ ИЗОБАРИЧЕСКИХ АНАЛОГОВЫХ РЕЗОНАНСОВ

Анализ данных рассеяния нейтронов на изотопах ^{118}Sn и ^{120}Sn показывает, что возбужденные состояния ^{119}Sn и ^{121}Sn являются изобарическими аналогами первых и вторых возбужденных состояний изотопов ^{119}In и ^{121}In.