Levels of $^{33}\text{S}$ Excited by $\alpha$-Capture Reactions\textsuperscript{*}

O.B. Okon\textsuperscript{**,} H. Bakhru, P. Sen\textsuperscript{***}, and N. Cue

Physics Department, State University of New York at Albany, New York, USA

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Highly excited levels of $^{33}\text{S}$ populated by $\alpha$-particle capture in $^{29}\text{Si}$ have been investigated for $E_\alpha=1.962$ MeV to 4.287 MeV. Excitation curves measured with Ge(Li) and BF$_3$ detectors are reported. More than fifty resonances can be identified with levels in $^{33}\text{S}$. ($\alpha$, $\gamma$) angular distributions measured on five strong resonances have yielded $J^\pi$ values $1/2^+$, $3/2^+$, $5/2^-$, $5/2^-$, and $3/2^+$ respectively, for the $E_\gamma=10.054$, 10.466, 10.523, 10.721, 10.758 and 10.776 MeV levels in $^{33}\text{S}$. Elastic scattering experiments have been performed and the $J^\pi$ assignments are found to be consistent with the $l$-values inferred from the elastic scattering data. Decay schemes from the above $^{33}\text{S}$ levels have been proposed. A new level at 9.245 MeV is also suggested and the $J^\pi$ values for the 4.425 and 2.87 MeV states are shown to be consistent with $7/2^+$ and $3/2^+$ assignment, respectively.

1. Introduction

Previous work \cite{1} on radiative $\alpha$-capture on low-medium weight nuclei have concentrated mainly on cases where neutron decay competitions are energetically forbidden. The main reason is that the NaI crystal, usually used in the $\gamma$-ray detection, can be disabled under neutron activation. With the availability of large volume Ge(Li) detectors, the aversion to cases with accompanying neutron producing reactions is no longer essential and we report here the study of $^{33}\text{S}$ excited states via $\alpha$-particle bombardment of $^{29}\text{Si}$. Many highly excited states of $^{33}\text{S}$ in the range of excitation energy around 10 MeV have been reported by McMurray et al. \cite{2} but with little information on their decay properties. In the present work, resonances belonging to the reactions $^{29}\text{Si}(\alpha, \gamma)^{33}\text{S}$ and $^{29}\text{Si}(\alpha, n)^{32}\text{S}$ have been differentiated by comparing the excitation function curves taken simultaneously with a 40 c.c. Ge(Li) detector and a BF$_3$ neutron counter. Spin and parity assignments have also been made on five of the strong resonances and on the intermediate levels populated in the $\gamma$-cascade deexcitations. The $J^\pi$ of these resonances are seen to be consistent with the $l$-values deduced from the present elastic scattering measurements. In addition, cascade de-excitation via the 4.425 and 2.87 MeV levels have enabled the $J^\pi$ values for these levels, originally uncertain, to be determined as $7/2^+$ and $3/2^+$ respectively.

2. Experimental Methods

Mono-energetic beams of singly ionized helium accelerated by the SUNY/Albany's 4-MV Dynamitron ac-
c electrometer was deflected and momentum analyzed by a magnet and focussed onto thin SiO₂ targets. A cryogenic refrigerator, located about 2 feet from the target on the beam entrance side, provided a satisfactory cold trap for carbon and other contaminants which might otherwise deposit on the target. For accurate determination of the beam energy the analyzing magnet was calibrated using the standard resonance at $E_\alpha = 2.000 \pm 0.001$ MeV for the reaction $^{24}\text{Mg}(\alpha, \gamma)^{28}\text{Si}$ [3]. The excitation energies of $^{33}\text{S}$ quoted in Figure 1 were based on the Q-value of 7.114 ± 0.005 MeV [5] for the reaction $^{29}\text{Si}(\alpha, \gamma)^{33}\text{S}$. The $^{29}\text{Si}$ targets consisted of SiO₂ enriched to better than 99.7% in $^{29}\text{Si}$. In the capture reaction work where intense α-particle beam (~15 μA) was used, the SiO₂ was evaporated on a copper disc with the uncoated side directly cooled by circulating water. Typical target thicknesses were 14 µg/cm² and 30 µg/cm² for the excitation function and angular distribution measurements, respectively. In the elastic scattering experiment the target consisted of a 14 µg/cm² layer of SiO₂ enriched in $^{29}\text{Si}$ deposited on a 20 µg/cm² carbon foil. Both the γ-ray and neutron yields were measured simultaneously in order to eliminate any ambiguities in differentiating the resonances in the two reaction channels. The 40 c.c. Ge(Li) detector and the BF₃ neutron counter were placed at 0° and 90° relative to the incident beam, respectively. For each incident energy, the γ-ray spectrum was also recorded via the on-line PDP 15/20 computer interfaced with a 4096-channel analog-to-digital converter. The energy calibration for the γ-ray detector was based on standard sources of $^{60}\text{Co}$, $^{56}\text{Co}$, $^{127}\text{Cs}$, $^{133}\text{Ba}$, $^{54}\text{Mn}$ and $^{57}\text{Co}$.

The BF₃ counter was calibrated by a Ra – Be source. A typical γ-ray spectrum is shown in Figure 1. In the measurement of γ-ray angular distributions at selected resonances, the Ge(Li) detector angle was varied and a stationary 13 cm x 13 cm NaI detector was used as a monitor for normalization purpose. The elastic scattering experiment was performed on a separate beam line using the ORTEC 17” scattering chamber and four Si-surface barrier detectors.

3. Results and Analysis

3.1. Excitation Functions

The yields of γ-rays having energy greater than ~7 MeV and neutrons (with energies above the detector noise level) following alpha capture in $^{29}\text{Si}$ are displayed in Figure 2 as a function of α-particle energy. Resonance structure becomes prominent only at the higher incident energies due primarily to the increasing penetrability in the entrance channel. Note that the maximum α-particle energy is still below the Coulomb barrier of ~6 MeV. The resonances in the two reaction channels do not in general correlate. For example, the strong γ-ray resonances at incident energies of 3.343, 3.788 and 4.162 MeV are not observed in the neutron channel while the reverse is true at 3.310, 3.489, 3.863 and 4.008 MeV. This fact is in accord with the earlier observations [1] that radiative α-capture, in general, proceed through high-spin states where particle decays are inhibited by the low penetrability through the large angular momentum barrier. However, as discussed