second μ^- track. This is incorporated by requiring that the hadron shower have sufficient energy to produce a μ with momentum greater than 9 GeV and be momentum analyzable.

[15]This was obtained from Young *et al.*, Ref. 3, under the assumption that the semileptonic charm branching ratio was 10%.

[16]Young *et al.*, Ref. 3, suggest that asymptotically x for events with $c\bar{c}$ production are the same as for all events.

[17]Obtained from Ref. 4 by assuming $\mu^-\mu^+/\mu^- = 0.65 \times 10^{-2}$.

Excited $K^\pi = 0^+$ Rotational Band in ^{28}Si

F. Glatz, P. Betz, J. Siefert, F. Heidinger, and H. Röpke
Fakultät für Physik der Universität Freiburg, D-7800 Freiburg im Breisgau, West Germany

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An excited $K^\pi = 0^+$ band in ^{28}Si which can be associated with the prolate Hartree-Fock solution has been observed in the reactions ^{25}Mg$(\alpha, n\gamma)$ and ^{27}Al(p, γ). The $I^\pi = 0^+$ through 6^+ band members have been located at $E_x = 6691$, 7381, 9164, and 11 509 keV, respectively. Strong distortion is indicated from $B(E2)$ values, resulting in $|Q_0| = 876^{+110}_{-85}$ mb.

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Hartree-Fock calculations of ^{28}Si yield oblate and prolate solutions which are nearly degenerate. Das Gupta and Harvey[1] proposed at an early stage that $K^\pi = 0^+$ rotational bands, which are based on the ground and 6691-keV states, be associated with the prolate and oblate solutions, respectively. Only the ground-state band has been observed so far[2] and its oblate nature has been confirmed.[3,4] In this work we present evidence of an excited $K^\pi = 0^+$ band from an investigation of the reactions ^{25}Mg$(\alpha, n\gamma)$ and ^{27}Al(p, γ).

The $(\alpha, n\gamma)$ measurements were performed by bombarding a 300-μg/cm^2 self-supporting ^{25}Mg foil with 14.5-MeV α particles. The 40-nA beam was provided by the 7-MV Van de Graaff accelerator of the University of Freiburg. Neutron-γ-ray coincidences were measured with two 120-cm^3 Ge(Li) detectors and a neutron time-of-flight (TOF) spectrometer at zero degrees with respect to the beam at a distance of 2.5 m from the target. The TOF spectrometer consists of nineteen liquid-scintillation detectors in a quasiannular array. An identical spectrometer with only seven detectors has been used previously.[5,6] Hence information concerning the quality of neutron and γ-ray spectra can be obtained from that work.

Complete n-γ angular correlations were measured at six angles. Several hitherto unknown ^{28}Si levels of high spin were observed, among them an 11509 keV level. Its decay mode is given in Table I. The full Doppler shift of the 11 509 → 6889 keV transition yielded a reliable lifetime limit $\tau(11\,509) < 30$ fs. (There was no evidence of a possible 11 509 → 6879 keV transition which would affect the life-time measurement.) The n-γ angular correlation of the same transition has (Fig. 1) the typical shape of a stretched $(I \to I-2)$ quadrupole transition, thus suggesting a $I = 6$ assignment to the 11 509 keV level. A simultaneous fit to the correlations of both the 11 509 → 6889 and 11 509 → 9164 keV transitions yields at a 0.1% confidence limit a $I = 6$, 4 assignment to the 11 509 keV level and a $I^\pi = 4^+$ assignment to the 9164 keV level, which hitherto had[7] $I^\pi = 3^-, 4^+$. The lifetime limit of the 11 509 keV level implies positive parity of the level because otherwise it would have $M2$

TABLE I. Branching ratios (%) and multipole transition rates $B(\lambda, \mu)$ (Weisskopf units) of rotational states.

E_f (keV)	I_f^π	Branch	$B(\lambda, \mu)$	
		11 509 keV, $I^\pi = 6^+$ state		
9164	4^+	24 ± 2	> 18	($E2$)
6889	4^+	68 ± 3	> 1.7	($E2$)
4617	4^+	8 ± 2	> 0.03	($E2$)
8543	6^+	< 2	$< 2 \times 10^{-3}$[a]	($M1$)
		9164 keV, $I^\pi = 4^+$ state		
7417	2^+	4.5 ± 0.5	$11.5^{+3.6}_{-2.7}$	($E2$)
7381	2^+	13.5 ± 1.0	32^{+8}_{-6}	($E2$)
6889	4^+	2.9 ± 0.3	$(20 \pm 5) \times 10^{-4}$	($M1$)
6879	3^-	1.9 ± 0.3	$(43 \pm 12) \times 10^{-6}$	($E1$)
4617	4^+	30.8 ± 0.4	$(27 \pm 4) \times 10^{-4}$	($M1$)
1778	2^+	46.4 ± 2.0	$(9 \pm 2) \times 10^{-2}$	($E2$)

[a]We assume $B(E2) < 36$ Weisskopf units for the 11 509 → 9164 keV transition.

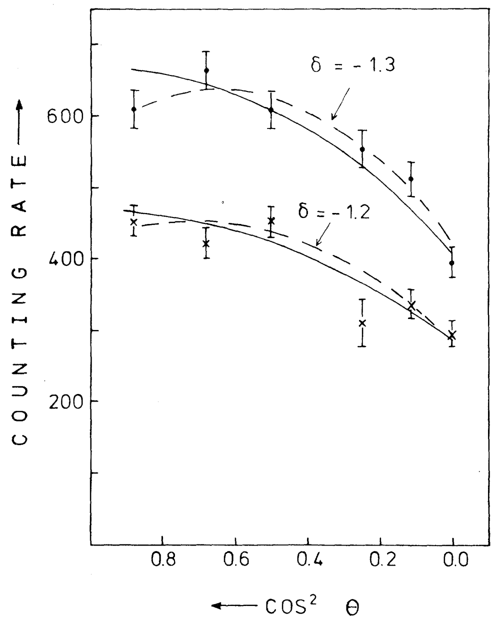

FIG. 1. Experimental n-γ angular correlations of the 11 509→ 6889 keV (full circles) and 11 509→ 9164 keV transitions (crosses). The full and dashed curves are best fits for 6→ 4 and 4→ 4 spin sequences, respectively, of both transitions. δ stands for the quadrupole/dipole mixing ratios of the 4→ 4 transitions.

transition rates in excess of the recommended[8] upper limit.

It is a well-known[9] problem of angular correlation work that a stretched ($I \rightarrow I-2$) quadrupole transition can always be simulated by a $I \rightarrow I$ transition with mixing ratio $\delta \simeq -1.2$. In the present case such a simulation would have occurred in both correlations of Fig. 1 if we assign $I=4$ to the 11 509 keV level. This seems very far fetched. In addition the 11 509 keV level is not populated[7] in the well investigated reactions ^{28}Si(p,p') and ^{24}Mg(α,γ) nor has it been observed from the resonances of the reaction ^{27}Al(p,γ). Also limits of 2% could be set on the branching ratios for the decay of the 11 509 keV level to all of the eight $I^\pi = 3^+$ and 2^+ states below the 9164 keV level.

Since all these facts speak against the lower-spin assignment we adopt $I^\pi = 6^+$ for the 11 509-keV level. Its decay to the 9164 keV level then has $B(E2) > 18$ Weisskopf units. Because of this enhanced transition rate and a $I(I+1)$ dependence of excitation energies it is compelling to propose a $K^\pi = 0^+$ rotational band with the 6691, 9164, and 11 509 keV levels as the $I^\pi = 0^+$, 4^+, and 6^+ members, respectively, and one of the $I^\pi = 2^+$ levels at 7381 or 7417 keV excitation energy as the $I^\pi = 2^+$ member.

To further substantiate this idea we have completely reinvestigated the properties of the 9164 keV level using the reaction ^{27}Al(p,γ) at the $E_p = 2160$ and 2312 keV resonances. Targets of 30 μg/cm^2 ^{27}Al on a tantalum backing were bombarded with a 8-μA proton beam. γ-ray singles spectra were taken on and off resonance with high statistical accuracy and 2.2 keV energy resolution at the ^{60}Co energies. Six decay modes of the 9164 keV level were observed of which only the two strongest ones were known[7] previously. A lifetime measurement by the Doppler-shift attenuation method exactly confirmed the reported value[10] $\tau(9164) = 37 \pm 5$ fs.

The 9164 keV level decays with enhanced $E2$ transition rates (Table I) to both the 7381 and 7417 keV levels, thus supporting the idea of ro-

TABLE II. Properties of $K^\pi = 0^+$ rotational bands in doubly even $N = Z$ nuclei compared with Hartree-Fock (HF) calculations.

	Q_0 (mb) Expt.	HF[a]	q ($=a/b$) Expt.[b]	HF[c]	δ[d]	θ/θ_R[e]
^{20}Ne(g.s.)	488 ± 24	478	1.43 ± 0.02	1.46	0.32 ± 0.01	0.82 ± 0.04
^{24}Mg(g.s.)	575^{+48}_{-53}	665	1.42 ± 0.04	1.47	0.31 ± 0.01	0.69 ± 0.04
^{28}Si(exc.)	876^{+110}_{-85} or -876^{+85}_{-110}	945	1.52 ± 0.06 or $0.55^{+0.03}_{-0.08}$	1.53	0.35 ± 0.03 or $-0.55^{+0.07}_{-0.11}$	0.80 ± 0.06 or 1.06 ± 0.07
^{28}Si(g.s.)	-480 ± 20	-723	0.86 ± 0.04	0.55	-0.27 ± 0.01	0.61 ± 0.04

[a] From Tables 7b and 8 of Ref. 12.
[b] Defined by $Q_0 = (2ZR^2/5)(q^{4/3} - q^{-2/3})$.
[c] From Table 7b or Ref. 12 with use of $D_0^M = 2(q^{4/3} - q^{-2/3})/(q^{4/3} + 2q^{-2/3})$.
[d] Defined by $q = (1 + 2\delta/3)^{1/2}/(1 - 4\delta/3)^{1/2}$.
[e] Defined by $\theta_R = (MR^2/5)(q^{4/3} + q^{-2/3})$.

tational structure. The $E2$ strength of the $4^+ \to 2^+$ in-band transition is evidently split which is not surprising in view of the near degeneracy of the final states. Thus the total collective $E2$ strength amounts to the sum of the two transition rates to within, say 1 Weisskopf unit. The 7381 keV level is more collective than the 7417 keV level.

Table II gives the properties of the new band compared to the properties of the ^{20}Ne, ^{24}Mg, and ^{28}Si ground-state bands. The experimental input parameters are the rotational constants $\hbar^2/2\theta$ and the intrinsic quadrupole moments $|Q_0|$ derived, for the sake of consistency, from the $B(E2)$'s[8] of the $4^+ \to 2^+$ in-band transitions. It seems to be a rule that the use of the $2^+ \to 0^+$ transition rates would lead to a 10% increase of $|Q_0|$. Deformation and rigidity of bands are deduced assuming ellipsoidal nuclei with axial symmetry, sharp surface, homogeneous charge and mass distribution, and volume $V = \frac{4}{3}\pi R^3$. The nuclear radius $R = (1.06A^{1/3} + 0.75)$ fm was chosen in accordance with Anderson, Wong, and McClure.[11] All relevant quantities are rigorously expressed in the footnotes of Table II in terms of $q = a/b$, where a is the elongation of the ellipsoid in the direction of the symmetry axis and b the elongation along a perpendicular axis. Nilsson's deformation parameter δ is included for convenience.

The possibility of an oblate shape in the new ^{28}Si band was considered and discarded because the moment of inertia θ would exceed or at least reach the rigid-body value θ_R. Hence an association of the new band with the prolate Hartree-Fock (HF) solution is preferred. Good agreement is in fact obtained with HF calculations that employ major-shell mixing.[12,13] The near equality of distortions in the prolate bands of ^{20}Ne, ^{24}Mg, and ^{28}Si is reproduced by the theory as well as the values of Q_0. In the oblate band of ^{28}Si the distortion is somewhat overestimated by the calculations.

In conclusion it appears that the prediction from HF theory of both oblate and prolate rotational bands in ^{28}Si is now, after fourteen years, supported experimentally.

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