in all cases. As no branching difference is seen for the α-particle–induced QFS, it appears that the FSI does not substantially affect the well-separated QFS peaks. The size and separation of the FSI peaks seen in this experiment are similar to those in the proton-induced case. The absence of a branching difference in the α-particle–induced QFS makes less likely the postulate[15] that the tails of FSI peaks contribute markedly to the proton-induced branching difference.

The study of the QFS reactions $D(\alpha, \alpha n)p$ and $D(\alpha, \alpha p)n$ over an incident α-particle energy of 30–80 MeV shows no difference in cross section, thus indicating that spin statistics play a dominant role in the deuteron breakup reactions, and that charge and FSI effects are unimportant when the QFE conditions are satisfied.

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$E1$ Decay of Members of the Low-Lying $K^\pi = \frac{1}{2}^-$ Band in ^{23}Na†

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A state at $E_x = 6.350$ MeV in ^{23}Na is shown to have $J^\pi = \frac{9}{2}^-$ and is assigned to the rotational band based on the $\frac{1}{2}^-$ state at 2.640 MeV. Its γ-ray decay lifetime and branching ratios are determined and combined with known information about the proposed $J = \frac{1}{2}$ to $\frac{7}{2}$ members of this band to show that there is an anomalous $E1$ decay pattern between the members of this band and the members of the ground-state band. This anomalous pattern can be explained using the Nilsson model with band mixing.

It is well known that heavy-ion reactions are particularly favorable for the study of high-spin states.[1,2] Recent studies at McMaster using the reaction $^{12}C(^{12}C, p)^{23}Na$ ($Q = +2.24$ MeV) have shown that known high-spin states in ^{23}Na are preferentially populated. In particular, the $\frac{7}{2}^+$, $\frac{9}{2}^+$, $\frac{11}{2}^+$, and $\frac{13}{2}^+$ members of the ground-state rotational band are strongly excited. In addition, a number of other states, of unknown spin, are also strongly populated in this reaction. One such state is that at $E_x = 6.350$ MeV. This Letter reports angular correlation and lifetime measurements for this state which lead to a $J^\pi = \frac{9}{2}^-$ assignment and to the suggestion that this level is the fifth level belonging to a $K^\pi = \frac{1}{2}^-$ rotational band.

A target consisting of 80 $\mu g/cm^2$ of ^{12}C evaporated onto a thick gold backing was bombarded using a 28.2-MeV ^{12}C beam from the McMaster FN tandem accelerator. Protons were detected using an annular surface-barrier detector centered at 180° with respect to the beam direction and subtending a laboratory angle of 160° to 170°. α particles from the competing reaction $^{12}C(^{12}C, \alpha)^{20}Ne$ ($Q = +4.62$ MeV) were stopped in a Ta foil placed in front of the detector. Coincident γ rays were detected at five angles between 0° and 120° using three large (≈ 40 cm^3) Ge(Li) detectors. Although in most cases the particle resolution obtained (250 keV) was insufficient to completely resolve individual levels, γ rays observed in coincidence could nevertheless be adequately identified. In a proton window corresponding to approximately 6 MeV excitation in ^{23}Na, γ-ray transitions from the 6.350-MeV level to four levels were identified. As indicated in Fig. 1, these include a $\frac{5}{2}^-$ level and levels with $J^\pi = \frac{7}{2}^+$, $\frac{9}{2}^+$, and $\frac{11}{2}^+$.

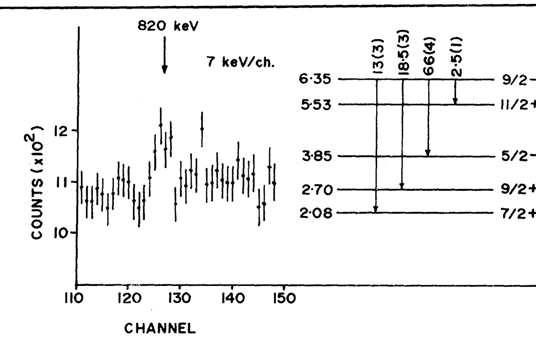

FIG. 1. A section of the coincidence γ-ray spectrum taken at 90° revealing the weak peak corresponding to the 6.350- to 5.534-MeV branch ($E_\gamma \simeq 820$ keV) along with the decay scheme and branching ratios found in the present work.

The Doppler-shift attenuation method was used to determine the lifetime of the 6.350-MeV level. Following the theory of Blaugrund[3] with electronic stopping powers taken from the semiempirical compilation of Northcliffe,[4] an $F(\tau)$ curve was generated for ^{23}Na ions stopping in layers of ^{12}C and ^{197}Au, averaged over the thickness of the target. From the energy shift as a function of angle of the γ ray corresponding to the transition from the 6.350-MeV level to the $\frac{5}{2}^-$ level [Fig. 2(b)], $F(\tau)$ was measured to be 0.945 ± 0.011. This cor-

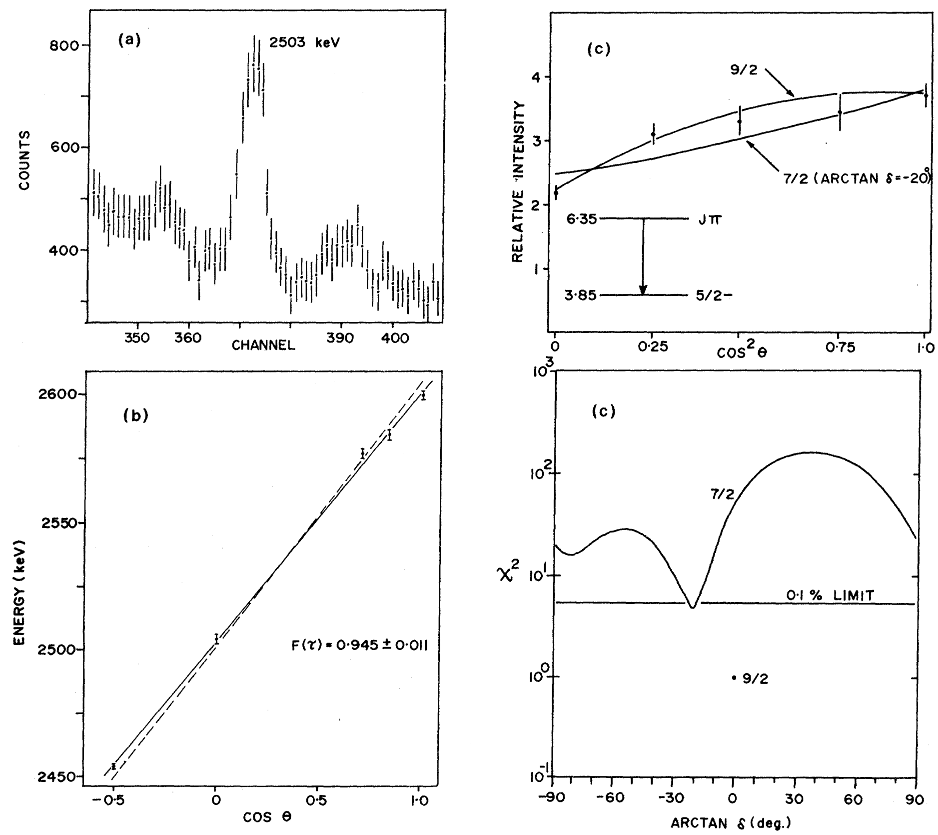

FIG. 2. (a) Part of the coincidence γ-ray spectrum taken at 90° showing the peak corresponding to the 6.350- to 3.851-MeV transition. (b) The energy of the γ ray associated with the 6.350- to 3.851-MeV transition plotted against $\cos\theta$. The full line is a least-squares fit to the experimental points and the broken line shows the expected full shift. (c) Angular distribution and χ^2 fits for the 6.350- to 3.851-MeV transition in ^{23}Na. Both spin assignments of $\frac{7}{2}$ and $\frac{9}{2}$ give acceptable fits but $\frac{7}{2}^+$ and $\frac{9}{2}^+$ can be eliminated on the basis of $M2$ strength considerations.

responds to a lifetime of 30 ± 7 fsec for the 6.350-MeV level, where an uncertainty of 25% in the density of the carbon has been included in the error.

In view of the measured lifetime it can be assumed that transitions from the 6.350-MeV level of multipole order 2 or less only can be present. Thus the decay modes of the 6.350-MeV level limit its spin to $\frac{7}{2}$ or $\frac{9}{2}$. Both of these spins yield acceptable fits to the angular distribution of the γ-ray transition to the $J^\pi = \frac{5}{2}^-$ level [Fig. 2(c)] where the population parameters have been limited to $P(\frac{1}{2}) \leq 1.0$, $P(\frac{3}{2}) \leq 0.4$, and $P(\frac{5}{2}) \leq 0.1$ based on the experimental geometry. It is to be noted that even without any restrictions on the population parameters no acceptable fit could be obtained with $\frac{7}{2}$ for values of the mixing ratio less than $|\delta| = 0.36$. However, assignments of $\frac{7}{2}^\pm$ and $\frac{9}{2}^+$ can be ruled out as follows. An assignment of $\frac{9}{2}^+$ for the 6.350-MeV level can be eliminated since the branch to the $\frac{5}{2}^-$ level would require an $M2$ strength of 1920 W.u. (Weisskopf units). From the fit to the angular distribution for $J = \frac{7}{2}$ the branch to the $\frac{5}{2}^-$ level has a mixing ratio of $\delta = -0.36$. Thus a spin assignment of $\frac{7}{2}^+$ can be eliminated since the $M2$ strength for this branch would need to be 215 W.u. Finally, an assignment of $\frac{7}{2}^-$ can be ruled out since the 2.5% branch to the $\frac{11}{2}^+$ level would require an $M2$ strength of 18 W.u. Thus a spin and parity of $\frac{9}{2}^-$ can be assigned to the 6.350-MeV level in ^{23}Na.

In the Nilsson model the $\frac{1}{2}^-$ state at 2.640 MeV in ^{23}Na is thought to be the lowest member of a $K = \frac{1}{2}$ rotational band formed by raising a proton from the $\frac{1}{2}^-$ [101] orbital to the $\frac{3}{2}^+$ [211] orbital leaving a hole in the lower orbital. Experimental

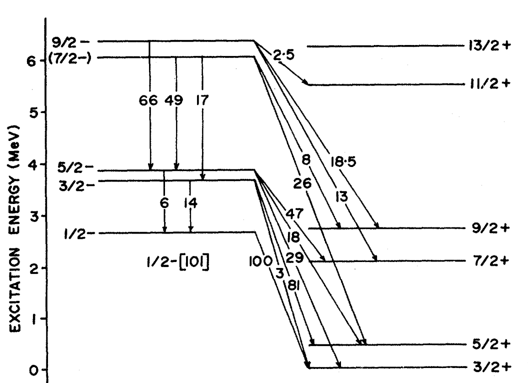

FIG. 3. The decay scheme of the proposed $K^\pi = \frac{1}{2}^-$ band members in ^{23}Na. Branching ratios for the first four levels are taken from Ref. 6; those for the $\frac{9}{2}^-$ level are found in this work.

information[5,6] about the γ-ray decay of the $\frac{3}{2}^-$ and $\frac{5}{2}^-$ states at $E_x = 3.679$ and 3.851 MeV yields $E2$ strengths of >5 and 30 ± 15 W.u., respectively, consistent with enhanced $E2$ strengths of transitions within rotational bands in *sd* shell nuclei. Assuming these two states are the next higher members in the band and that the band is pure one expects the $\frac{7}{2}^-$ and $\frac{9}{2}^-$ pair to lie at 6.26 and 6.56 MeV, respectively. A state at 6.045 MeV, seen in the reaction ^{26}Mg$(p, \alpha)^{23}$Na,[6] is a likely candidate for the $\frac{7}{2}^-$ member since it decays 49% to the $\frac{5}{2}^-$ state and 17% to the $\frac{3}{2}^-$ state. The 6.350-MeV state is most likely the $\frac{9}{2}^-$ member since its 66% branch to the $\frac{5}{2}^-$ state implies an $E2$ strength of 47 ± 12 W.u. The decay scheme of the above-mentioned negative-parity states is summarized in Fig. 3.

An interesting pattern exhibited by the $E1$ transitions from these negative-parity states can be seen from the tabulation of relative reduced $E1$ strengths (Table I), namely, that *a spin-J state of negative parity decays preferentially to a spin-(J+1) state in the ground-state band.* The $E1$ decay pattern expected to arise from pure bands[7] is not followed. This expectation is tabulated under the heading "pure bands." However, the energies of the members of the ground-state band de-

TABLE I. A comparison of experimental and predicted relative reduced $E1$ transition strengths for the decay of the $\frac{1}{2}^-$ [101] band members in ^{23}Na. The $J \rightarrow J+1$ preference is evident in the experimental results and compares well with the predictions of the band-mixing calculations.

J^π		Relative reduced $E1$ strengths	Nilsson-model predictions	
Initial	Final	Expt	Pure bands	Band mixing
$\frac{3}{2}^-$	$\frac{5}{2}^+$	97.5	60	97.3
	$\frac{3}{2}^+$	2.5	40	2.7
$\frac{5}{2}^-$	$\frac{7}{2}^+$	89.7	47.6	89.5
	$\frac{5}{2}^+$	4.8	45.7	0.0
	$\frac{3}{2}^+$	5.5	6.7	10.5
$(\frac{7}{2}^-)$	$\frac{9}{2}^+$	60	41.7	85.8
	$\frac{7}{2}^+$	⋯	47.6	4.0
	$\frac{5}{2}^+$	40	10.7	10.2
$(\frac{9}{2}^-)$	$\frac{11}{2}^+$	89	38.2	73.5
	$\frac{9}{2}^+$	8	48.2	0.0
	$\frac{7}{2}^+$	3	13.3	26.5

viate strongly from the $J(J+1)$ spacing expected for a pure band, suggesting appreciable mixing. A band-mixing calculation[8] has shown that the ground-state band contains large (~10% in intensity) admixtures from three orbitals besides the $\frac{3}{2}^+$ [211] orbital; namely the $\frac{1}{2}^+$ [211], $\frac{5}{2}^+$ [202], and $\frac{1}{2}^+$ [220] orbitals. A similar calculation using the above four positive-parity bands resulted in the relative reduced $E1$ strengths shown in Table I. The deformation was fixed at $\delta = 0.32$ for all bands and the band-head energies and moment-of-inertia parameters ($\hbar^2/2I$) were varied to give reasonable energy-level fits. Although the agreement with experiment is not complete, the results appear to exhibit the correct trend and do not critically depend on the choice of parameters. Band mixing thus appears to account for the gross features of the above-mentioned general behavior of the $E1$ rates. It can be shown that this behavior results primarily from the presence of the admixed $\frac{1}{2}^+$ [211] wave function while the $J(J+1)$ energy deviation results mainly from the addition of the strongly decoupled $\frac{1}{2}^+$ [220] band.

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SU(3) Comparison of φ and $K(890)$ Production*

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We have utilized SU(3) invariance to relate the reactions $K^-p \to (\Lambda, \Sigma^0)\varphi$ with $\pi^-p \to (\Lambda, \Sigma^0)K(890)$ in the peripheral region. We find that in all observable distributions, including the baryon polarization and the vector-meson density-matrix elements, the data are in good agreement with the SU(3) predictions. These observations lead us to conclude that potential sources for the symmetry breaking, such as external-mass–dependent factors or absorptive effects, do not significantly affect the simple SU(3) picture.

The SU(3) symmetry scheme has been remarkably successful in describing the spectroscopy of the well-known boson and baryon states. The situation with regard to dynamics (i.e., predicting relations among cross sections) has been less clear.[1] In this Letter we address ourselves to several SU(3) dynamical predictions which satisfy the expected regularities to within the experimental errors. These involve reactions (whose relationship is not entirely transparent) in which vector mesons are produced via a meson exchange process with the baryon vertex remaining invariant. The most noteworthy previous such example has been the similarity of ω and ρ^0 production and decay characteristics as measured in K^-p interactions.[2] Here we examine differential cross sections, polarization, and density-matrix elements of $\varphi(1020)$ and $K(890)$ produced in the following channels:

$$K^-p \to \Lambda\varphi, \quad (1a)$$

$$\to \Sigma^0\varphi, \quad (1b)$$

$$\pi^-p \to \Lambda K(890), \quad (2a)$$

$$\to \Sigma^0 K(890). \quad (2b)$$

If the production mechanism of Reactions (1) and (2) is meson exchange, they can be related to each other by application of SU(3) symmetry at the meson vertex, since the baryon vertex remains the same. Very little needs to be assumed about the nature of the exchanged meson. If K