gives a variety of prescriptions for deducing the spin and parity of the lowest member of a three-particle multiplet. These prescriptions, however, fail to describe the situation we observe for ^{127}Sb. We show in Fig. 1 the levels of ^{126}Sn observed by Flynn, Beery, and Blair using the reaction $^{124}\mathrm{Sn}(t,p)^{126}\mathrm{Sn}$.[7] In ^{127}Sb, a $\frac{15}{2}^-$ state can result from coupling a $g_{7/2}$ proton to the 5^- two-neutron state in ^{126}Sn. The principal component of the wave function for the $\frac{15}{2}^-$ isomer could thus be stated by $[\nu\nu(1h_{11/2}2d_{3/2})_{5^-}\pi(1g_{7/2})]_{15/2^-}$. It is not clear why the $\frac{15}{2}^-$ state should be the lowest member of a resulting eight-state multiplet. Possibly configuration mixing with the $\frac{15}{2}^-$ member of a six-state multiplet formed by coupling a $d_{5/2}$ proton to the 5^- state of ^{126}Sn could be responsible for stabilizing the $\frac{15}{2}^-$ state with respect to the $\frac{17}{2}^-$ state.

As a consequence of the characterization of this isomer, it is possible to suggest the presence of similar isomerism in ^{125}Sb, to predict an approximate 8-μsec half-life for the 5^- state in ^{126}Sn at 2054 keV, and to point to the need for better theoretical treatment of $\pi\nu^2$ states and other three-quasiparticle states.

The authors wish to express thanks to the late Professor C. D. Coryell, Professor G. E. Gordon, and Professor E. S. Macias for helpful discussions during the course of this investigation.

†Work supported in part by the U. S. Atomic Energy Commission.

[1]S. H. Devare, R. M. Singru, and H. G. Devare, Phys Rev. 140, 536 (1965).

[2]I. Bergström, S. Borg, G. B. Holm, and B. Rydberg, in Proceedings of a Conference on the Properties of Nuclei Far From the Region of Beta-Stability, Lysin, Switzerland, 31 August 1970 (unpublished).

[3]C. Heiser, H. F. Brinckmann, W. D. Fromm, and V. Hagemann, Nucl. Phys. A145, 81 (1970).

[4]K. E. Apt and W. B. Walters, Bull. Amer. Phys. Soc. 15, 1622 (1970), and Laboratory for Nuclear Science Chemistry Progress Report, MIT (1970), and to be published.

[5]E. S. Macias, J. P. op de Beeck, and W. B. Walters, Nucl. Phys. A147, 513 (1970).

[6]L. K. Peker, in *Fourth Winter Seminar on the Theory of the Nucleus and the Physics of High Energies, Leningrad, U.S.S.R., 5-17 February 1969* (Akad. Nauk SSSR, Leningrad, 1969), Pt. 1, p. 167.

[7]E. R. Flynn, J. G. Beery, and A. G. Blair, Nucl. Phys. A154, 225 (1970).

Hexadecapole Moments of ^{20}Ne and ^{28}Si from Scattering of 104-MeV α Particles

H. Rebel, G. W. Schweimer, J. Specht, and G. Schatz
Kernforschungszentrum Karlsruhe, Zyklotron-Laboratorium, Karlsruhe, Germany

and

R. Löhken, D. Habs, G. Hauser, and H. Klewe-Nebenius
II. Physikalisches Institut der Universität Heidelberg, Heidelberg, Germany
(Received 22 March 1971)

We have measured the cross sections for the inelastic scattering of 104-MeV α particles from ^{20}Ne and ^{28}Si. The experimental results for the ground-state band have been analyzed in terms of a coupled-channel calculation on the basis of the rotational model. This technique proves to be quite sensitive to contributions of hexadecapole deformations. Quadrupole and hexadecapole deformation lengths and their signs are determined for both nuclei.

The deformation for nuclei in the first half of the $2s$-$1d$ shell ($A = 20$-28) is borne out by the well-known rotational spectra, the accurate measurements of γ-ray transition probabilities and of the static quadrupole moments for the 2^+ states[1-11], as well as by the considerable success of Hartree-Fock and Hartree-Fock-Bogoljubov calculations.[12-17] Some of the theoretical results[15,18-20] suggest large hexadecapole in addition to quadrupole deformations. This is supported by the results of several experiments.[21-23] Recently, a systematic analysis of inelastic scattering of 24.5-MeV protons[24] brought definite evidence for Y_4 deformation of ^{20}Ne, ^{24}Mg, ^{28}Si, and ^{32}S. For ^{20}Ne, an analysis of inelastic scattering of 104-MeV α particles[25] on the basis of the Austern-Blair model lead to the same result.

α particles are a good probe of the nuclear surface. The diffraction-type angular distributions of the scattered α particles assure that the scat-

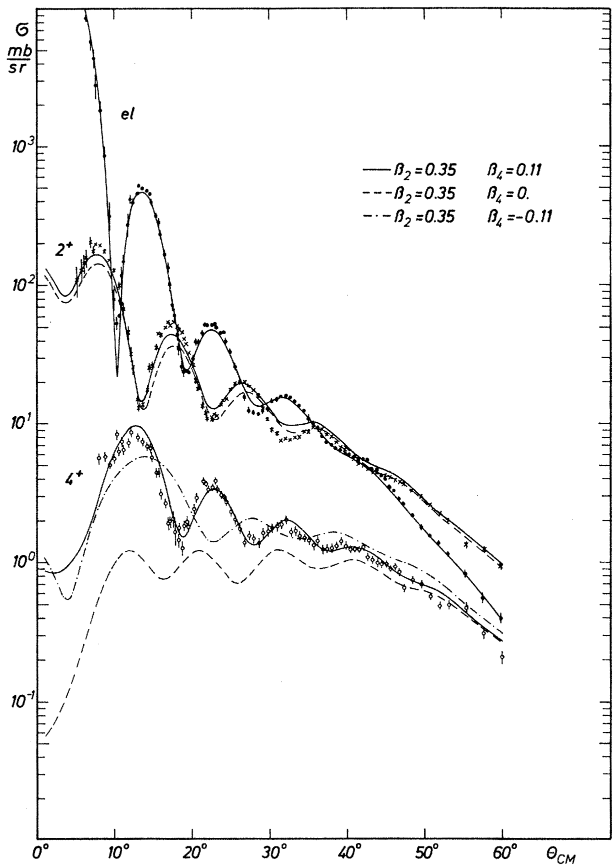

FIG. 1. Experimental and theoretical differential cross sections for 104-MeV α-particle scattering from ^{20}Ne.

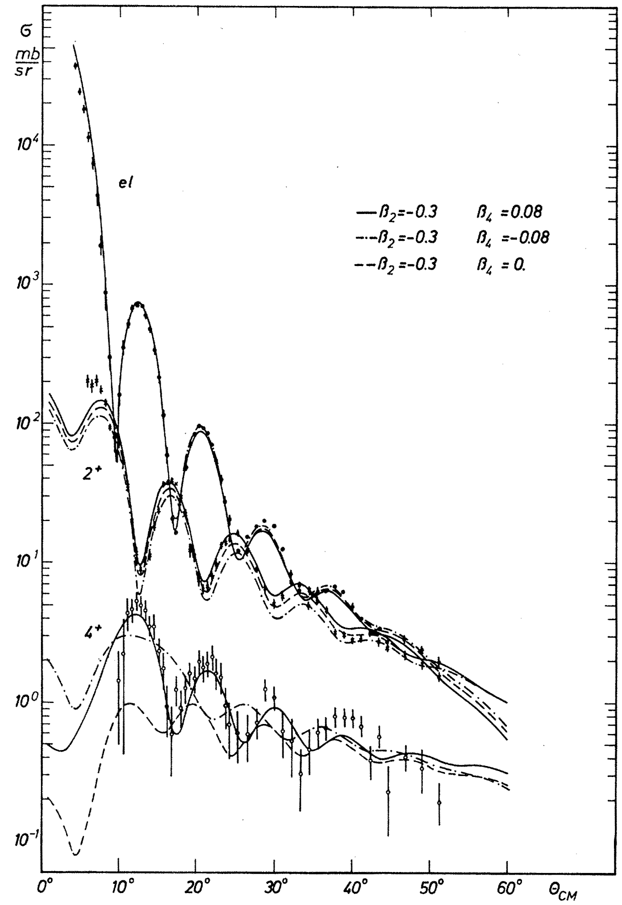

FIG. 2. Experimental and theoretical differential cross sections for 104-MeV α-particle scattering from ^{28}Si.

tering is caused by a surface interaction. The magnitude, slope, and phase of the diffraction-type cross sections allow a precise and sensitive analysis of the experimental data. If the energy is sufficiently high, the "grazing" α particles carry high-enough momenta so that large direct angular-momentum transfer is possible. This is a necessary feature for a study of higher multipole moments ($L > 2$) since this becomes possible only when direct excitation of the $J=L$ member of the band contributes significantly. Furthermore, in favorable cases the interference of multiple and single excitation allows to determine the signs of the deformation parameters. The pronounced oscillation pattern of α-particle scattering is more sensitive to this interference than the less structured proton-scattering cross sections.

Here we report a systematic study of the deformations of ^{20}Ne and ^{28}Si through excitation of the ground-state band by 104-MeV α particles of the Karlsruhe Isochronous Cyclotron. A ^{20}Ne gas target of 1 atm pressure and a ^{28}Si foil (400 μg/cm^2) were used.

The differential cross sections were taken with a 5-mm-thick Si(Li) detector cooled to $-25°$C. The total energy resolution achieved was 200-400 keV. Special care was taken to maintain an overall angular resolution of better than 0.6°. Details of the experimental arrangement and procedures are described elsewhere.[26,27] The measured experimental cross sections are shown in Figs. 1 and 2 along with theoretical curves described below.

In our analysis we assume that interaction of α particles with the nucleus can be represented by a deformed complex optical potential and that the nucleus is a rigid rotator, at least up to the first 4^+ state. Furthermore Coulomb excitation is included. For the nuclear part we use the six-parameter Woods-Saxon form. We assume axial symmetry of the intrinsic nuclear deformation so

Table I. Results of the analysis.

	V (MeV)	r_v (fm)	a_v (fm)	W (MeV)	r_w (fm)	a_w (fm)	β_2	β_4
^{20}Ne [a]	110.6	1.22	0.82	17.9	1.77	0.63	...	...
^{20}Ne [b]	109.7	1.27	0.79	13.9	1.82	0.48	$+0.34$ -0.01	$+0.15$ ± 0.04
^{20}Ne [c]	98.4	1.35	0.74	17.1	1.69	0.57	$+0.35$ ± 0.01	$+0.11$ ± 0.01
^{28}Si [a]	104.7	1.25	0.66	37.1	1.36	0.77	...	...
^{28}Si [b]	97.1	1.39	0.65	23.1	1.55	0.61	-0.30 ± 0.01	$+0.05$ ± 0.04
^{28}Si [c]	98.1	1.40	0.65	22.9	1.52	0.65	-0.30 ± 0.01	$+0.08$ ± 0.01

[a] Optical-model analysis for elastic scattering.
[b] Coupled-channel analysis for 0^+ and 2^+ states.
[c] Coupled-channel analysis for 0^+, 2^+, 4^+ states in a 0^+-2^+-4^+-6^+ coupling scheme; Coulomb excitation included.

that the nuclear radius may be represented by

$$R = R_0(1 + \beta_2 Y_2^0 + \beta_4 Y_4^0)$$

in the body-fixed system. On this basis the cross sections of the lowest 0^+, 2^+, and 4^+ states are analyzed with the coupled-channel method. For most of the calculations a modified and improved version of the coupled-channel code JUPITOR 1 by Tamura is used.[28,29] A first set of optical-potential parameters was obtained by fitting only the elastic cross sections. These parameters, especially the imaginary part of the potential, have to be readjusted in course of the coupled-channel calculation. This is done by an automatic search routine in the program. It is interesting to see that the best fits of the 0^+ and 2^+ cross sections already require a Y_4 deformation which is, of course, more precisely determined from the 4^+ cross section. Inclusion of the 6^+ state has little effect on the calculated 0^+, 2^+, 4^+ cross sections. The final results calculated in a 0^+-2^+-4^+-6^+ coupling scheme including Coulomb excitation are presented in Table I and are shown in Figs. 1 and 2. In order to give an impression of the sensitivity of the analyzing technique, calculated cross sections for different values of β_4 are included in the figures.

For ^{20}Ne the choice of positive signs for both β_2 and β_4 proves to be the best. Other choices result in much poorer fits with the parameters of the complex potential strongly deviating from those of the optical-model fits. For ^{28}Si the analysis favors the negative sign of the quadrupole deformation parameter β_2. This result supports those of reorientation measurements in Coulomb excitation of the 2^+ state.[8,10]

Table II shows a comparison of our results with results obtained by other experimental methods or theoretical studies. As suggested by Austern and Blair[25] the nuclear excitation is determined by the magnitudes $\delta_\lambda = \beta_\lambda R_0$. We therefore quote these values. The various results are in sufficient agreement though there is no reason to assume that different particles see the same surface structure of the nucleus. The main source of uncertainty of our results is the strict rotational-model description of the studied nuclei. The imperfection of this picture is obvious from the existence of low-lying vibrational states, the inconsistencies of transition and static moments (see Table II for ^{20}Ne), and the fact that the $B(E2, 4^+ \to 2^+)/B(E2, 2^+ \to 0^+)$ ratios deviate from the rotational-model values. Therefore the question arises to what extent the extracted β_4 values may be interpreted as hexadecapole moments (either static or transition). This can only be decided on the basis of additional information and a more refined description of the studied nuclei.

We thank Dr. W. J. Thompson for making available to us T. Tamura's coupled-channel code JUPITOR 1. Two of us (H.R. and R.L.) wish to thank Dr. P. E. Hodgson and his group for their kind hospitality during a short period at Oxford. Here valuable coupled-channel calculations using A. Hill's codes were performed which allowed a check of Tamura's program. The excellent service of the Atlas Computer Laboratory, Chilton, Didcot, England is gratefully acknowledged. We thank Mrs. G. Hoffmann, Miss U. Martens, and

Table II. Experimental and theoretical results for the deformations of ^{20}Ne and ^{28}Si. CC: Coupled-channel analysis. AB: Austern-Blair analysis, using the radius $R_v = 1.3 \times A^{1/3}$ fm. HF(B): Hartree-Fock (-Bogoljubov) calculations. Where the sign is known, it is explicitly given. For the calculation of the intrinsic quadrupole moments Q_{20} from $B(E2)$ and from the measured static moments of the 2^+ states, the rotational model is assumed.

	β_2	β_4	$\delta_2=\beta_2 R_v$ [fm]	Q_{20} [b]	Method	Ref.
^{20}Ne	+0.35±0.01	+0.11±0.01	1.29	+0.40	(α,α')CC	this work
	0.42	0.10	1.49	0.56	(α,α')AB	21
	+0.36	+0.04	1.27	+0.41	(α,α')AB	25
	+0.47	+0.28±0.05	1.34	+0.43	(p,p')CC	24
				0.69±0.04	$B(E2,2^+\to 0^+)$	11
				+0.84±0.11	Reorient.	11
	+0.35				HF	15
	+0.34			+0.54	HFB	16
	+0.43	+0.14				18
	+0.39	+0.17				19
^{28}Si	−0.32±0.01	+0.08±0.01	−1.25	−0.55	(α,α')CC	this work
	0.36				(α,α')CC	30
	0.45		1.79		(d,d')CC	31
	0.41		1.43		(p,p')CC	32
	(−)0.34	+0.25±0.08	1.28	(−)0.54	(p,p')CC	24
				0.56±0.02	$B(E2,2^+\to 0^+)$	8
				−0.63±0.18	Reorient.	8
	−0.29				HF	15
	−0.21			−0.75	HFB	16
				−0.84	HF	17
				−0.92	HF	12

G. Nowicki for their help during the measurements and in data handling.

[1]H. Grawe and K. P. Lieb, Nucl. Phys. A127, 13 (1969).

[2]J. H. Anderson and R. C. Ritter, Nucl. Phys. A128, 305 (1969).

[3]M. M. Aleonard *et al.*, Nucl. Phys. A146, 90 (1970).

[4]F. C. P. Huang and D. K. McDaniels, Phys. Rev. C 2, 1342 (1970).

[5]A. Bamberger, P. G. Bizetti, and B. Povh, Phys. Rev. Lett. 21, 1599 (1968).

[6]O. Häusser *et al.*, Phys. Rev. Lett. 22, 359 (1969), and Can. J. Phys. 48, 35 (1970).

[7]D. Schwalm and B. Povh, Phys. Lett. 29B, 103 (1969).

[8]O. Häusser *et al.*, Phys. Lett. 23, 320 (1969).

[9]D. Pelte, O. Häusser, T. K. Alexander, and H. C. Evans, Can. J. Phys. 47, 1929 (1969).

[10]K. Nakai, J. L. Québert, F. S. Stephens, and R. M.

Diamond, Phys. Rev. Lett. 24, 903 (1970).
[11]K. Nakai, F. S. Stephens, and R. M. Diamond, Nucl. Phys. A150, 114 (1970).
[12]B. Castel and J. P. Sennen, Nucl. Phys. A127, 141 (1969).
[13]S. Das Gupta and M. Harvey, Nucl. Phys. A94, 602 (1967).
[14]G. Ripka, in *Advances in Nuclear Physics*, edited by M. Baranger and E. Vogt (Plenum, New York, 1968).
[15]A. P. Stamp, Nucl. Phys. A105, 627 (1967).
[16]P. U. Sauer, in *Nuclear Structure and Nuclear Reaction, International School of Physics "Enrico Fermi," Course XL*, edited by M. Jean (Academic, New York, 1967); P. U. Sauer, A. Faessler, H. H. Wolter, and M. M. Stingl, Nucl. Phys. A125, 257 (1969).
[17]B. Castel and J. C. Parikh, Phys. Lett. 29B, 341 (1969), and Phys. Rev. C 1, 990 (1970).
[18]C. Brihaye and G. Reidemeister, Nucl. Phys. A100, 65 (1967).
[19]H. G. Benson and B. H. Flowers, Nucl. Phys. A126, 305 (1969).
[20]J. C. Parikh, Phys. Lett. 25B, 181 (1967).
[21]A. Springer and B. G. Harvey, Phys. Lett. 14, 116 (1965).
[22]F. Hinterberger *et al.*, Nucl. Phys. A115, 570 (1968).
[23]R. W. Barnard and G. D. Jones, Nucl. Phys. A108, 655 (1968).
[24]R. de Swiniarski *et al.*, Phys. Rev. Lett. 23, 317 (1969).
[25]N. Austern and J. S. Blair, Ann. Phys. (New York) 33, 15 (1965).
[26]J. Specht *et al.*, Nucl. Phys. A143, 373 (1970). The values for $\delta_2(\beta_2)$ and $\delta_4(\beta_4)$ quoted in Table II for this reference are extracted from an analysis of the 2^+ state of ^{20}Ne. A more improved analysis including the 4^+ state results in $\delta_2=1.29$ and $\delta_4=0.25$.
[27]G. Häuser *et al.*, Nucl. Phys. A128, 81 (1969).
[28]T. Tamura, ORNL Report No. ORNL-4152, 1967 (unpublished).
[29]H. Rebel and G. W. Schweimer, Kernforschungszentrum Karlsruhe, KFK Report No. 1333, 1970 (unpublished).
[30]J. Kokame, K. Fukunaga, N. Inoue, and H. Nakamura, Phys. Lett. 8, 342 (1964).
[31]H. Niewodniczański *et al.*, Nucl. Phys. 55, 386 (1964).
[32]P. K. Cole, Ch. N. Wadell, R. R. Dittmann, and H. S. Sandhu, Nucl. Phys. 75, 241 (1966).

Study of $\bar{K}N \to Y\pi$ below $\bar{K}N$ Threshold and the Dynamical Nature of the $Y_0^*(1405)$†*

D. Cline, R. Laumann, and J. Mapp
University of Wisconsin, Madison, Wisconsin 53706
(Received 24 February 1971)

We have studied the $Y\pi$ angular distributions for the reaction $K^-d \to Y\pi N$ for the $Y\pi$ mass range 1350-1530 MeV. These data are used to study the $\bar{K}N \to Y\pi$ amplitudes below $\bar{K}N$ threshold. The analysis confirms previous SU(3) multiplet assignments for the $\Lambda(1520)$ and $\Sigma(1385)$, and indicates that the S_{01} channel is dominated by a repulsive background with the $\Lambda(1405)$ being a small effect superimposed on the background. This conclusion is at odds with the usual K-matrix analysis of the low-energy $\bar{K}N$ data but is somewhat supported by recent evidence from baryon-exchange production of the $\Lambda(1405)$.

Over the past few years considerable effort has been applied to the extrapolation of scattering amplitudes below $\bar{K}N$ threshold. Recently Dalitz has emphasized the possible uncertainties in these analyses.[1] In this Letter we suggest another way of studying the low-energy region using $\bar{K}$ scattering on virtual nucleons in the deuteron to obtain $Y\pi$ mass values below $\bar{K}N$ threshold.[2]

A different approach to the study of the below $\bar{K}N$ threshold may be useful in deciding the dynamical nature of the $\Lambda(1405)$ state. Again, as recently stressed by Dalitz,[1] there are two different viewpoints concerning the $\Lambda(1405)$:

(i) The $\Lambda(1405)$ is a virtual bound state of the $\bar{K}N$ system. The nearness of $\bar{K}N$ threshold plays an important role in the dynamical origin of this state.

(ii) The $\Lambda(1405)$ is a member of a supermultiplet whose dynamical origin perhaps derives from forces between very massive objects such as quarks. In this case the nearness of the $\bar{K}N$ threshold is not of dynamical significance.

These alternative dynamical explanations of the $\Lambda(1405)$ have also been discussed by Rajasekaran.[3] Previous analyses of low-energy $\bar{K}N$ data using the K-matrix formalism appear to favor viewpoint (i).[1,4] As shown below, the results of this work disagree with these extrapolation analyses and favor the viewpoint expressed in (ii).

In a previous note it was explicitly shown that the impulse approximation can be used to obtain