Such a ground-to-ground β transition of ^{68}Cu to ^{68}Zn would imply that the most probable spin of 30-sec ^{68g}Cu is 1. Bakhru and Mukherjee[3] tenuously assigned a spin of 2 to 30-sec ^{68g}Cu since they did not observe a 4.6-MeV ground-to-ground β-ray transition.

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Mean Lifetimes and Branching Ratios of Low-Lying Levels in ^{33}S †

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The mean lifetimes of the levels of ^{33}S below 3.3-MeV excitation energy have been measured by the Doppler shift attenuation method. The $^{30}Si(\alpha, n)^{33}S$ reaction was used to populate these states. SiO_2 targets (enriched to 95% in ^{30}Si) evaporated onto Ni backings were bombarded with α-particles ranging in energy 5.5–9.0 MeV. γ-ray spectra were recorded with a 20-cc Ge(Li) detector at 0°, 90°, and 510° to the beam. The following mean lifetimes were found: τ(0.842-MeV level) $=1.66\pm0.34$ psec, $\tau(1.968)=182\pm22$ fsec, $\tau(2.313)=183\pm25$ fsec, $\tau(2.869)<15$ fsec, $\tau(2.937)>4$ psec, $\tau(2.970)=82\pm12$ fsec, $\tau(3.221)<65$ fsec. The branching ratios of the 2.970-MeV level were determined to be $(90\pm5)\%$ to the ground state and $(10\pm5)\%$ to the second excited state.

I. INTRODUCTION

THE low-lying levels of ^{33}S have been the subject of a number of investigations; the available information up to 1967 is summarized by Endt and Van der Leun.[1] The energy levels have been located primarily by the $^{32}S(d, p\gamma)^{33}S$ and $^{32}S(n, \gamma)^{33}S$ reactions.[2–4] However, relatively little is known about the absolute strengths of the γ-ray transitions. Recently, certain collective aspects of ^{33}S have been studied via the $^{31}P(^3He, p)^{33}S$ reaction,[5] and Dubois[6] has used the $^{34}S(^3He, \alpha)^{33}S$ reaction to study the lowest $T=\frac{3}{2}$ states as well as some of the low-lying $T=\frac{1}{2}$ states.

Theoretical calculations have been carried out by Bishop,[7] Glaudemans *et al.*,[8] and Glaudemans, Wildenthal, and McGrory.[9] The calculations for the $(2s_{1/2}, 1d_{3/2})$ shell performed by Glaudemans, Wildenthal, and McGrory[9] using a surface δ interaction give good agreement with experiment. Wiechers and Brussaard[10] have calculated the $M1$-transition probability for the $0.842\rightarrow0$ transition in ^{33}S using the wave functions of Glaudemans *et al.*[8]

The present paper[11] describes a study of the low-lying levels of ^{33}S up to an excitation energy of 3.3 MeV. The mean lifetimes of the first seven excited states of ^{33}S were measured using the Doppler-shift attenuation method (DSAM). States of interest were populated by the $^{30}Si(\alpha, n)^{33}S$ reaction. The γ-ray decay modes of the 2.97-MeV state were determined, and limits on the branching of other states were obtained.

II. PROCEDURE

A. General

The Triangle Universities Nuclear Laboratory FN tandem Van de Graaff accelerator was used to accelerate

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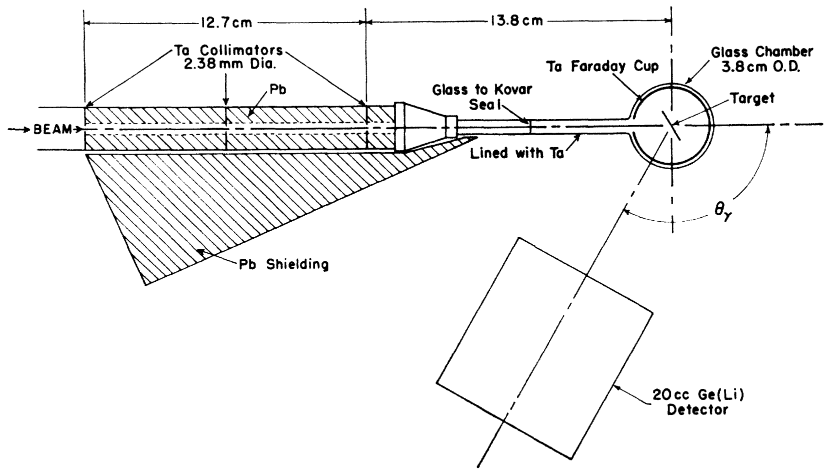

FIG. 1. Schematic drawing of the scattering chamber showing the beam path to the target, the collimating system, and the lead used to shield the 20-cc Ge(Li) detector.

α particles to energies ranging from 5.5–9.0 MeV. In Fig. 1a schematic drawing of the experimental setup is shown. A series of three Ta collimators served to define the beam. Each collimator was followed by a coaxial lead tube for shielding purposes. The stainless-steel beam pipe immediately before the collimators was lined with Ta sheet.

The target chamber (a glass cylinder approximately 13.5 cm high$\times$3.8 cm diam) was connected to the beam pipe by a Ta-lined glass tube. The chamber was also lined with Ta which served as a Faraday cup. A vacuum of 5×10^{-7} Torr was maintained in the target chamber by a Vac-Ion pump connected to the top of the chamber.

The γ rays were detected with a 20-cc Ge(Li) detector placed ~8 cm from the target. The resolution of the detector was ~4.5 keV [full width half-maximum (FWHM)] for 1.33-MeV γ rays. Spectra were recorded with a 2048-channel analog-to-digital converter in conjuction with a DDP-224 on-line computer. After a spectrum was recorded at each angle it was stored on magnetic tape for later analysis.

B. Experimental Procedure

Targets were prepared by evaporating SiO_2 (enriched to 95% in ^{30}Si) from a Ta boat onto 1.5-μ Ni foils. The thickness of the SiO_2 targets ranged 15–150 μg/cm^2. The target thickness was estimated by noting the thin film interference pattern formed on a glass slide during evaporation. Another estimate of the target thickness was obtained by measuring the energy lost by α particles in the SiO_2 target. This value was converted into a target thickness by use of the energy-loss data of Whaling.[12] (The energy loss was determined by measuring the energy difference between α particles which had been elastically scattered at 135° from the Ni foil and those which had been scattered from the Ni foil after passing through the target.) The results of the two methods of measurement agree to within 10%.

The particular form of the DSAM used follows closely that described by Warburton, Olness, and Poletti.[13] The heavy-ion recoils were produced by using the endothermic reaction ^{30}Si$(\alpha, n)^{33}$S with a Q value of -3.504 MeV. These recoils were confined to a narrow cone about the beam axis by using an α-particle energy slightly above the threshold energy. Beam energies 0.5–1.0 MeV above threshold produced half-angles of the heavy-ion recoils of the order of 10°. The velocities of the ^{33}S recoils, v/v_0, ranged from 0.88–1.11, where $v_0=c/137$.

For most of the transitions studied, data were acquired at several different bombarding energies and with several different target thicknesses. The γ rays were detected at 0°, 90°, and 150° to the beam axis in order to obtain several values of the experimental Doppler shift ΔE_γ and thus several values of $F(\tau)$ for each experimental condition. (Data were accumulated at each angle for several hours at a time, and then the runs at each angle were combined.) The energy calibration of the detector was based on the γ rays from ^{56}Co.

In most of the spectra small baseline or gain shifts were noted. These shifts were monitored by recording γ rays of known energy from radioactive sources at the same time as γ rays from the reaction. In most cases, the energy of the "source" γ ray was chosen to be very close to the energy of the "reaction" γ rays; thus, any observed shifts could be corrected by treating them as baseline shifts. The source γ rays were chosen to be lower in energy than the reaction γ rays in order to minimize background contributions to the γ rays of interest. The primary sources used were ^{137}Cs, ^{60}Co, and ^{88}Y. The 2.937-MeV γ ray from the fifth excited state of ^{33}S, which was determined to be a long-lived state in many preliminary runs, was also used to monitor the stability of the system.

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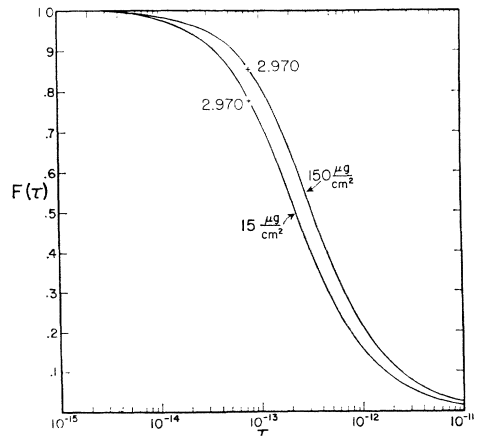

FIG. 2. Theoretical curves of $F(\tau)$ versus τ in seconds for two different target thicknesses. The upper curve is for a 150-$\mu g/cm^2$ SiO_2 target evaporated onto a Ni backing, and the lower curve is for a 15-$\mu g/cm^2$ SiO_2 target on a Ni backing. The two experimental values of $F(\tau)$ for the 2.97-MeV state are shown, and the lifetimes are seen to agree rather well. α_B and α_T are the characteristic slowing down times for ^{33}S ions in Ni and SiO_2, respectively.

In order to determine the branching ratios, spectra were recorded with the detector at 60° using a bombarding energy of 8.75 MeV and a target thickness of 150 $\mu g/cm^2$. The efficiency of the Ge(Li) detector was determined by using the known energies and intensities[14] of the γ rays from a ^{56}Co source placed ~8 cm from the detector.

C. DSAM

The DSAM has become a widely used method of measuring lifetimes of nuclear levels. The details of the method outlined here follow closely those given by Warburton, Olness, and Poletti.[13] The experimental Doppler-shift attenuation factor $F_{exp}(\tau)$ is given by

$$F_{exp}(\tau)=\Delta E_\gamma/E_{\gamma 0}\beta(0)(\cos\theta_1-\cos\theta_2), \qquad (1)$$

where ΔE_γ is the experimentally observed shift between the two detector angles θ_1 and θ_2, $E_{\gamma 0}$ is the unshifted γ-ray energy, and $\beta(0)=v(0)/c$, where $v(0)=v_z(0)$ is the initial recoil velocity of the excited nucleus. The initial recoil velocity of ^{33}S along the beam direction $v_z(0)$ can be calculated from the center-of-mass velocity $v_{c.m.}$. Since the outgoing neutrons in the $^{30}Si(\alpha,n)^{33}S$ reaction have some ditribution in the c.m. system, the value of $v_z(0)$ has some upper and lower limit. These limits can be computed from

$$\langle v_z(0)\rangle=v_{c.m.}[1+\gamma^{-1}\langle\cos\theta_{c.m.}\rangle], \qquad (2)$$

where $\theta_{c.m.}$ is the c.m. angle of the outgoing ^{33}S nucleus, and γ^{-1} is the ratio of the speed of the outgoing ^{33}S nucleus in the c.m. to the speed of the c.m. in the laboratory system. Following Warburton *et al.*,[13] $\langle\cos\theta_{c.m.}\rangle$ was set equal to 0 ± 0.33. Thus, Eq. (2) becomes

$$\langle v_z(0)\rangle\simeq v_{c.m.}(1\pm0.33\gamma^{-1}). \qquad (3)$$

For an ensemble of N nuclei with lifetime τ recoiling into a backing there are a certain number dN which decay in time dt, i.e.,

$$dN/dt=-N/t. \qquad (4)$$

If the velocity as a function of time is known, then this expression can be converted to an expression for $dN(V)/dV$, where $V\equiv v_z(t)/v(0)$. The general theory for the stopping of heavy ions in different backings has been given by Lindhard, Scharff, and Schiøtt (LSS).[15] Their expression for the energy loss can be approximated[13] by

$$-M_1(dv_z/dt)=K_e(v_z/v_0)+K_n(v_z/v_0)^{-1}, \qquad (5)$$

where M_1 is the mass of the recoiling nucleus and K_e and K_n are constants determined from the LSS value and experimental data. Using Eq. (5) the expression for $dN(V)/dV$ becomes

$$dN(V)/dV=[N_0/(\gamma_i^{-2}+1)^{x/2}$$
$$\times[xV(\gamma_i^{-2}+V^2)^{x/2-1}+\gamma_i^{-x}\delta(V)], \qquad (6)$$

where $x=\alpha/\tau$, $\alpha=M_1v_0/K_e\rho,\gamma_i^2=(K_e/K_n)[v(0)/v_0]^2$, and ρ is the density of the backing.

TABLE I. γ-ray branching ratios for the low-lying levels of ^{33}S.

Level	E_i (MeV)	E_f (MeV)	Branching ratios Ref. 1	Present
2	1.968	0	100	100
		0.842	<0.5	<1.5
3	2.313	0	35	34±5
		0.842	65	66±5
		1.968	<3	<6
4	2.869	0	100	100
		0.842	<3	<3
		1.968	<3	<3
		2.313	···	<4
5	2.937	0	50	···
		0.842	<2	<2
		1.968	50	···
		2.313	···	<2
6	2.970	0	···	90±5
		0.842	···	<3
		1.968	···	10±5
		2.313	···	<2
7	3.221	0	40	38±5
		0.842	60	62±5
		1.968	···	<2
		2.313	···	<5
		2.869	···	<7
		2.937	···	<2
		2.970	···	<2

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TABLE II. Mean lifetimes of the levels of ^{33}S.

Level number	E_x (MeV)	E_α (MeV)	Target thickness (μg/cm^2)	$F(\tau)$[a]	Mean lifetime[a] (fsec)	⟨Mean lifetime⟩[b] (fsec)
1	0.842	5.60	15	0.095±0.013	$1.60_{-0.21}^{+0.29}$psec	1.66±0.34 psec
			150	0.111±0.031	$2.07_{-0.47}^{+0.88}$psec	
2	1.968	7.20	150	0.671±0.012	182±8	182±22
3	2.313	7.20	150	0.651±0.028	196±18	
		8.08	15	0.566±0.046	180±28	183±25
		8.08	150	0.700±0.037	164±22	
4	2.869	8.08	15	1.019±0.019	<10	
		8.08	150	0.999±0.013	<10	<15
		8.75	150	1.004±0.022	<14	
5	2.937	8.08	150	0.00±0.038	>4.7 psec	>4 psec
6	2.970	8.08	15	0.778±0.018	80±7	
		8.08	150	0.858±0.007	79±4	82±12
		8.75	150	0.831±0.023	91±7	
7	3.221	8.75	150	0.944±0.050	<60	<65

[a] Statistical errors.

[b] Total errors calculated as explained in the text.

The quantity $F(\tau)$, in terms of $dN(V)/dV$, is given by

$$F(\tau)=\int_0^1 V\frac{dN(V)}{dV}dV \Big/ \int_0^1\frac{dN(V)}{dV}dV. \quad (7)$$

Using Eqs. (6) and (7) gives

$$F(\tau)=\frac{x\gamma_i^x}{(1+\gamma_i^2)^{x/2}}\int_0^1 V^2(\gamma_i^{-2}+V^2)^{x/2-1}dV. \quad (8)$$

If the recoiling ions are stopping in two different media and v_c is the velocity at which the ions cross from one media to the other, then

$$F(\tau)=\frac{1}{A_1^{x_1/2}}\left[\frac{x_2C_1^{x_1/2}}{C_2^{x_2/2}}\int_0^{V_c}V^2B_2^{x_2/2-1}dV + x_2\int_{V_c}^1 V^2B_1^{x_1/2-1}dV\right], \quad (9)$$

where $V_c=v_c/v_c(0)$, $A_j=(1+\gamma_{ij}^{-2})$, $B_j=(V^2+\gamma_{ij}^{-2})$, and $C_j=(V_c^2+\gamma_{ij}^{-2})$. The subscript 1 refers to the target and 2 refers to the backing.

Since an ensemble of nuclei recoiling into a backing have a certain velocity distribution, the emitted γ rays have a certain energy distribution, and this gives rise to a particular line shape for the detected γ rays. The theoretical line shape can be determined by folding the response function of the γ-ray detector into the distribution given by Eq. (6). If the response function of the detector is Gaussian, then the theoretical distribution is given by

$$(dN/dV)_{\text{th}}=C_n\int_0^1[dN(U)/dU]\times\exp[-(U-V)^2/\sigma^2]dU, \quad (10)$$

where the normalization C_n and σ are determined from the experimental distribution. The theoretical distribution given in Eq. (10) is fitted to the experimental distribution by normalizing the two distributions at the unshifted energy $E_{\gamma 0}$ and then varying x and γ_i^2 in discrete steps. The best fit is determined from the minimum value of χ^2.

D. Analysis

The centroids of the peaks of interest in each spectrum were determined by a computer program which calculated the first moment and its statistical uncertainty after subtracting background. The background was approximated by least-squares fitting an exponential to the portions of the spectrum near the peaks. The Doppler shifts were then computed and corrected for any baseline shifts by observing the shifts of the "source" γ rays. The experimental Doppler shift attenuation factor $F_{\exp}(\tau)$ was then computed from Eq. (1).

In order to extract the lifetime from the experimental value of $F_{\exp}(\tau)$, Eq. (8) was used to evaluate $F(\tau)$ as a function of the lifetime. The value of K_e, the electronic stopping parameter, was obtained for ^{33}S ions recoiling in Ni by increasing the LSS value of $(-dE/dx)_{\text{electronic}}$ at $v_z=v_0$ by 15%. Evidence presented by several investigators[16–19] indicates that for $Z=16$ ions in any backing the value of K_e is ~15% larger than the LSS value. The value of K_n, the nuclear-stopping parameter, was obtained directly from the LSS theory by using the value of $(-dE/dx)_{\text{nuclear}}$ at $v_z=v_0$.

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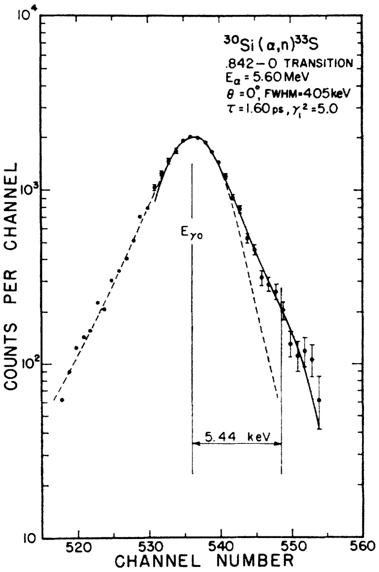

FIG. 3. 0.842-MeV γ ray from the ^{33}S 0.842→0 transition observed at 0°. The state was populated by bombarding a 15-μg/cm^2 SiO_2 target evaporated onto a Ni backing with 5.60-MeV α particles. The spectrum has a dispersion of 0.435 keV/channel. Background has been subtracted. The solid curve is a theoretical fit to the line shape and was obtained as explained in the text. The dashed curve is the line shape observed with the detector at 90°. The parameters of the theoretical fit are given in the figure.

The target thickness was taken into account explicitly in calculating the theoretical value of $F(\tau)$. The target was divided into 10 layers, and $F_i(\tau)$ was calculated for each layer i by using Eqs. (8) and (9). The velocity of the ion as it crossed into the backing V_c was calculated for each layer of the target using an expression for the distance along the beam direction as a function of V. The cross section for the reaction was assumed to be uniform throughout the target, and the average value of $F(\tau)$ was calculated from the 10 values of $F_i(\tau)$ for values of τ ranging 10^{-15}–10^{-11} sec. Figure 2 shows $F(\tau)$ plotted against τ for two different target thicknesses. The experimental values of $F(\tau)$ for the 2.970-MeV state are shown for two target thicknesses, and the lifetimes are seen to agree rather well. The characteristic slowing down times for ^{33}S ions in Ni and SiO_2 (α_B and α_T) are also indicated.

Most of the γ rays studied in this work exhibited line shapes as well as shifts. Information on the stopping parameters of the backing as well as the lifetime can be extracted from a line-shape analysis. However, for all but one of the γ rays the shoulder caused by the Doppler shift is on the low-energy side of the peak. This introduces difficulties in folding in the detector response function since the Ge(Li) detector exhibited a pronounced low-energy tail. The response function is not Gaussian, and the line shape is degraded by the tailing. The 0.842-MeV γ ray had a shoulder on the high-energy side, and a line-shape analysis was carried out.

In calculating the statistical error in $F(\tau)$ and τ the statistical uncertainty in the position of each centroid was doubled, and this uncertainty was then used in determining a statistical error in $F(\tau)$ and τ. The total error was then calculated by assuming the following errors in addition to the statistical errors: a 15% error in the electronic stopping parameter (K_e) of the target and the backing, a 20% error in the nuclear stopping parameter (K_n) of the target and the backing, a 10% error in the target thickness, and a variation in the initial recoil velocity of ~5% determined from Eq. (3). These assumptions provide error estimates that are rather conservative.

III. RESULTS

A. Branching Ratios

Branching ratios were determined by using the spectra recorded with the detector at 60° since this is the nearest angle measured to 55°, the zero of $P_2(\cos\theta)$. A limit on the branching of a given state was obtained by summing the region of the spectrum at which the γ ray was expected. This sum plus two standard deviations was used to set a limit on the branch. The branching ratios of the first seven excited states of ^{33}S are given in Table I. The 0.969-MeV γ ray resulting from the transition 2.937→1.968 was broadened by a contaminant γ ray, and the branching of the 2.937-MeV state could not be determined. Assuming that the branching is 50% to the ground state and 50% to the second excited state,[1] a limit of <2% is obtained for the 2.937→2.313 transition. The information obtained on the branching of the 2.970-MeV state is new. The branching ratios for the 3.221- and 2.313-MeV states are in good agreement with the previous work, and limits on all possible branches of the 3.221-MeV state have been obtained.

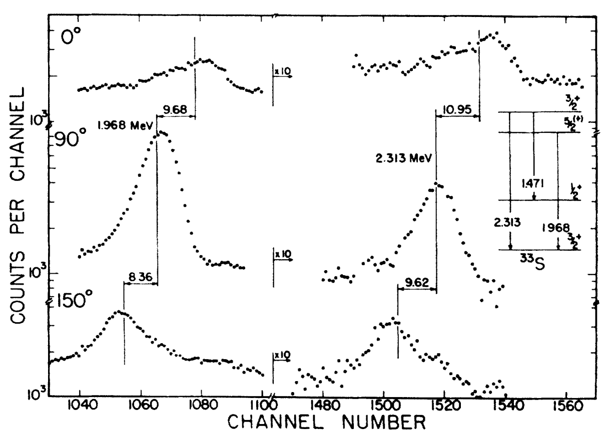

FIG. 4. Full-energy loss peaks of the 1.968- and the 2.313-MeV γ rays corresponding to the 1.968→0 and 2.313→0 transitions, respectively. The levels were populated by bombarding a 150-μg/cm^2 SiO_2 target evaporated onto a Ni backing with 7.20-MeV α particles. Spectra were recorded with the detector at 0°, 90°, and 150°. The experimental shifts in keV are shown. These spectra have a dispersion of 0.768 keV/channel.

TABLE III. Electromagnetic transition strengths in ^{33}S.

E_x (MeV)	E_γ (MeV)	J_i^π	J_f^π	δ Reference 2	δ Reference 3	δ	Multipole	$\lvert M \rvert^2$ (Weisskopf units)
0.842	0.842	$\frac{1}{2}+$	$\frac{3}{2}+$			± 0.18[a]	$M1$	3.1×10^{-2}
							$E2$	6.0
1.968	1.968	$\frac{5}{2}+$	$\frac{3}{2}+$	$0.38<\delta<1.04$	0.79 ± 0.26	0.79	$M1$	1.4×10^{-2}
							$E2$	9.3
2.313	2.313	$\frac{3}{2}+$	$\frac{3}{2}+$			0[b]	$M1$	4.9×10^{-3}
						∞[b]	$E2$	3.7
2.313	1.471	$\frac{3}{2}+$	$\frac{1}{2}+$	$0.13<\delta<1.33$		0.47[c]	$M1$	2.9×10^{-2}
				$-8.1<\delta<-0.73$			$E2$	11.9
2.937	2.937	$\frac{7}{2}-$	$\frac{3}{2}+$	0.09 ± 0.27	0.48 ± 0.09	0[b]	$M2$	$10^{-3}\lvert M\rvert^2<(2.5)$[d]
				$2.1<\delta<\infty$	1.64 ± 0.45	∞[b]	$E3$	$0.7<\lvert M\rvert^2<(2\times 10^3)$[d]
2.937	0.969	$\frac{7}{2}-$	$\frac{5}{2}+$	0.0 ± 0.01	0.08 ± 0.09	0[b]	$E1$	$5\times 10^{-8}<\lvert M\rvert^2<(10^{-4})$[d]
3.221	3.221	$\frac{3}{2}-$	$\frac{3}{2}+$			0[b]	$E1$	$>1.7\times 10^{-4}$
3.221	2.379	$\frac{3}{2}-$	$\frac{1}{2}+$			0[b]	$E1$	$>6.5\times 10^{-4}$

[a] Calculated from τ and $B(E2\uparrow)$.
[b] Assumed.
[c] Assumed near midpoint of the range of arctanδ.
[d] Upper limit on τ of 10^{-8} sec from Ref. 2.

B. Lifetimes

Table II is a summary of the measured values $F(\tau)$ and τ. Columns 1–4 list the level number, the excitation energy, the bombarding energy, and the target thickness. Columns 5 and 6 list the weighted averages of $F(\tau)$ and τ based on shifts between different combinations of angles for each experimental condition. Column 7 gives the weighted averages of the lifetimes given in column 6. In columns 5 and 6 the errors are statistical, but in column 7 the total error is given. In setting limits on lifetimes the values of $F(\tau)$ used were obtained by adding or subtracting the total error on $F(\tau)$ to the value of $F(\tau)$ shown in Table II.

0.842-MeV Level

As mentioned previously the 0.842-MeV γ ray shown in Fig. 3 was the only one on which a line-shape analysis was carried out. The solid curve is the best fit to the 0° data minus the background using the method described in Sec. II C. Because of the low-energy tail, the theoretical distribution was fitted only to the points from $E_{\gamma 0}-0.5$ (FWHM) to the last data point shown. The dashed line shown in Fig. 3 is the line shape observed with the detector at 90°. The maximum shift in this case was only 5.44 keV, and the shoulder is so small that this shape was used only to check the previous values of the stopping parameters. The minimum value of χ^2 was obtained with the stopping parameters of Sec. II D; the lifetime of 1.60 psec is consistent with the value of 1.66 ± 0.34 psec obtained from the shift measurement.

1.968- and 2.313-MeV Levels

Sample spectra obtained in the investigation of these two levels are shown in Fig. 4. These spectra were obtained with the detector at 0°, 90°, and 150° with a beam energy of 7.20 MeV and a target thickness of 150 μg/cm^2. The γ rays are the ground-state branches of these two levels. Neither of the γ rays are shifted by the maximum amount, as can be seen by comparing the observed shift shown in the figure to the maximum shift [which is just the denominator of Eq. (1)]. Both of the states have a value of $F(\tau)\approx 0.66$, which implies nearly equal lifetimes. The lifetime of the 1.968-MeV level is 182 ± 22 fsec, while the lifetime of the 2.313-MeV level is 183 ± 25 fsec.

Triplet at 2.9 MeV

Sample spectra of the ground state branches of the triplet at approximately 2.9 MeV are shown in Fig. 5. These spectra were recorded under the same conditions as those of Fig. 4, except for an increase of the beam energy to 8.08 MeV. The lifetimes of the 2.869- and the 2.970-MeV levels were determined to be less than 15 and 82 ± 12 fsec, respectively. As mentioned previously the 2.937-MeV state is long lived and the ground-state branch of this level was used to correct the spectra in Fig. 5 for baseline shifts. In setting a lower limit of 4 psec on the lifetime of the 2.937-MeV level an error of 1.0 channel was assumed for the error in the experimental Doppler shift. This corresponds to a $F(\tau)$ of 0.0 ± 0.04.

3.221-MeV Level

This level was populated by bombarding the target with 8.75-MeV α particles. Only the thick target (150 μg/cm^2) yield was high enough for a lifetime analysis. The value of $F(\tau)$ is sufficiently close to one that only an upper limit of 65 fsec can be set on the lifetime. The value of $F(\tau)$ quoted in Table II (0.944) corresponds to a lifetime of 34 fsec.

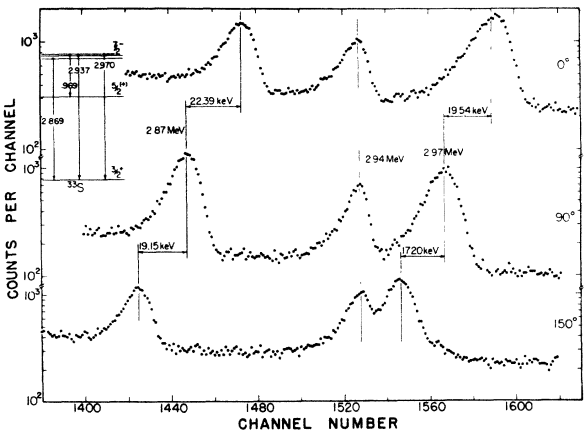

FIG. 5. Full-energy loss peaks of the ground-state branches of the triplet at approximately 2.9 MeV. The levels were populated by bombarding a 150-μg/cm^2 SiO_2 barget evaporated onto a Ni backing with 8.08-MeV α particles. Spectra were recorded with the detector at 0°, 90°, and 150°. The experimental shifts in keV are indicated. These spectra have a dispersion of 0.854 keV/channel.

IV. DISCUSSION

The calculated values of the electromagnetic transition strengths in Weisskopf units[20] (W.u.) are given in Table III for the levels of ^{33}S below 3.3 MeV with known spins. The values of the measured mixing ratios[2,3] are given in columns 5 and 6, while the values used to calculated the transition strengths are shown in column 7. The branching ratios used to calculate the transition strengths are those given in Ref. 1. For the decays from the 2.937-MeV level, only pure transitions were assumed since only upper and lower limits of the lifetime are known. The value of the mixing ratio $|\delta| = 0.18$ for the first excited state at 0.842 MeV was obtained from the value of $B(E2\uparrow)$ from Coulomb excitation measurements[21] and from the lifetime determined by this experiment. This yields an $M1$ strength of 3.1×10^{-2} W.u. and an $E2$ strength of 6.0 W.u.

[20] D. H. Wilkinson, in *Nuclear Spectroscopy*, edited by F. Ajenberg-Selove (Academic Press Inc., New York, 1960), Part B, p. 862 ff.

[21] I. Kh. Lemberg, in *Reactions Between Complex Nuclei*, edited by A. Zucker, F. T. Howard, and E. C. Halbert (Wiley-Interscience, Inc., New York, 1960), p. 112.

Wiechers and Brussaard[10] have calculated $M1$-transition probabilities in the ($2s_{1/2}$, $1d_{3/2}$) shell using the wave functions of Glaudemans *et al.*[8] For the 0.842-MeV transition in ^{33}S these authors give values of $\Gamma(M1)$ of 0.023 and 0.013 meV, where the two values are calculated using single-particle and effective nucleon g factors, respectively. The transition strengths are then 1.9×10^{-3}, and 1.0×10^{-3} W.u. and are smaller than the experimental value of 3.1×10^{-2} by approximately a factor of 10. This difference is of the same order of magnitude as that observed for the 1.28-MeV level in ^{29}Si and the 1.26-MeV level in ^{31}P.

The two levels of ^{33}S at 2.869 and 2.970 MeV do not have spin assignments. On the basis of the present lifetime measurements, the spins and parities $\frac{1}{2}^{\pm}$, $\frac{3}{2}^{\pm}$, $\frac{5}{2}^{\pm}$, and $\frac{7}{2}^{+}$ are allowed.

As was pointed out by Becker *et al.*,[2] the decay of the 2.937-MeV level ($J^{\pi}=\frac{7}{2}^{-}$) via $E3/M2$ radiation to the ground state and $E1$ radiation to the 1.968 level is unusual. The lower limit of 4 psec set on the lifetime by this experiment indicates that either the recoil-distance[22] or electronic timing method would be suitable for an accurate lifetime measurement. Knowledge of the transition strengths for this level should provide a sensitive test for theoretical calculations as well as allow one to determine whether a large inhibition of the $E1$ or an enhancement of the $E3/M2$ is resonsible for this unusual competition.

Following a preliminary report of this work,[11] we became aware of a similar study[23] of the levels of ^{33}S.

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[22] K. W. Jones, A. Z. Schwarzschild, E. K. Warburton, and D. B. Fossan, Phys. Rev. **178**, 1773 (1969).

[23] J. E. Cummings and D. J. Donahue (to be published).