PHYSICAL REVIEW C VOLUME 11, NUMBER 1 JANUARY 1975

$^{29}Si(\alpha, n)^{32}S$ reaction from 2.15 to 5.25 MeV bombarding energy

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(Received 25 June 1974)

Levels in the compound nucleus ^{33}S have been investigated by measuring the reaction cross section for the reaction $^{29}Si(\alpha,n)^{32}S$ for incident α energies from 2.15 to 5.25 MeV, mostly in steps of 2.5 keV, using a 4π-geometry neutron counter. One hundred and thirty-four resonances have been identified. The reciprocity theorem has been used to calculate the total cross section for the inverse reaction $^{32}S(n,\alpha)^{29}Si$. Total widths have been determined for 107 resonances, and partial widths Γ_α, Γ_n and corresponding reduced widths γ_α^2, γ_n^2 have been extracted for 19 cases where spin values are known. Statistical strength function analysis of the cross section under the excitation curve gave the averaged α particle strength function value as $\langle \bar{S}_\alpha \rangle = 0.067 \pm 0.012$ for this reaction.

[NUCLEAR REACTIONS $^{29}Si(\alpha, n)$, $E = 2.15–5.25$ MeV; measured $\sigma(E)$; ^{33}S levels, deduced Γ_α, Γ_n, S. σ $^{32}S(n, \alpha)$ reaction, reciprocity theorem; statistical analysis, deduced $\bar{S}_\alpha$.]

I. INTRODUCTION

The measurement of $^{29}Si(\alpha, n)^{32}S$ reaction cross section gives information about the level structure in the compound nucleus ^{33}S. The bombarding energy range $E_\alpha = 2.15$ to 5.25 MeV corresponds to the excitation energy range of about 9.00 to 11.86 MeV in ^{33}S. The elastic scattering of α particles by ^{29}Si, neutrons by ^{32}S, and the radiative capture of α particles by ^{29}Si are other possible reactions leading to this range of excitation energies in ^{33}S. When this work was started no direct measurement of the total $^{29}Si(\alpha, n)^{32}S$ reaction cross sections were available, except some early measurements by Gibbons and Macklin.[1] The measurement of this reaction cross section has significance for astrophysical problems also.[2] There has been a recent measurement of the differential cross section by McMurray, Holz, and Van Heerden[3] who have measured the excitation function at 30° from 2.9 to 4.8 MeV. They have also determined angular distributions for 19 resonances observed in the excitation function from which they assign spins to corresponding levels in ^{33}S. These spin assignments have been utilized in analyzing the data in this work. In a recent report Sanin *et al.*[4] have mentioned spin parity assignment to 45 levels in the same excitation regions. However, as no specific numbers for these assignments are published, they could not be considered for the analyses in the present work.

The region up to 5.9 MeV excitation in ^{33}S has been studied mainly through the $^{32}S(d, p)^{33}S$ and $^{32}S(n, \gamma)^{33}S$ reactions.[5] Excitation energies, 1_n values, and relative reduced widths have been extracted and some of the single particle states have been identified in these studies. Above the neutron binding energy of 8.641 MeV in ^{33}S, resonances have been studied up to 9.4 MeV, mostly through the elastic scattering of neutrons on ^{32}S. The present study of resonances observed in the measurement of the reaction cross section, for the reaction $^{29}Si(\alpha, n)^{32}S$ has given new information regarding total and partial widths for the states of the compound nucleus ^{33}S in the region of excitation 9.00 to 11.86 MeV. The extraction of the relevant reduced widths γ_α^2 and γ_n^2 from these values can throw more light on the configuration of compound nuclear states at medium excitation in ^{33}S which is an s-d shell nucleus. Reported nuclear structure calculations[6] in this mass region encourage the expectation that this information would be useful in testing the predictions of such calculations.

II. EXPERIMENTAL PROCEDURE

Singly ionized helium ions from the 5.5 MeV Van de Graaff accelerator at Trombay were used to bombard a 84% enriched ^{29}Si target (SiO_2 deposited on a 250 μm tantalum backing). The outgoing neutrons were detected by a calibrated 4π-geometry neutron counter.[7] The efficiency of this counter as a function of neutron energy has been recently redetermined.[8] The absolute thickness of the target was determined by measuring the shift in the edge of the continuous spectrum of α particles scattered at a backward angle from the blank tantalum side of the target and from the side with the $^{29}SiO_2$ deposit, respectively. This shift is due to the energy loss suffered by the α particles in passing through the target material and is shown in Fig. 1.

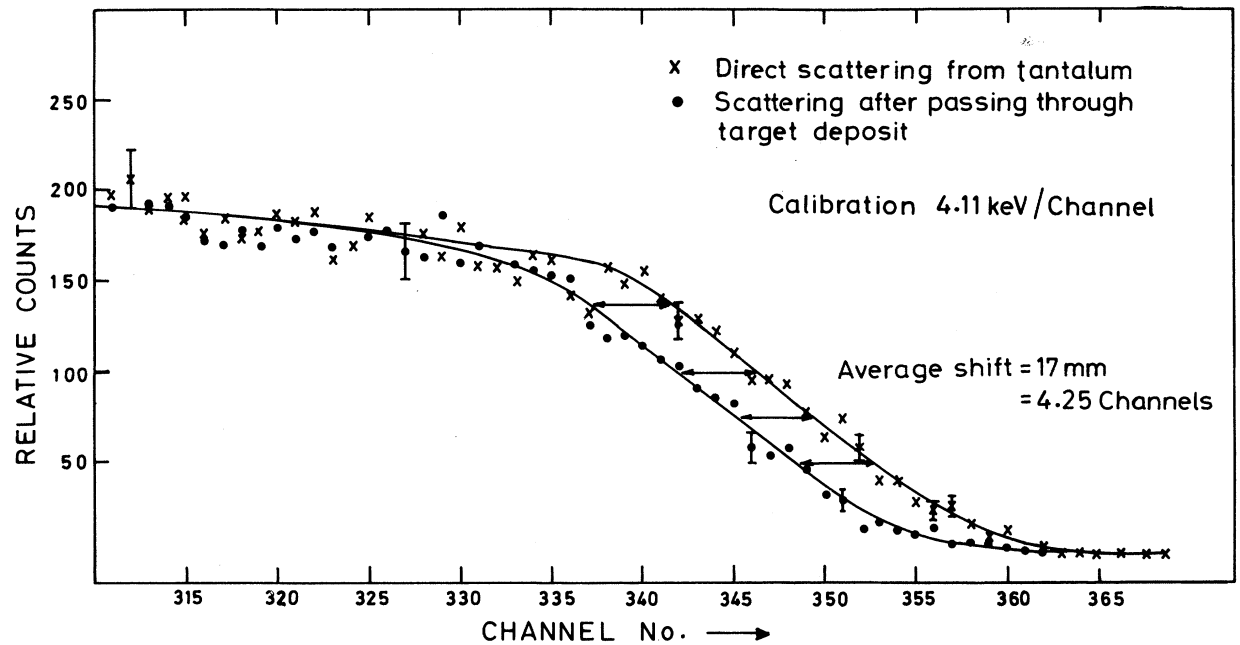

FIG. 1. The elastically scattered spectrum from tantalum for an incident α energy 1.7 MeV. The energy shift in the profile is due to energy loss for the α beam in passing through the target deposit.

The thickness of the SiO_2 in $\mu g/cm^2$ was determined from this shift by the help of range energy tables[9] and from this the number of ^{29}Si atoms present per cm^2 of the target was calculated as the enrichment of ^{29}Si was known. The amount of ^{28}Si present does not contribute to the (α, n) reaction, as the threshold for it is 9.308 MeV. These measurements gave about 5 keV as total target thickness for 3.5 MeV α particles and 6.29×10^{16} atoms of ^{29}Si per cm^2 of the target. From this the absolute total cross sections were obtained, which agree well with reported measurements of Gibbons and Macklin.[1]

The 4π-neutron counter was calibrated to within ±7% accuracy.[8] The error in the target thickness determination described is estimated to be ±15%. The incident beam was monitored by a current integrator built in our laboratory[10] and is calibrated to ±2%. The background in the yield measurement was determined by rotating the target through 180° and measuring the yield when the beam was bombarding the back surface of the tantalum backing. The estimated error in the correction for this background is negligible except below 3 MeV bombarding energy, where the yield itself is very small. The over-all error in the absolute cross section determination was estimated to be ±17%, above 3 MeV bombarding energy, and

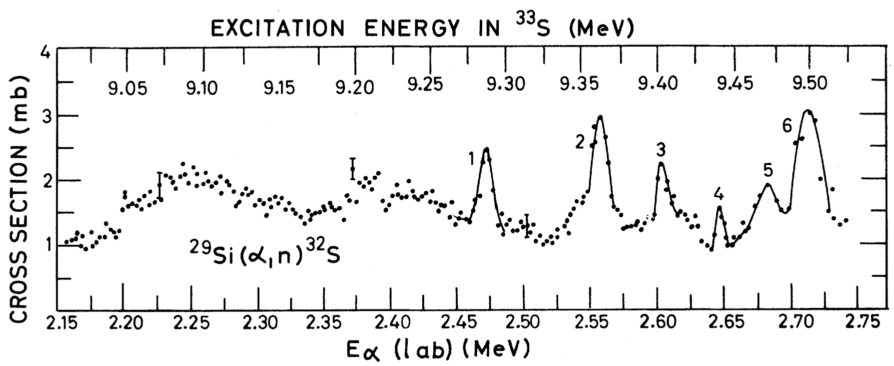

FIG. 2. The total (α, n) cross section expressed in mb for the reaction $^{29}Si(\alpha, n)^{32}S$ for incident α energy range $E_\alpha = 2.15$ to 2.75 MeV in steps of 2.5 keV.

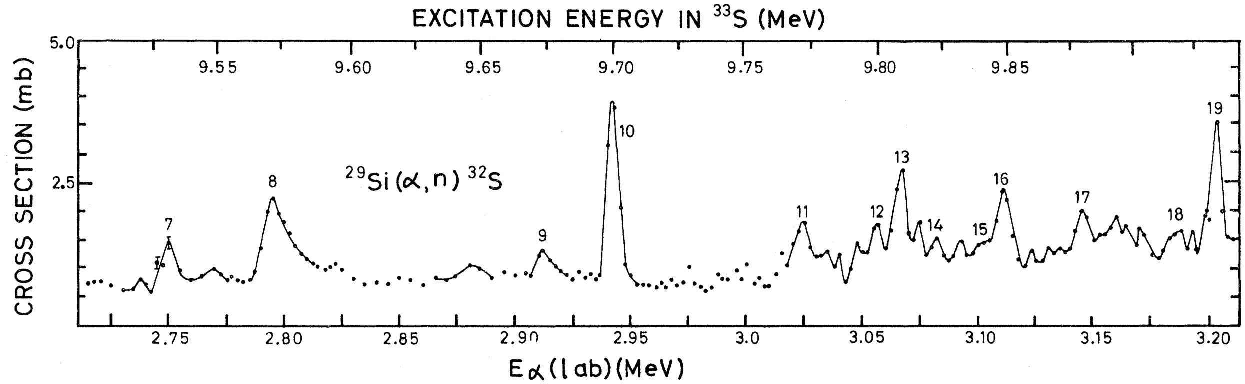

FIG. 3. The total (α, n) cross section expressed in mb for the reaction $^{29}Si(\alpha, n)^{32}S$ for incident α energy range $E_\alpha = 2.75$ to 3.20 MeV in steps of 2.5 keV.

it varies from ±50% to ±30% from 2.15 to 3 MeV bombarding energy. The larger error is mainly due to the fact that the yield is comparable to the background. The bombarding energy of the α particles is determined by a 90° energy analyzing magnet. As the magnet is known to exhibit saturation effects at higher energies, it was calibrated over the entire range covered in this experiment utilizing (i) the known 1 keV wide resonance[11] in the reaction $^6Li(\alpha, \alpha)^6Li$ at 2.785 ± 1.5 keV; (ii) the resonance energies for the $^{29}Si(\alpha, n)$ reaction reported in the work of McMurray *et al.*,[3] and the resonance at 5.295 MeV[12] in the reaction $^{24}Mg(\alpha, \alpha)$. The absolute error in the α particle energy varies from ±5 keV at low energies to as much as ±20 keV near 5 MeV bombarding energy. The relative error from resonance to resonance however is less than 5 keV.

III. EXPERIMENTAL RESULTS

The excitation function measured for the incident α particle energy range 2.15 to 5.25 MeV in steps varying from 2.5 to 5 keV is shown in Figs. 2 to 7. The excitation function is full of resonant structure. Most of the resonances have widths less than 10 keV, the lower limit being set by the target thickness (5 keV for 3.5 MeV α particles). Some of them exhibit a very sharp rising edge in-

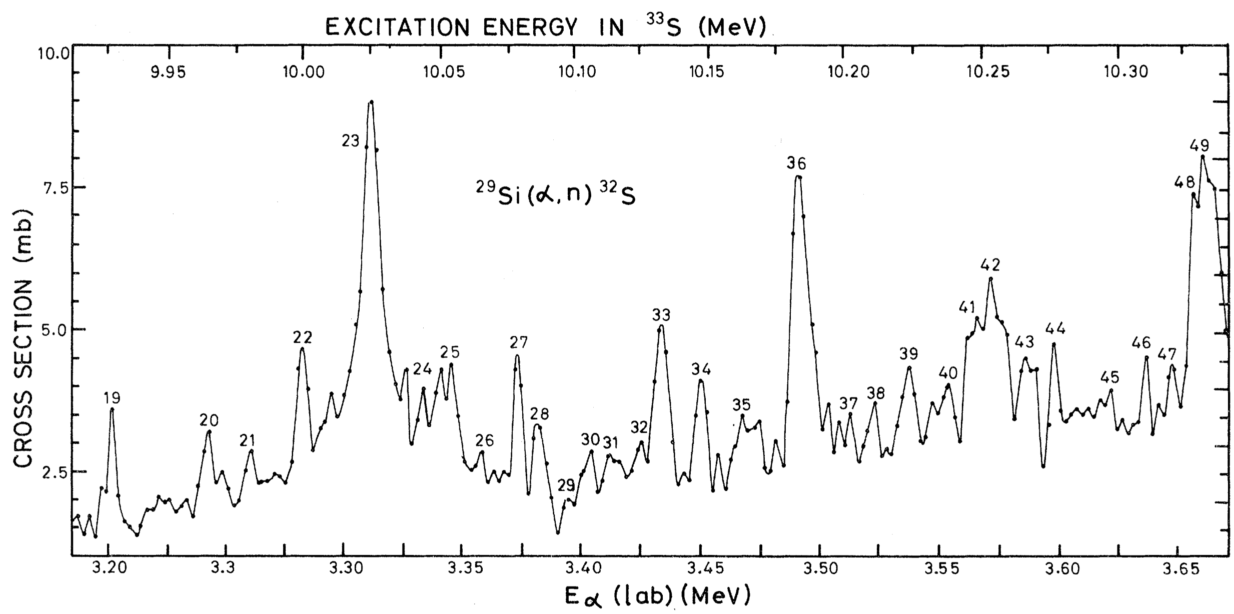

FIG. 4. The total (α, n) cross section expressed in mb for the reaction $^{29}Si(\alpha, n)^{32}S$ for incident α energy range $E_\alpha = 3.20$ to 3.65 MeV in steps of 2.5 keV.

dicating widths considerably less than the target thickness. Most of the resonances are resolved so that the corresponding resonance energies and the experimental widths could be determined. In all, 134 resonances have been identified, and the total widths for 107 cases could be determined from the excitation function. The spins for the levels corresponding to nineteen of these resonances are known from the work of McMurray *et al.*[3] For these resonances, the total widths determined in the present work (corrected for the target thickness contribution) are listed in Table I, along with the resonance energies as well as the corresponding excitation energies.

The cross section for the inverse reaction ^{32}S$(n, \alpha)^{29}$Si was calculated by applying the reciprocity theorem to the measured (α, n) cross section point by point upto the $E_\alpha = 4.6$ MeV above which the neutron group corresponding to the first excited state in ^{33}S is expected to be prominent. Table I also indicates the (α, n) and the inverse (n, α) cross section corresponding to the peaks of the 19 resonances.

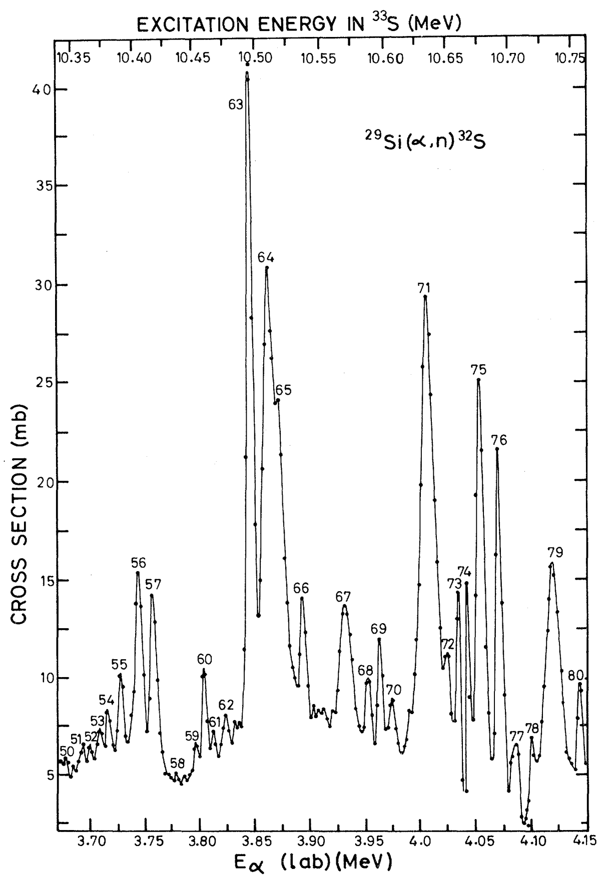

FIG. 5. The total (α, n) cross section expressed in mb for the reaction ^{29}Si$(\alpha, n)^{32}$S for incident α energy range $E_\alpha = 3.65$ to 4.15 MeV in steps of 2.5 keV.

IV. ANALYSIS

A. Individual resonance analysis

When the observed total widths of the 107 resonances are corrected for the target thickness, the average width turns out to be 5.2 ± 1 keV. The average separation $\langle D \rangle$, between two successive levels comes to 29 keV and thus the important statistical parameter $\langle \Gamma \rangle / \langle D \rangle$ is around 0.25. This indicates that although the resonances may be slightly overlapping the use of Breit-Wigner expression for individual resonances is justified. In such a case the thin target integrated yield Y under a resonance is related to the total width Γ and the partial widths Γ_α and Γ_n through the expression[13]

$$\frac{2\epsilon Y}{\lambda\!\!\!^{-2}\mathcal{E}} = \frac{(2J+1)}{(2i+1)(2I+1)} \sum \frac{\Gamma_n \Gamma_\alpha}{\Gamma} . \tag{1}$$

J is the total angular momentum of the compound

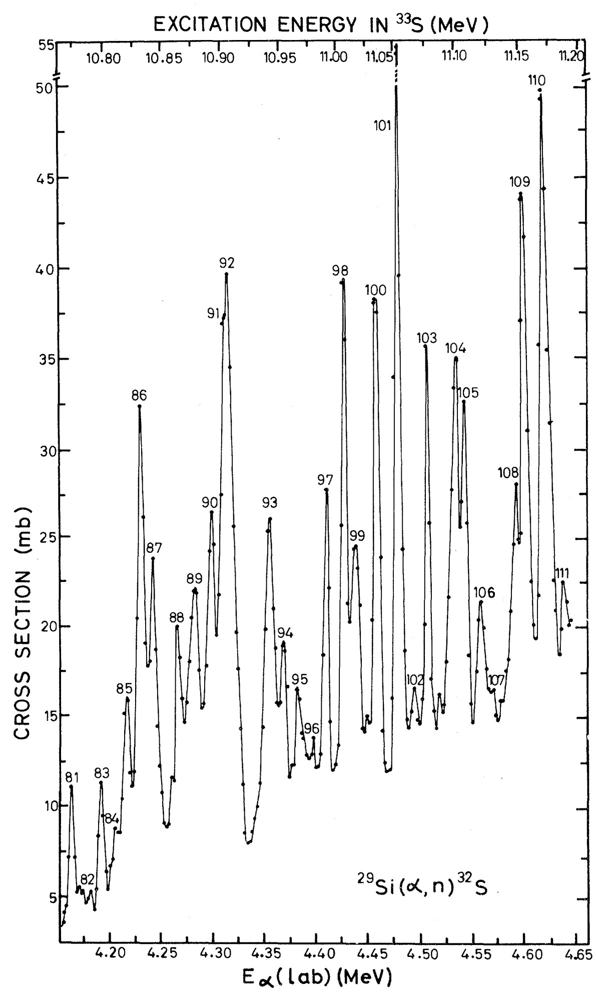

FIG. 6. The total (α, n) cross section expressed in mb for the reaction ^{29}Si$(\alpha, n)^{32}$S for incident α energy range $E_\alpha = 4.14$ to 4.65 MeV in steps of 2.5 keV.

nucleus level; i, I are the spin angular momenta of the incident and the target nucleus, respectively, and Γ, Γ_α, and Γ_n are the total width, the partial α width, and partial neutron width, respectively; $\epsilon = k/n$ the stopping power of the target in units of energy times cm^2/atom, λ is the center of mass wave length in centimeters of the incident particle, $\mathcal{E}$ is the target thickness in energy units at the

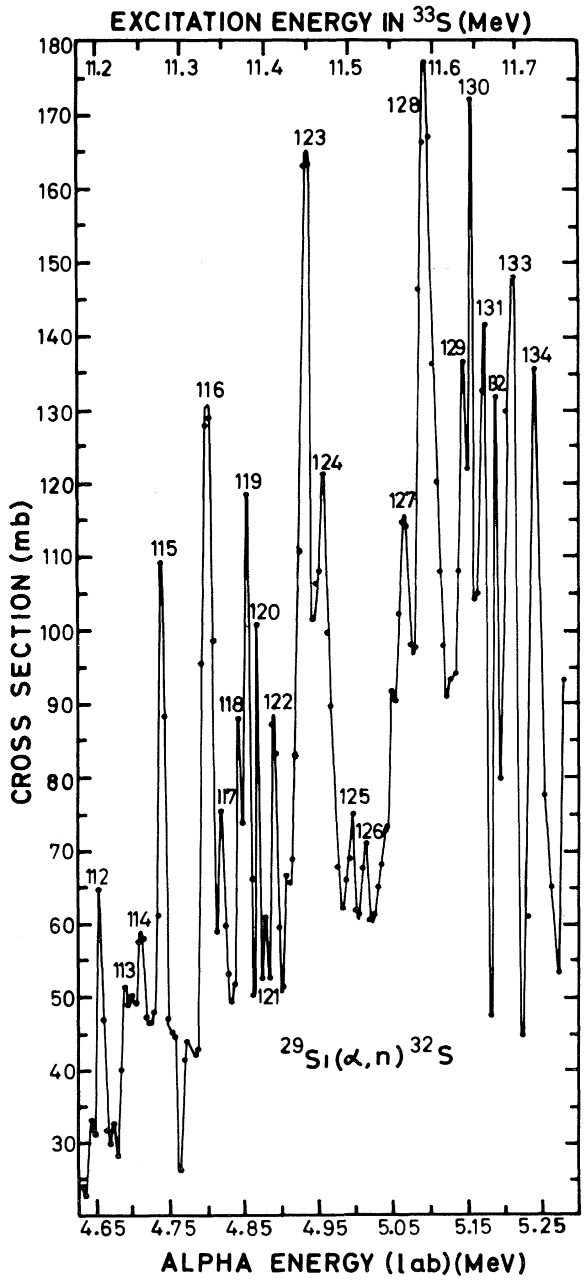

FIG. 7. The total (α, n) cross section expressed in mb for the reaction $^{29}\mathrm{Si}(\alpha, n)^{32}\mathrm{S}$ for incident α energy range $E_\alpha = 4.65$ to 5.25 MeV mostly in steps of 5 keV.

resonant energy and is given by $\mathcal{E} = kt$, where k is the stopping power, t is the target thickness in $\mathrm{g/cm}^2$ and n is the number of atoms per gram of the target. The total width Γ was extracted from the experimental width $\Gamma_{\exp}$ and target thickness $\mathcal{E}$ (keV), from the expression $\Gamma_{\exp}{}^2 = \Gamma^2 + \mathcal{E}^2$. The spread in the incident beam energy was neglected in these estimates. The maximum error in extracted widths was estimated to be ±1 keV. The above expressions have been used to evaluate the products of the partial widths Γ_α and Γ_n of the 19 resonances whose spin values are known.[2] The values of the partial widths were obtained assuming $\Gamma_\alpha + \Gamma_n = \Gamma$, as no other particle channels are open and Γ_γ can be neglected. It is also assumed that $\Gamma_n > \Gamma_\alpha$. In view of the Coulomb barrier for α particles (6.2 MeV) this is a reasonable assumption; however, it may not be valid in all cases. The reduced width and the ratio of the reduced width to the Wigner limit, as a percentage, were calculated from the expressions

$$\Gamma_s = 2P_l \gamma_s{}^2, \qquad (2)$$

$$\theta_s = 100\gamma_s{}^2/(3\hbar^2/2\mu_s a_s{}^2), \qquad (3)$$

where P_l is the penetrability factor for the lth partial wave, $\gamma_s{}^2$ is the reduced width of the level for the channel s. θ_s is the reduced width in terms of the Wigner limit expressed as a percentage and μ_s and a_s are the reduced mass and radius respectively for the channel s.

The α particle penetrabilities were obtained from a computer programme written in our laboratory which calculates the Coulomb wave functions corresponding to the η and ρ values relevant to this work where $\eta = ZZe^2/\hbar v$ and $\rho = kr$. The neutron penetrabilities were taken from an Argonne National Laboratory report by Monahan, Biedenharn, and Schiffer.[14] Table II lists the reduced widths and other resonance parameters for the two sets of l values that are possible for the 19 resonances whose spins are known. The resonance energies, the widths, the peak cross sections, and other parameters for all the resonances observed in this work will be included in a detailed report which is under preparation.

B. Statistical analysis

As the number of levels observed is large (~134) it is possible to subject the measured numbers to statistical analysis. The distribution of level spacings and the average strength function can be extracted from this data. It has been shown by Wigner[15] that spacings between levels for a given spin may not be completely random.[16] However, if levels having several values of spin are observed, the distributions of spacing is probably not far from random. If one assumes the exponential distribution to be more valid than Wigner distribution, a plot of log N versus D, where N is the number of levels having a level spacing greater than a given spacing D, should be a straight line, with a slope inversely proportional to the average level spacing.[17]

Figure 8 shows the plot, against D, of the common log of the number of levels in ^{33}S obtained from the present study having a spacing greater than some spacing D. The data shows deviation for level spacings below 5 keV and such deviations can occur if the experimental resolution is sufficiently poor to cause narrow resonances to be missed. This is in agreement with the over-all resolution of the experiment used (~ 5 keV for 3.5 MeV α particles) in the present work. The intercept on the log N axis yields the total number of levels as 200, out of which 134 have been observed. The number of levels obtained from the intercept and the energy range covered gives an average spacing of 13.7 keV for the levels, which is in good agreement with the value 14.3 keV obtained from the slope of the line.

Following the analysis used by Schiffer and Lee, and also by Bair and Haas,[17] the cross-section data were averaged over an energy interval ΔE; the area under this averaged excitation curve per unit ΔE was then plotted as a function of the incident α particle energy. A value of $\Delta E = 400$ keV was used in this work. This would smooth out the

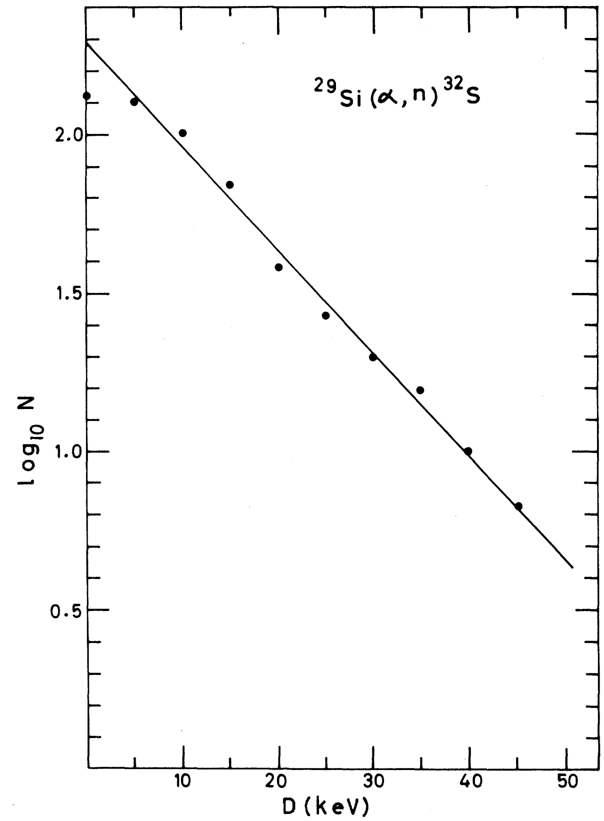

FIG. 8. The level distribution plotted as the log of the number of levels in ^{33}S, having a spacing greater than some spacing D, against D.

TABLE I. Peak total cross sections and total widths of levels in ^{33}S. Only 19 levels (out of 134 identified resonances) are listed whose spin values are known from Ref. 3.

Resonance energy E_α (MeV)	Excitation energy in ^{33}S, E_x (MeV)	Peak total cross sections $^{29}Si(\alpha,n)^{32}S$ (mb)	$^{32}S(n,\alpha)^{29}Si$ (mb)	Neutron energy E_n (MeV)	Total level width (c.m.) Γ (keV)
2.942	9.699	3.65	32.66	1.08	2.2
3.066	9.808	1.80	15.23	1.19	1.0
3.203	9.929	2.64	21.04	1.32	1.0
3.284	10.000	2.92	22.66	1.39	4.7
3.311	10.024	6.43	49.60	1.41	6.6
3.375	10.080	3.16	23.67	1.48	1
3.435	10.133	3.40	25.07	1.53	5.0
3.492	10.182	6.32	45.88	1.58	6.3
3.637	10.310	1.83	12.78	1.71	1
3.759	10.417	8.00	53.97	1.83	6.3
3.806	10.459	4.37	29.22	1.87	3.3
3.845	10.493	3.21	21.33	1.90	4.0
4.007	10.635	22.87	146.9	2.05	14.9
4.059	10.678	19.80	126.22	2.09	7.6
4.354	10.940	17.07	103.5	2.36	9.3
4.408	10.988	16.27	97.75	2.41	4.0
4.430	11.007	27.89	167.0	2.43	5.1
4.507	11.075	21.83	129.3	2.50	3.0
4.621	11.175	31.94	186.5	2.60	8.0

effect of individual narrow resonances as well as that of any intermediate structure (discussed in the following section). This result is shown as points in Fig. 9. With the assumption that $\Gamma_n \gg \Gamma_\alpha$, a value of the α particle strength function $\bar{S}_\alpha$ can be obtained for each averaged data point from the expression[17]

$$\frac{A_{\Delta E}}{\Delta E} = \left[\frac{2\pi^2\lambda\!\!\!^{-2}}{2I+1}\sum_J (2J+1)\sum_{l=|J-I|}^{J+I}\frac{2kR}{A_l^{\,2}}\right]\bar{S}_\alpha\,. \qquad (4)$$

Here, $A_{\Delta E}/\Delta E$ is the area for unit energy interval under the averaged cross-section curve; the other symbols have their usual meaning. The bar over $\bar{S}_\alpha$ indicates averaging over ΔE.

The value of $\bar{S}_\alpha$ as a function of energy is also shown in Fig. 9. It is apparent that $\bar{S}_\alpha$ has a very high value for low energies. For the purpose of astrophysical calculations the standard practice is to take an average of $\bar{S}_\alpha$ over the entire energy range which then is used to calculate expected yields for the reaction at low energies utilizing the above expression. This would be difficult to do in the present case because of the very high values of $\bar{S}_\alpha$ for low energies. One may consider the first few points as anomalous or obtain an average $\bar{S}_\alpha$, denoted by $\langle \bar{S}_\alpha \rangle$, excluding these three points. A value of $\langle \bar{S}_\alpha \rangle = 0.067 \pm 0.012$ was obtained this way where the error reflects the variance of $\bar{S}_\alpha$. The solid line in Fig. 9 is a calculation of $A_{\Delta E}/\Delta E$

TABLE II. The partial widths and reduced widths for levels in ^{33}S determined in the present work.

Resonance energy (MeV)	J	l_α	Γ_α (keV) ±20%	γ_α^2 (keV) ±20%	l_n	Γ_n (keV) ±20%	γ_n^2 (keV) ±20%	Percentage of Wigner limit θ_α	θ_n
2.942	$\frac{3}{2}$	1	0.05	17.7	1	2.15	1.33	4.2	0.070
		2		40.1	2		5.01	9.57	0.264
3.066	$\frac{3}{2}$	1	0.02	4.1	1	0.98	0.56	0.98	0.029
		2		18.0	2		1.91	4.29	0.101
3.203	$\frac{5}{2}$	2	0.01	2.5	2	0.99	1.61	0.60	0.085
		3		15.9	3		14.43	3.79	0.762
3.284	$\frac{1}{2}$	0	0.08	4.5	0	4.62	1.60	1.07	0.084
		1		1.33	1		2.31	0.32	0.122
3.311	$\frac{3}{2}$	1	0.12	9.0	1	6.48	3.20	2.15	0.169
		2		39.1	2		9.34	9.33	0.493
3.375	$(\frac{5}{2})$	2	0.02	2.5	2	0.98	1.32	0.60	0.069
		3		15.3	3		10.22	3.65	0.543
3.435	$\frac{5}{2}$	2	0.08	8.2	2	4.92	6.24	1.96	0.329
		3		49.7	3		46.24	11.86	2.443
3.492	$\frac{3}{2}$	1	0.15	5.9	1	6.15	2.78	1.41	0.147
		2		12.5	2		7.36	2.98	0.389
3.637	$\frac{7}{2}$	3	0.01	1.5	3	0.99	6.75	0.36	0.356
		4		12.2	4		103	2.91	5.441
3.759	$\frac{3}{2}$	1	2.18	37.4	1	4.12	1.67	8.92	0.088
		2		149.3	2		3.95	35.63	0.209
3.806	$\frac{3}{2}$	1	0.04	0.6	1	3.26	1.29	0.14	0.068
		2		2.4	2		2.99	0.58	0.158
3.845	$\frac{3}{2}$	1	0.03	0.4	1	3.97	1.56	0.09	0.082
		2		1.6	2		3.57	0.38	0.189
4.007	$\frac{3}{2}$	1	0.55	4.8	1	14.35	5.32	1.14	0.281
		2		18.8	2		11.54	4.48	0.610
4.059	$(\frac{3}{2})$	1	0.28	2.16	1	7.32	2.67	0.52	0.141
		2		8.4	2		5.71	2.00	0.302
4.354	$\frac{3}{2}$	1	0.30	1.2	1	9.00	3.01	0.28	0.159
		2		4.4	2		5.95	1.05	0.314
4.408	$(\frac{3}{2})$	1	0.17	0.61	1	3.83	1.26	0.15	0.067
		2		2.2	2		2.45	0.53	0.129
4.430	$\frac{3}{2}$	1	0.34	1.16	1	4.76	1.56	0.28	0.082
		2		4.3	2		3.01	1.01	0.159
4.507	$(\frac{5}{2})$	2	0.22	1.2	2	2.78	1.69	0.29	0.089
		3		5.8	3		6.76	1.38	0.357
4.621	$\frac{3}{2}$	1	0.54	1.3	1	7.46	2.33	0.31	0.123
		2		4.6	2		4.31	1.09	0.228

utilizing the expression (4) in which the value of $\langle \bar{S}_\alpha \rangle = 0.067$ was used. It would be interesting to extend the measurements to lower energies to determine whether the high values of $\bar{S}_\alpha$ at low energies represent any specific clustering effects in the compound nucleus at the corresponding energies (in which case omission of those points for evaluation of $\langle \bar{S}_\alpha \rangle$ would be justified) or whether it is just a fluctuation from the average.

V. INTERMEDIATE STRUCTURE

Since Block and Feshbach[18] and Kerman, Rodberg, and Young[19] suggested that simple modes of excitation of compound nucleus might lead to structures with widths intermediate in value between those for the normal compound nuclear states (~5 keV in the present case) and those for single particle states (giant resonances, of the order of a few MeV), many attempts have been made[20,21] to identify these states in nuclear reactions. According to Feshbach, Kerman, and Lemmer[21] such "doorway states" will be most readily observable in an excitation function if each exit channel is being separately detected. Since the doorway states corresponding to each channel are incoherent, the structure due to them will be smoothed out if the experiment sums over more than one exit channel. In such a case a simple interpretation in terms of doorway states of any observed structure would be questionable. (Of course, if a doorway state is formed in the entrance channel itself such consideration would not apply.)

However, in the present case, up to the bombarding energy of 4.3 MeV only one neutron group would be present populating the ground state of the residual nucleus ^{32}S. Thus, effectively only one reaction channel is being detected and any structure of intermediate width observed in the excitation function could be a candidate for consideration as a doorway state. An examination of the 60 keV averaged data shown in Fig. 10 indicates the presence of structure having widths around 75 keV at positions marked by the arrows. The most noticeable point is the uniformity of the width (~75 keV) and regularity of occurrence up to about 4.3 MeV (at a spacing of about 200 keV). As the excitation function represents an integrated cross section over angles, kinematic interference between resonances could be ruled out as a possible cause for such structure. Thus, it is very likely that this intermediate structure represents simple modes of excitation of the compound nucleus. It is the presence of one of such peak below 3.00 MeV bombarding energy which results in the anomalously large value of $\bar{S}_\alpha$ referred to earlier at these energies. A study of cross correlation with excitation function for different channels going through the com-

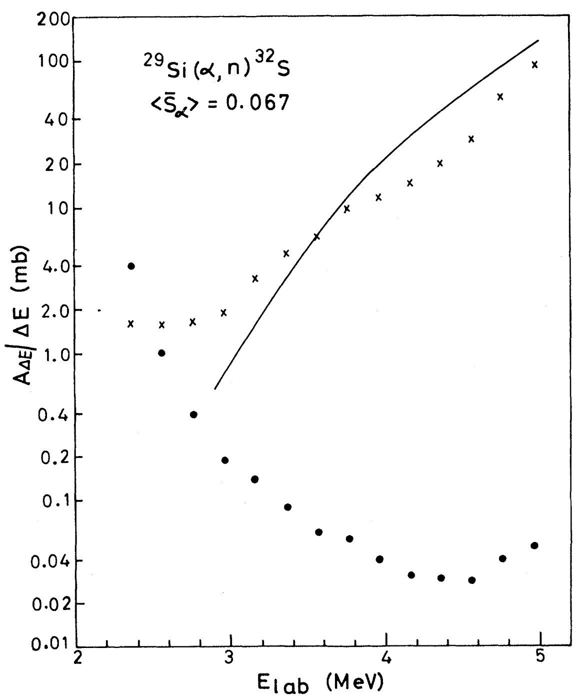

FIG. 9. Plot of $A_{\Delta E}/\Delta E$ against the bombarding energy in MeV. The crosses represent the values calculated from the excitation function with averaging interval $\Delta E = 400$ keV. The dots show the values of strength function $\bar{S}_\alpha$ obtained for each averaging interval. The continuous line indicates the same quantity calculated with a value of averaged strength function $\langle \bar{S}_\alpha \rangle = 0.067$. As discussed in the text, the value of $\langle \bar{S}_\alpha \rangle$ is obtained excluding the three points with the lowest energies.

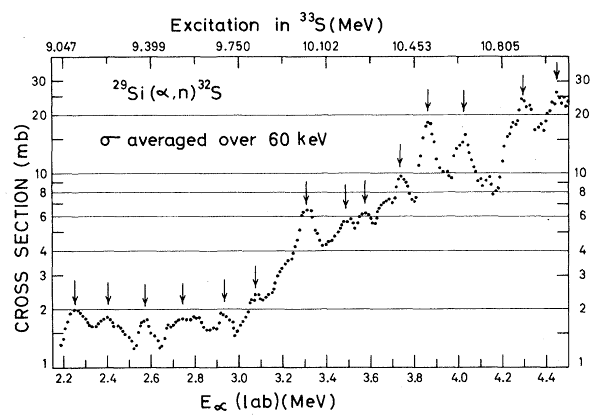

FIG. 10. The total $^{29}Si(\alpha, n)^{32}S$ reaction cross section averaged over an energy interval of 60 keV. The arrows indicate the positions of structures wider than compound resonances.

pound nucleus ^{33}S at this excitation would be a better way to confirm the presence or absence of this intermediate structure. There is some indication of a cross correlation between the (n,p) and (n,α) excitation functions on ^{32}S covering some part of the same excitation region.[22]

The observed widths indicate that the doorway states responsible for this structure could not be explained in terms of simple configurations like "α particle" states (expected width: ~400 keV) or "three quasiparticle states" (expected width: ~300 keV[21]). Shakin[23] and Lande and Block[24] have estimated the spacing for three quasiparticle doorway states as about 330 keV at such an excitation in medium heavy nuclides. The slightly smaller spacing (~200 keV) and the smaller widths observed in the present case indicate the possibility of a more complicated parentage for the observed intermediate structure.

VI. CONCLUSIONS

The reaction cross section for the $^{29}Si(\alpha,n)^{32}S$ reaction has been measured in the bombarding energy range from 2.15 to 5.25 MeV with an accuracy of ±17%. Out of the 134 identifiable observed resonances, the total width Γ for 103 have been determined.[25] These represent levels in the compound nucleus ^{33}S at excitation energies ranging from 9.0 to 11.75 MeV. The partial widths Γ_α and Γ_n and corresponding reduced widths $\gamma_\alpha{}^2$ and $\gamma_n{}^2$ have been calculated for 19 resonances, the spins of which are known. In all these analyses it is assumed that $\Gamma_n > \Gamma_\alpha$, but it is possible that it is not so for some cases. This can be ascertained only if the $^{29}Si(\alpha,\alpha)^{29}Si$ cross sections are also known for these resonances. The use of reciprocity theorem has resulted in determining the (n,α) cross section on ^{32}S up to equivalent neutron bombarding energy of 2.4 MeV.[26] These cross sections can be of value in reactor calculations and for astrophysical work.

Total neutron cross sections on ^{32}S between 0.5 and 30 MeV have been measured by S. Cierjacks *et al.*[26] with very high resolution (less than 1 keV). Their data indicate presence of a large number of resonances. However, comparison between these and the resonances seen in the present work is not possible as the measured total cross sections are greater than 1.5 b while the (n,α) cross section, calculated from the measured (α,n) cross sections, are of the order of mb. Thus resonances observed in the total cross section work are far too strong to make any meaningful comparison with the (n,α) resonances of the present work which are 100 times weaker. Only a few of the resonances observed in the (n,α) excitation function in the present work can be approximately correlated with some structure exhibited in the total cross sections at the corresponding neutron energies. However, general lack of correlation between the two can be explained by the fact that the α particle width would be negligible for most of the resonances compared to the neutron widths (because of the penetrabilities involved), and while the (n,α) reaction selects out the levels having measurable α widths, the total cross section is completely dominated by the levels having large neutron widths.

The only other reaction channels open in this region are elastic scattering and the γ decay. Most recent work on the (n,γ) cross section measurement by Halperin, Macklin, and Winters[27] at Oak Ridge National Laboratory up to 1100 keV neutron bombarding energy indicate a large number of sharp resonances rising to a peak cross section of 30 mb above 250 keV neutron energy. Thus in this region the major contribution to the total cross section is from the compound elastic scattering as both the α particle and the γ exit channel cross sections add up to less than 100 mb. One-to-one identification can be made for resonances numbered 4, 5, 6, and 7 of Fig. 2 of the present work with four relatively strong resonances seen in the work of Ref. 27 between neutron energies of 825 and 925 keV. Resonance 10 of Fig. 3, which is the first one in Table I, appears as a weak resonance at neutron energy of about 1040 keV in Ref. 27. Again the absence of more correlation can be understood in terms of differing γ and α particle widths of the corresponding levels.

Two interesting facts emerge from an analysis of excitation function:

(i) The presence of strong narrow resonances almost throughout the excitation function. The average width to average separation ratio is sufficiently small to make an individual resonance analysis meaningful. However, the extracted partial and reduced widths for 19 resonances do not indicate very strong α or neutron structure for the corresponding compound nuclear levels, as the ratio to corresponding Wigner limits is not large for any resonance.

(ii) The observance of relatively higher cross section below 3 MeV bombarding energy when compared with extrapolation downward from the observed cross section at higher energies. This is evident from the high value of the α strength function $\bar{S}_\alpha$ below 3 MeV. This may be an indication of probable α clustering in the compound nucleus ^{33}S or the presence of a doorway state at the excitation energy just above 9 MeV.

There is some indication of presence of intermediate structure especially up to 4.20 MeV bombarding energy. The regularity and uniformity of the observed structure points towards a possible interpretation as doorway states.

ACKNOWLEDGMENT

We are thankful to Dr. P. K. Iyengar for his interest in this work. The authors also thank Mr. C. V. Fernandes, Mrs. L. V. NamJoshi, and Mr. K. K. Sekharan for their help in the data taking and the Van de Graaff crew for the operation of the machine during the course of these experiments.

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