ROTATIONAL BANDS IN Ne^{20}

A. E. Litherland, J. A. Kuehner, H. E. Gove, M. A. Clark, and E. Almqvist
Atomic Energy of Canada Limited, Chalk River, Ontario, Canada
(Received June 30, 1961)

In recent years evidence has been obtained[1,2] which strongly suggests that the low-lying levels of Mg^{24}, Mg^{25}, and Al^{25} can be arranged into rotation-like bands. In this Letter we discuss new evidence which suggests that the low-lying levels of Ne^{20} can also be arranged into overlapping rotational bands. A separation of the level spectrum of Ne^{20} into rotational bands is shown in Fig. 1. Ne^{20} is of great interest in this respect because it is close enough to the closed shell at O^{16} for detailed shell-model calculations to be feasible.[3]

Last year Broude and Gove[2,4] showed that the spins of the 4.25- and 4.97-Mev levels in Ne^{20} were 4 and 2 and that the quadrupole to dipole amplitude ratio for the cascade transition from the 4.97- to the 1.63-Mev level was +0.08. These results have been confirmed recently and the parities of the levels measured.[5-7] The parity of the 4.97-Mev level was found unexpectedly to be negative and the astrophysical implications of this measurement have been discussed recently.[7] Measurements on the lifetimes of the levels in Ne^{20} using the Doppler shift attenuation method[8,9] and Coulomb excitation[10] have indicated that the electric quadrupole transitions from the 1.63-Mev level and the 4.25-Mev level were enhanced some twenty times over the single-particle estimate. The spins, parities, and lifetimes of the first three levels of Ne^{20} suggest that they form the first three members of a perturbed rotational band. Preliminary evidence for a level in Ne^{20} at about 7.6 Mev has been obtained recently in a study of gamma-gamma coincidences[11] and a magnetic spectrometer analysis[12] of the alpha particles from the reaction $C^{12}(C^{12},\alpha)Ne^{20}$. This level has some of the properties required for a 6+ level but is shown dashed in Fig. 1 because of the preliminary nature of the evidence.

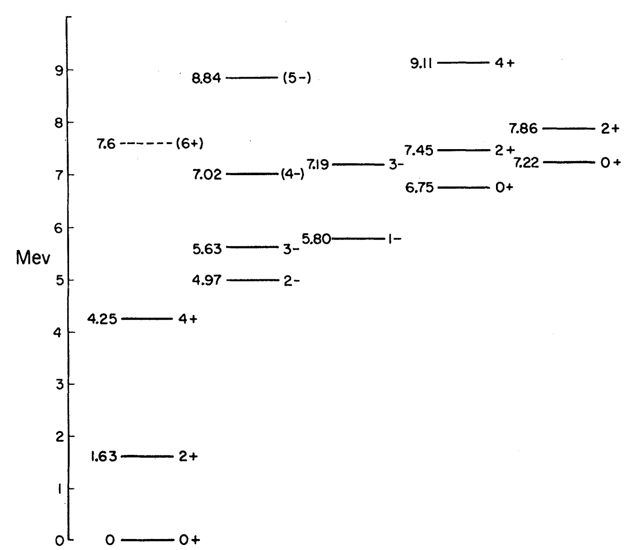

FIG. 1. A separation of the level spectrum of Ne^{20} into rotational bands. A level in Ne^{20} above about 4.75 Mev can break up into O^{16} and an alpha particle if its parity is $(-1)^J$.

Measurements[13] have been made which showed that the spins and parities of the 5.63-Mev level and of a level reported recently by Adams <u>et al.</u>[14] at 5.80 Mev are 3- and 1-, respectively. These assignments together with the measured values[15] of Γ_γ/Γ of 0.07(±0.01) and 0.003 (±0.003) show that both these levels, like the 2- level at 4.97 Mev, have strongly inhibited $E1$ de-excitation widths. Bearing in mind the rotation-like band based on the ground state of Ne^{20}, it was conjectured that the 2-, 4.97-Mev level, the 3-, 5.63-Mev level, and the (5-), 8.84-Mev level[16] formed a negative-parity band. A 4- level would then be expected at an excitation of about 7 Mev. The enhancement of $E2$ transitions within the ground-state rotational band and the strong inhibition of the $E1$ transitions from the 4.97-, the 5.63-, and 5.80-Mev levels[10,15] suggested that the 4- level, if it exists and if it is indeed a member of the postulated rotational band, should decay by $E2$ transitions to the 2-, 4.97-Mev and the 3-, 5.63-Mev levels in strong competition with a possible $E1$ decay to the 4+, 4.25-Mev level.

A new level in Ne^{20} at 7.02 Mev, exhibiting several of the expected properties, has now been located using the $C^{12}(C^{12},\alpha\gamma)Ne^{20}$ reaction. The new level shows gamma-ray transitions to the 2-, 4.97-Mev level and the 3-, 5.63-Mev level with relative intensity approximately 2:1. It is interesting to note that if these gamma-ray transitions are pure electric quadrupole the collective model predicts[17] a relative intensity of 3:1. No other cascade gamma rays with intensities greater than 15% of that for the transition to the 4.97-Mev level have been observed. Alpha-gamma angular correlations are consistent with spin and parity of

4- but do not conclusively prove this assignment. Recent measurements[12] of alpha-particle spectra using a magnetic spectrometer at 0°, 10°, and 50° to the beam show that the 7.02-Mev state very probably has parity $(-1)^{J+1}$.

In Fig. 2 the energy levels of Ne^{20} are plotted as a function of $J(J+1)$. In this plot one can see deviations from the simple rotational expression, $E(J)=(\hbar^2/2\mathscr{I})J(J+1)$. The lines connecting states of each rotational band are expected to be approximately parallel and this appears to be the case. The average slope of the lines, which is equal to $\hbar^2/2\mathscr{I}$, is approximately 150 kev. This may be compared with a slope of about 135 kev expected for the rotations of a rigid spheroid of distortion parameter[1] $\delta \sim 0.3$. The dashed lines shown in Fig. 2 are possible extensions of the rotational bands.

The absence of a 1- level below the 2-, 4.97-Mev level indicates that the band based on that level can be assigned a K-quantum number of 2. Possible levels of spin and parity 2- and 4-, which might be members of the band based on the 1-, 5.80-Mev level, have not yet been observed and the present evidence suggests that they do not exist. This point is of interest because the 1-, 5.80-Mev level and the 3-, 7.19-Mev levels may then be the first two members of a band with $K=0$. If negative-parity bands with $K=0$ and $K=2$ can be established conclusively, then it is possible that these bands may be explained as rotations of the Ne^{20} nucleus which is undergoing surface octupole vibrations.[18] The alternative explanation that the negative-parity bands are based upon states of particle excitation must also be considered. According to the Nilsson model,[19] the lowest of these is expected to be a configuration in which one particle is removed from the [101] level and put into the [211] level. Such particle configurations would give rise to two bands of $K=1-$, $J=1$, 2, 3, etc., and $K=2-$, $J=2$, 3, 4, etc. Calculations[20] indicate that these bands would not occur as low as 5 Mev in Ne^{20} and the absence of the $J=2-$ level at ~6.3 Mev argues against a $K=1$ assignment to the band based on the $J=1-$ level at 5.8 Mev.

Clearly more experimental evidence is required on the existence of other band members and their properties before a complete account of Ne^{20} is possible. However, the collective model gives a good account of the properties of the low-lying levels of Ne^{20} which are known at present.

We would like to acknowledge the stimulating interest shown in this work by Dr. L. G. Elliott.

[1]A. E. Litherland, H. McManus, E. B. Paul, D. A. Bromley, and H. E. Gove, Can. J. Phys. 36, 378 (1957).

[2]H. E. Gove, Proceedings of the International Con-

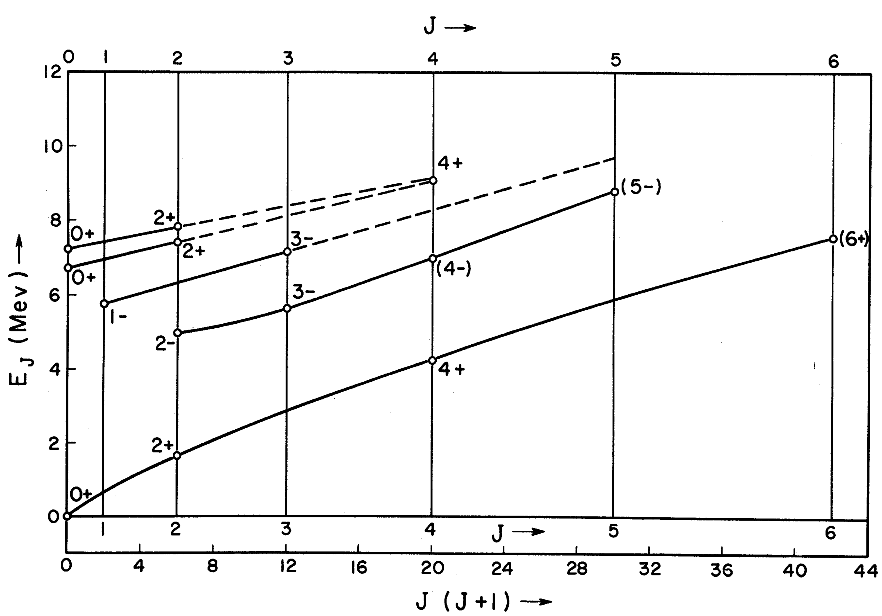

FIG. 2. The energies of the levels in Ne^{20} are plotted against $J(J+1)$, where J is the total angular momentum of the level. Solid lines join the levels that are suspected to form rotational bands.

ference on Nuclear Structure, edited by D. A. Bromley and E. Vogt (University of Toronto Press, Toronto, 1960), p. 438 ff.

[3]J. P. Elliot, Proc. Roy. Soc. (London) A245, 128 (1958).

[4]C. Broude and H. E. Gove, Bull. Am. Phys. Soc. 6, 37 (1961).

[5]H. E. Gove, A. E. Litherland, and M. A. Clark (to be published).

[6]E. Almqvist, D. A. Bromley, J. A. Kuehner, and B. Whalen (to be published).

[7]H. E. Gove, A. E. Litherland, and M. A. Clark (to be published).

[8]S. Devons, G. Manning, and J. H. Towle, Proc. Phys. Soc. (London) A69, 173 (1956).

[9]M. A. Clark, H. E. Gove, and A. E. Litherland, Bull. Am. Phys. Soc. 6, 249 (1961), and to be published.

[10]I. Kh. Lemberg, Proceedings of the Second Conference on Reactions Between Complex Nuclei, edited by A. Zucker, E. C. Halbert, and F. T. Howard (John Wiley & Sons, New York, 1960), p. 112.

[11]A. E. Litherland, M. A. Clark, and H. E. Gove (to be published).

[12]E. Almqvist and J. A. Kuehner (to be published).

[13]J. A. Kuehner (to be published).

[14]H. S. Adams, J. D. Fox, N. P. Heydenburg, and G. M. Temmer, Bull. Am. Phys. Soc. 6, 250 (1961), and private communication.

[15]J. A. Kuehner and E. Almqvist (to be published).

[16]L. C. McDermott, K. W. Jones, H. Smotrich, and R. E. Beneson, Phys. Rev. 118, 175 (1960).

[17]G. Alaga, K. Alder, A. Bohr, and B. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. 29, No. 9 (1955).

[18]P. O. Lipas and J. P. Davidson, Bull. Am. Phys. Soc. 6, 232 (1961).

[19]B. R. Mottelson and S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Skrifter 1, No. 8 (1959).

[20]T. D. Newton (private communication).