HIGH-SPIN STATES IN ^{22}Ne

C. Broude,* W. G. Davies, and J. S. Forster
Atomic Energy of Canada Limited, Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada
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Three levels have been observed above the neutron-decay threshold in ^{22}Ne, at 11.01, 11.11, and 11.49 MeV; they undergo γ decay exclusively to the 6.30-MeV 6^+ state. Of these states the one at 11.01 MeV has γ-ray angular correlations in agreement with an 8^+ spin and parity assignment, and that at 11.49 MeV with spin 7. The spin of the 11.11-MeV state is limited to 6 or 7.

The γ-decay properties of high-spin states in the lower half of the s-d shell constitute a stringent test of the SU(3) model. The recent identification[1] of the 6.30-MeV level[2] in ^{22}Ne as the 6^+ member of the $K=0^+$ ground-state rotational band prompted us to search for the 8^+ and other high-spin states.

Levels in ^{22}Ne were observed via the reaction ^{19}F$(\alpha,p\gamma)^{22}$Ne by bombarding a 110-μg/cm^2 ^{6}LiF target, evaporated onto a 15-μg/cm^2 carbon foil, with 20-MeV α particles from the Chalk River model MP tandem accelerator. The beam was collimated by a sequence of apertures placed before the target and was collected in a shielded beam catcher placed about 10 ft beyond the target. Protons were detected in a cooled annular surface-barrier Si detector with a depletion depth of 1 mm placed so that it subtended a mean angle of 174° to the beam. A 200-μg/cm^2 aluminum foil placed in front of the particle counter prevented scintillation light from the target from reaching the counter. Under these conditions a proton resolution of 50-keV full width at half-maximum was obtained. γ rays were detected by six 6-in.-long by 5-in.-diam NaI(Tl) detectors mounted on the Lotus goniometer[3] and spaced at approximately equal intervals in $\cos^2\theta$ from 0 to 0.73. Coincident events between the particle and γ-ray counters were recorded on magnetic tape, event by event, using a model PDP-1 on-line computer. The tapes were played back on a model PDP-10 computer to produce γ spectra in coincidence with up to 21 individual particle groups at one time. Background due to the continuum of counts under the particle groups was subtracted by setting windows as close as possible to the proton groups of interest. Pairs of windows placed in the time spectra allowed subtraction of random events during playback. Approximately 40 levels in ^{22}Ne were observed. Figure 1 shows a typical γ-ray spectrum in coincidence with the particle group at 11.01 MeV, which is shown in the inset: The dotted lines define the coincidence window.

^{22}Ne is unstable against α emission above 9.667 MeV and against neutron emission above 10.366 MeV. The latter breakup, especially, ensures that above about 10.5 MeV only high-spin states

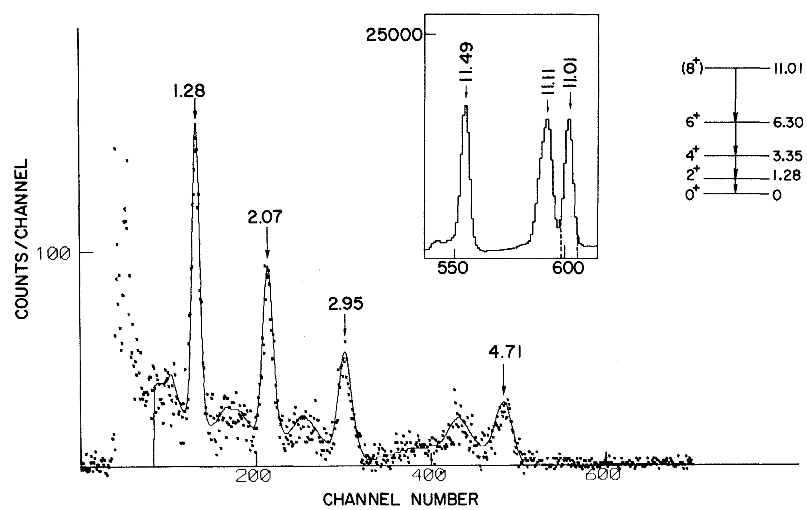

FIG. 1. The γ-ray spectrum in coincidence with the particle group at 11.01 MeV for the NaI(Tl) detector positioned at $\theta_\gamma = 90°$. The relevant portion of the particle spectrum is shown in the inset; the dotted lines define the coincidence window.

are observed through p-γ coincidences. We have observed three prominent levels at excitations of 11.01, 11.11, and 11.49 MeV, well above the neutron-decay threshold. All three states undergo γ decay exclusively to the 6.30-MeV 6^+ state of ^{22}Ne which then decays successively through the 4^+ and 2^+ members of the ground-state rotational band to the 0^+ ground state. No state below 11.01-MeV excitation has been observed to decay exclusively to the 6^+ state.

Detection of the outgoing particles near the beam axis approximates method II of Litherland and Ferguson[4] which in this reaction restricts the magnetic substates to 0 and 1. Analysis of the correlations included the decay of the primary level to the 6^+ level and the 6^+-4^+ and 4^+-2^+ transitions. The 2^+-0^+ transition was excluded since its long lifetime (5 psec) and recoil velocity ($v/c = 2.3\%$) into vacuum perturbs the correlation through the well-known deorientation effect.

The correlations for the 11.01-MeV state can be fitted by spin 6 with χ^2 equal to 23 for 13 degrees of freedom or by spin 8 with χ^2 equal to 24 for 14 degrees of freedom. Other spin assignments are outside the 0.1% confidence limit. Further discrimination cannot be obtained from a comparison of estimates of single-particle radiative widths with neutron-decay widths for spins of 6 or higher, since such arguments depend strongly on the inhibitions of the electric- or magnetic-dipole strengths. The absence of γ decay to the 4^+ 3.35-MeV state favors an 8^+ assignment although it cannot exclude spin 6. It can be concluded that the state at 11.01 MeV is consistent with a spin and parity assignment of 8^+ and is the lowest level observed in our work for which this is true.

The γ-ray spectra from the level at 11.11 MeV are contaminated by γ rays from ^{19}F in coincidence with an underlying α group from the reaction $^{19}\mathrm{F}(\alpha, \alpha'\gamma)^{19}\mathrm{F}$ resulting in a less precise angular-correlation measurement. Spin assignments of 5, 6, and 7 are within the 0.1% confidence limit for this level. The spin-5 assignment can be excluded since the neutron-decay width is at least 1000 times greater than the γ width for any reasonable combination of γ-decay estimates.

Only spin assignments of 5 and 7 are within the 0.1% confidence limit for the 11.49-MeV level. The spin-5 solution can be excluded on the basis of the above arguments. A mixing ratio of $\delta = 0.00 \pm 0.05$ is obtained for the spin-7 solution and is consistent with negative parity.

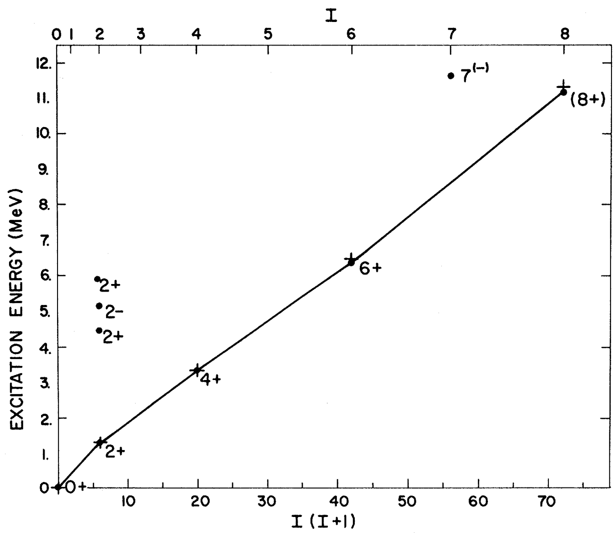

FIG. 2. Rotational bands in ^{22}Ne. The dots represent experimental values; the crosses are the results of the calculations of Akiyama, Arima, and Sebe.

In a recent effective-interaction shell-model calculation, Akiyama, Arima, and Sebe[5] calculated the positive-parity levels of ^{22}Ne using an SU(3) basis. The parameters of the effective interaction were determined mainly from the $A = 18$ system but were adjusted to give the best fit to the 2^+, 4^+, and 6^+ members of the ground-state band in ^{22}Ne. Using these parameters the 8^+ member of the band was predicted to be at 11.06 MeV, in excellent agreement with our proposed 8^+ level at 11.01 MeV. Figure 2 shows a plot of the experimental and theoretical level energies versus $I(I+1)$ for the ground-state band in ^{22}Ne. The (82) SU(3) representation of the [42] symmetry comprises about 73% of the wave function of the ground-state band in this calculation with many other representations making up the rest.

Also shown in Fig. 2 is the 2^- level at 5.14 MeV[6] which has been suggested as the beginning of a negative-parity band. It is clear from the figure that our proposed 7^- level at 11.49 MeV is consistent with a negative-parity band having a moment of inertia about equal to that for the ground-state band.

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*Present address: Weizmann Institute, Rehovot, Israel.

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tory (W. G. Davies and J. S. Forster, to be published) show that the 6^+ level is at 6.30 MeV, not at 6.35 MeV as reported by Kutschera, Pelte, and Schrieder. (Ref. 1).

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NEW BAND-MIXING ANOMALIES IN ^{178}Hf

J. H. Hamilton, A. V. Ramayya, and P. E. Little
Physics Department, Vanderbilt University, Nashville, Tennessee 37203*

and

Noah R. Johnson
Oak Ridge National Laboratory,† Oak Ridge, Tennessee 37830
(Received 3 August 1970)

γ-$\gamma(\theta)$ measurements with a NaI-Ge(Li) detector arrangement were carried out to measure the $M1$ admixture in the 1183-keV, $2^+ \to 2^+$ transition in ^{178}Hf. These results yield $M1 = (85.6^{+1.1}_{-2.1})\%$ for the 1183-keV transition. Accurate branching ratios were also obtained from singles spectra taken with a large-volume Ge(Li) detector. It is possible to obtain from these intensities the same Z_β value from the different branching ratios if a $(73.0 \pm 1.3)\%$ $M1$ admixture is assumed in the $2^+ \to 2^+$ transition. Thus the measured $M1$ admixture yields branching ratios that are not explained by the present band-mixing picture in contrast to earlier reports.

Since the first reports[1,2] of what seemed to be anomalous gamma-ray branching ratios from the 2^+ members of β-vibrational bands in ^{152}Sm and ^{154}Gd, there has been much interest in establishing the cause of this effect. An early suggestion was that there existed a very large $M1$ component in the $2_\beta{}^+ \to 2_g{}^+$ transitions of these two nuclei despite the long-standing prediction of essentially no $M1$ admixtures in the quadrupole beta vibrations.[3] At the International Conference on Nuclear Structure in Tokyo, however, Mottelson[4] pointed out how the theory could be modified to include sizable $M1$ admixtures and stressed the crucial importance of observing these $M1$ admixtures in order to preserve the application of rotational relationships to these nuclei. Our directional correlation measurements in ^{154}Gd have shown,[5] however, that the 692-keV, $2_\beta{}^+ \to 2_g{}^+$ transition has less than or equal to 2% $M1$ admixture. The 50% $M1$ component required[1,2] to obtain a consistent band-mixing parameter, Z_β, from the reduced transition probabilities in ^{154}Gd is clearly ruled out.

On the other hand, Nielsen, Nielsen, and Rud[6] carried out γ-$\gamma(\theta)$ measurements on ^{178}Hf, the 1183-93 keV cascade which originates at a 1276-keV, 2^+ level, assigned as a beta vibrational state. An $M1$ admixture of $(85 \pm 10)\%$ (as calculated from their δ) was found in the 1183-keV transition. When this large $M1$ admixture was considered, they obtained[6] a consistent band-mixing parameter for the 1276-keV level as a beta vibrational state.

In support of our finding of a very low $M1$ admixture in the $2_\beta{}^+ \to 2_g{}^+$ transition in ^{154}Gd, recent Coulomb-excitation work[7,8] has shown similar results in ^{152}Sm. However, it now appears[7,9] that instead of the $2_\beta{}^+ \to 2_g{}^+$ transitions being responsible for the inconsistent branching ratios, the problem is in the $2_\beta{}^+ \to 4_g{}^+$ transition. Thus, it is surprising to find reported[6] in ^{178}Hf that it is the $2^+ \to 2_g{}^+$ transition that is involved in the alteration of the $B(E2)$ branching ratios.

Nielsen, Nielsen, and Rud[6] carried out their γ-$\gamma(\theta)$ studies with two NaI detectors. In the NaI spectrum the 0.11%, 1183-keV transition is seen as a weak shoulder on the 0.44%, 1106-keV photopeak. The problem is also complicated by a 0.02%, 1189-keV transition (in a skip correlation) that is very difficult to resolve even by computer. More important, we also have discovered an unreported[10] 1174-keV transition with 0.015% intensity that was not considered in the work of Nielsen, Nielsen, and Rud.[6] It is important to establish that it is indeed an $M1$ admixture in the $2^+ \to 2_g{}^+$ transition in ^{178}Hf that gives rise to inconsistent Z_β values in contrast to ^{154}Gd where it appears that the $2_\beta{}^+ \to 4_g{}^+$ transition[7,9] is responsible. Thus, we have repeated the ^{178}Hf γ-$\gamma(\theta)$ measurement with our directional