Title
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Abstract

A very unusual rotational band has been found in ^{178}Os. It consists of seven regularly spaced transitions about 36 keV apart, which corresponds closely to that of the superdeformed band in ^{152}Dy after an $A^{5/3}$ normalization. This band populates the yrast band directly, thus permitting rather reliable spin assignments. Based on these, the moment of inertia $J^{(1)}$ is found to be much smaller than the $J^{(2)}$ derived from the above γ-ray spacings. The most likely interpretation of this is a band with large deformation which is undergoing systematic changes in deformation, pairing and/or alignment.

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In this paper, we report the discovery of an unusual band in ^{178}Os.This band connects directly to the yrast band and has a very large moment of inertia $J^{(2)}$. It is the first time, to our knowledge, that a discrete band has been seen with a $J^{(2)}$ so much larger than the kinematic moment of inertia $J^{(1)}$.

The nucleus ^{178}Os was produced at the 88-inch cyclotron of the Lawrence Berkeley Laboratory in the $^{154}Sm(^{29}Si,5n)^{178}Os$ reaction using beams of 150 and 155 MeV ^{29}Si. The ^{154}Sm target was composed of two or three self-supporting foils, each 0.5 mg/cm^2 thick. The γ rays emitted by the reaction products were observed in 20 Compton-suppressed Ge detectors of the HERA array. Only three- and higher-fold events were recorded on magnetic tape. During the 155 MeV run the two-fold events were also recorded directly into a two dimensional matrix (2048 x 2048) in an external memory. In order both to reduce the event rate being digitized, and to observe preferentially the spectra of higher multiplicity, the two-fold events were gated by one or more of eight 5"x 6" NaI(Tl) detectors. In the 150 MeV run, 55 million three- and higher-fold events were recorded, and in the 155 MeV experiment, 220 million such events and 994 million double-gated coincidences were accumulated. The prompt gamma rays recorded by the Ge detectors were Doppler-shifted, hence the gains of the detectors were adjusted so that all the spectra had the same energy calibration and could be added.

A double-coincidence analysis was carried out, where each three- and higher-fold event was broken into pairs. Ridges about 36 keV apart were observed in the background-subtracted two-dimensional matrix[1]. Further analysis revealed a band of seven regularly-spaced transitions about 36 keV apart. Each line is in coincidence with the other members of the band and each one is in coincidence with the known[2,3] yrast rotational band of ^{178}Os.

Figure 1a shows the sum of the coincidence spectra gated by the six lowest members of the regularly spaced (new) band (after background subtraction).

In addition to the new band seen in Fig. 1a, only the yrast-band transitions in ^{178}Os appear at lower energies. We have also observed a new 803.5 keV gamma transition in coincidence with the lines, but we did not see the 833 keV transition that had been previously placed[3] as the top line in the yrast band. Gates set on the top lines of the yrast band, i.e., the 643, 719, and 772 keV transitions, produced only the new band and the 803 keV line above these energies and yielded the relative intensities shown in Table 1. Figure 1a shows the intensity pattern obtained when gates are set on several members of the new band. From this spectrum, it appears that this band feeds the yrast band with full intensity (after correcting for the missing counts in the lines used as gates, for the relative intensities of the lines, and for the efficiency of the detectors, every peak has the same number of counts, N_γ in Table 1). Also, an upper limit of 7% has been found for a combined feeding of the five other bands[3]. Thus, the evidence is strong that the band feeds directly into the yrast band and forms a direct continuation of that band. The proposed level sequence is shown in Fig. 1b.

The spin assignments were deduced from angular correlation data[4]. Eight detectors were in the forward or backward directions with a mean angle of ~36° to the beam axis and six were at ~100°. The coincidence events were sorted into a two-dimensional spectrum (x,y) with the 36° detectors along the x axis and the 100° ones along the y axis. The quantity R is the ratio of the intensity of a known quadrupole line (x axis) in coincidence with an unknown line (y axis) to that when x and y are interchanged. If the unknown transition is of stretched quadrupole character, then R=1. If the unknown line is a stretched dipole, R=2 (assuming short lived states, <1 psec, where the deorientation of the nucleus is small). In Table 1, the R values are given for some lines in the new band and for some in the yrast band. To improve statistics, these were obtained by using as gates yrast lines down to the

488 keV line. In the last row of the table, the R value of the 904.4 keV dipole transition is given for comparison. The R value smaller than two for this line is probably due to a partial deorientation of the nucleus. The R values for the five lower members of the new band and for the three uppermost yrast transitions are certainly consistent with stretched E2 transitions, and a stretched dipole assignment can be ruled out for any of them. The intensities of the remaining two transitions were too weak to make any assignment, so the suggested spins for them are placed in brackets.

In Fig. 2a, the angular momentum (I) versus the rotational frequency ($\hbar\omega$) is shown for ^{178}Os and some other neighboring even Os nuclei. The pronounced S shape pattern in ^{184}Os, due to the crossing of a band having a rotational-aligned pair of $i_{13/2}$ neutrons[3,5], is gradually washed out for the lighter Os nuclei. Two features are special to ^{178}Os. First, the slope for the new band (which for equal moments of inertia, $J^{(1)} = J^{(2)}$, would have passed through the origin) is very steep (has a high value of $J^{(2)}$) and has a negative intercept (I=-18). Second, it appears that the line connecting the higher-energy states could be a direct continuation of the upbending curve below the backbend. Since one possibility for this upbending was a change in the ground-state deformation as a function of frequency[5], the continuation might signify a continued gradual stretching of the nucleus.

As can be seen from Fig. 2b, the value of the moment of inertia $J^{(2)}$ for the new band is $J^{(2)}=110\hbar^2$/MeV. Judging from this alone, one tends to conclude that this is a highly deformed band. In fact the $J^{(2)}$ value corresponds rather closely to that of the superdeformed (SD) (ε_2=0.6) band[6] in ^{152}Dy after an $A^{5/3}$ normalization. Since in the present work the spin assignments and the connection of the band to the ground state band are known, we can, in addition, derive values of $J^{(1)}$ which are also plotted in Fig. 2b. Whereas the $J^{(2)}$ values of the band are well above the rigid-sphere result, the $J^{(1)}$ values are barely equal to this result at the top of the band. Such behavior is unusual and we will discuss in the following paragraphs the gradual changes in alignment, pairing and/or deformation that could be explanations for it.

A priori, a change in pairing or shape seems to be more likely than one in alignment, since either of the former could naturally result in a larger $J^{(2)}$, and thereby in a steeper slope on Fig. 2a, whereas the latter would not. On the other hand, during a gradual change in any of these three processes, $J^{(2)}$ can temporarily become large; and, in fact, a behavior somewhat similar to that observed here has been seen[7,8] in ^{156}Dy and ^{157}Ho and attributed to an alignment effect. However, the effects are either different or much larger in ^{178}Os, since: (a) the value of $J^{(2)}$ for the latter is about 20% larger, even after correction by $A^{5/3}$; (b) the ratio of $J^{(2)}$ to $J^{(1)}$ is 1.45 for Os, and only 1.18 and 1.05 for Dy and Ho, respectively; and (c) the I intercept in the plot of I versus $\hbar\omega$ is -18 for Os and -7 and -1.5 for Dy and Ho, respectively. The most unusual feature in ^{178}Os is the large difference between $J^{(2)}$ and $J^{(1)}$, where the former is of "superdeformed" size, while the latter does not even reach the rigid-sphere value. Since ^{178}Os is clearly deformed, the very small value of $J^{(1)}$ probably indicates that the pairing correlations are still present--a conclusion consistent with the rather low spins involved. The very large $J^{(2)}$ value may well be associated then with the decrease in pairing with increasing spin.

In the following, we attempt to estimate the effect on the moment of inertia of changes in pairing and deformation, assuming for the moment that the alignment remains constant. In Fig. 3, $J^{(1)}/J_{rig}$ values are plotted versus the deformation ε_2 for various values of the energy gap (Δ) parameters, using formulas given by Bohr and Mottelson[9] (these are for even-even nuclei with $\gamma=\varepsilon_4=0$). On the same plot are drawn the experimental $J^{(1)}/J_{rig}$ values for the top of the new band, the bottom of the new band and the bottom of the ground-state band. The dashed vertical arrows starting on the Δ=0.5 and Δ=1.0 MeV curves represent two possible solutions for the variation in Δ over the band assuming the deformation is constant. Similarly, the arrows on the Δ=0.5 and 1.0 MeV curves represent the possibilities for increasing the deformation without changing Δ. Of course, there could also be combinations of these changes. Since we suppose Δ is likely to lie between 0.5 and 1.0 MeV, the most likely situations seem to us to be between these two possibilities and are indicated by the two solid arrows, corresponding to a deformation of ε_2=0.4±0.1. Hence, it is plausible that the new band is a highly deformed band having deformation similar to the SD bands[10,11] in the Ce-Nd region. Still, the new band in ^{178}Os differs from the SD Ce-Nd bands in that $J^{(2)}$ is much larger than $J^{(1)}$.

Thus, this band in ^{178}Os can be readily explained as one undergoing modest changes in pairing and/or deformation. However, alignments, which represent changes in the quasiparticle population, are frequently the triggers of other changes in deformed nuclei. So, a plausible scenario in ^{178}Os would be an alignment in a band with rather large deformation, accompanied by changes in pairing and/or deformation (including shape). Why such a combination would produce a long regular band is not really clear, but if the interaction between the bands involved in the alignment is rather large, it seems reasonable that the whole process might proceed in a steady (equilibrated) manner. It appears to us likely that this same kind of thing is happening in the ^{156}Dy and ^{157}Ho cases, which are not so likely to be simple alignments with enormous interaction strengths (as previously analyzed). Another case where there is more direct evidence for simultaneous changes occurring in a band is in ^{166}Yb, where at spins ~30, the deformation in the yrast sequence decreases rather dramatically while both $J^{(1)}$ and $J^{(2)}$ remain surprisingly constant and equal, due presumably to a concurrent change in pairing and/or alignment[12]. While such simultaneous changes are not really understood in detail, it is well known that there are rather strong influences of pairing, deformation (shape), and alignment on one another. The unusual band in ^{178}Os is the most striking manifestation of this interplay that has been so far observed, if that is indeed the explanation for this behavior, and offers us a chance to study this process in much greater detail. An obvious next step is to measure the lifetimes of these states (which are sensitive mainly to the deformation), and we are planning to do this.

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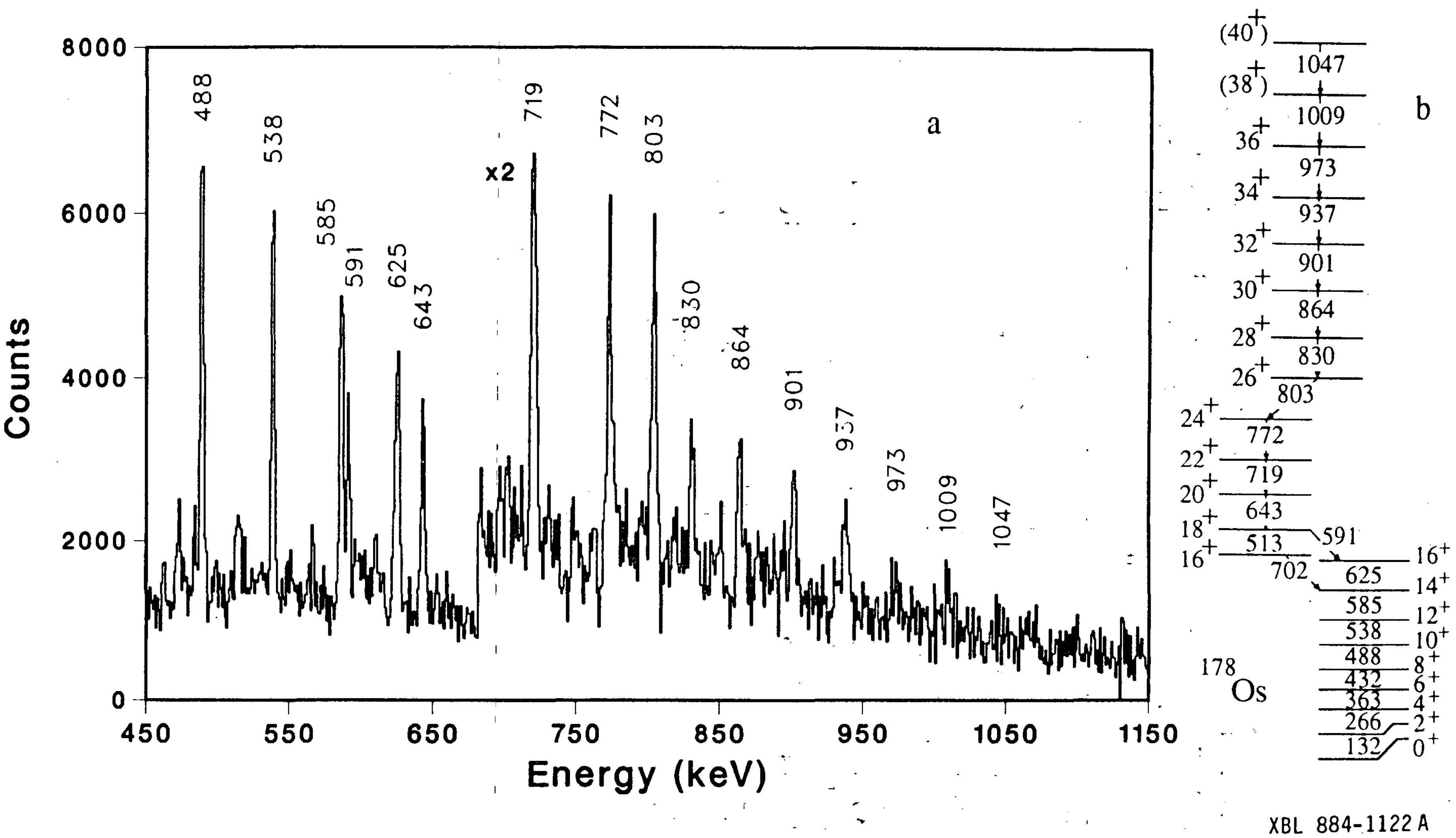

Counts
Energy (keV)
a
b
x2
488
538
585
591
625
643
719
772
803
830
864
901
937
973
1009
1047
178 Os
XBL 884-1122 A

Fig. 1

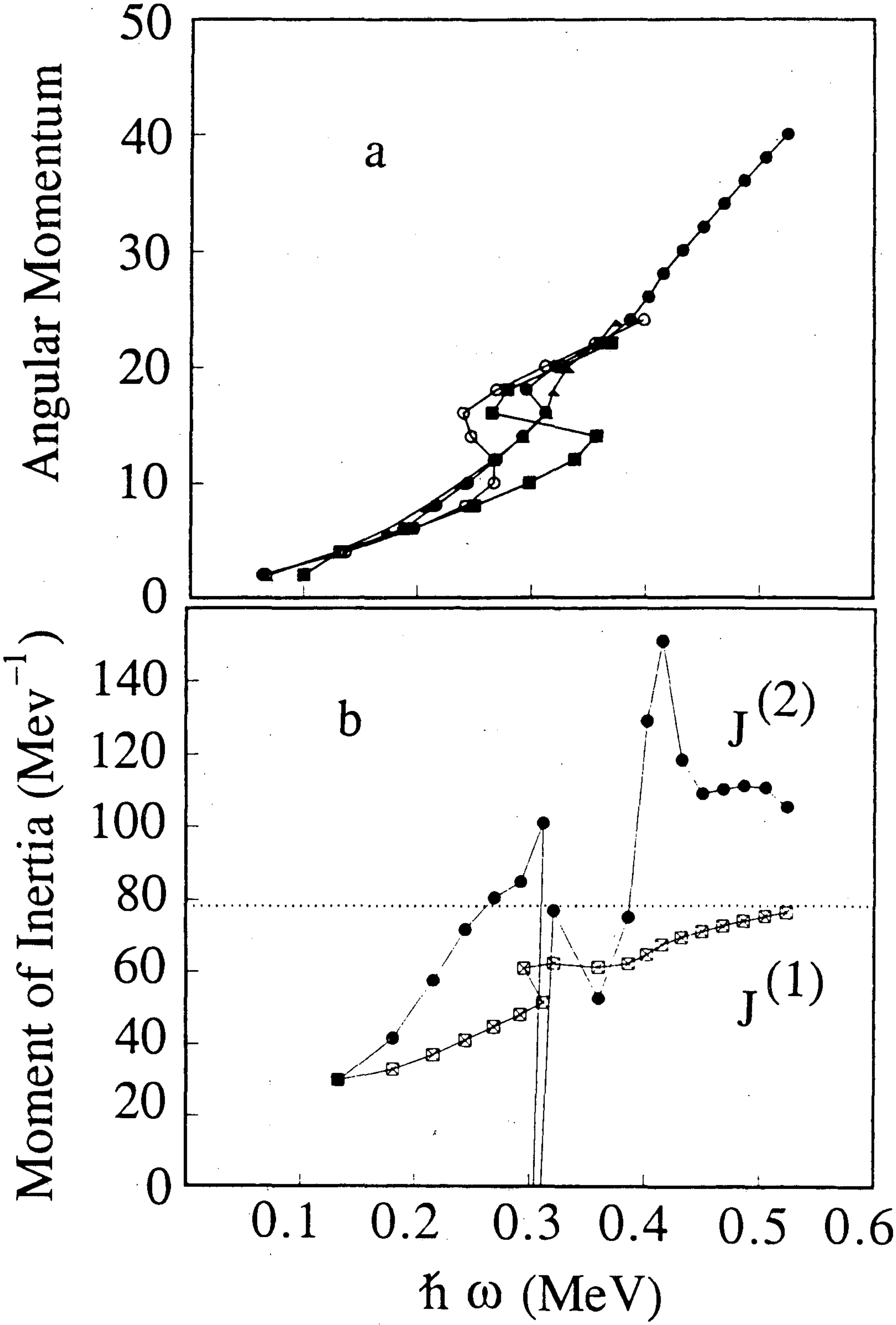

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Fig. 2

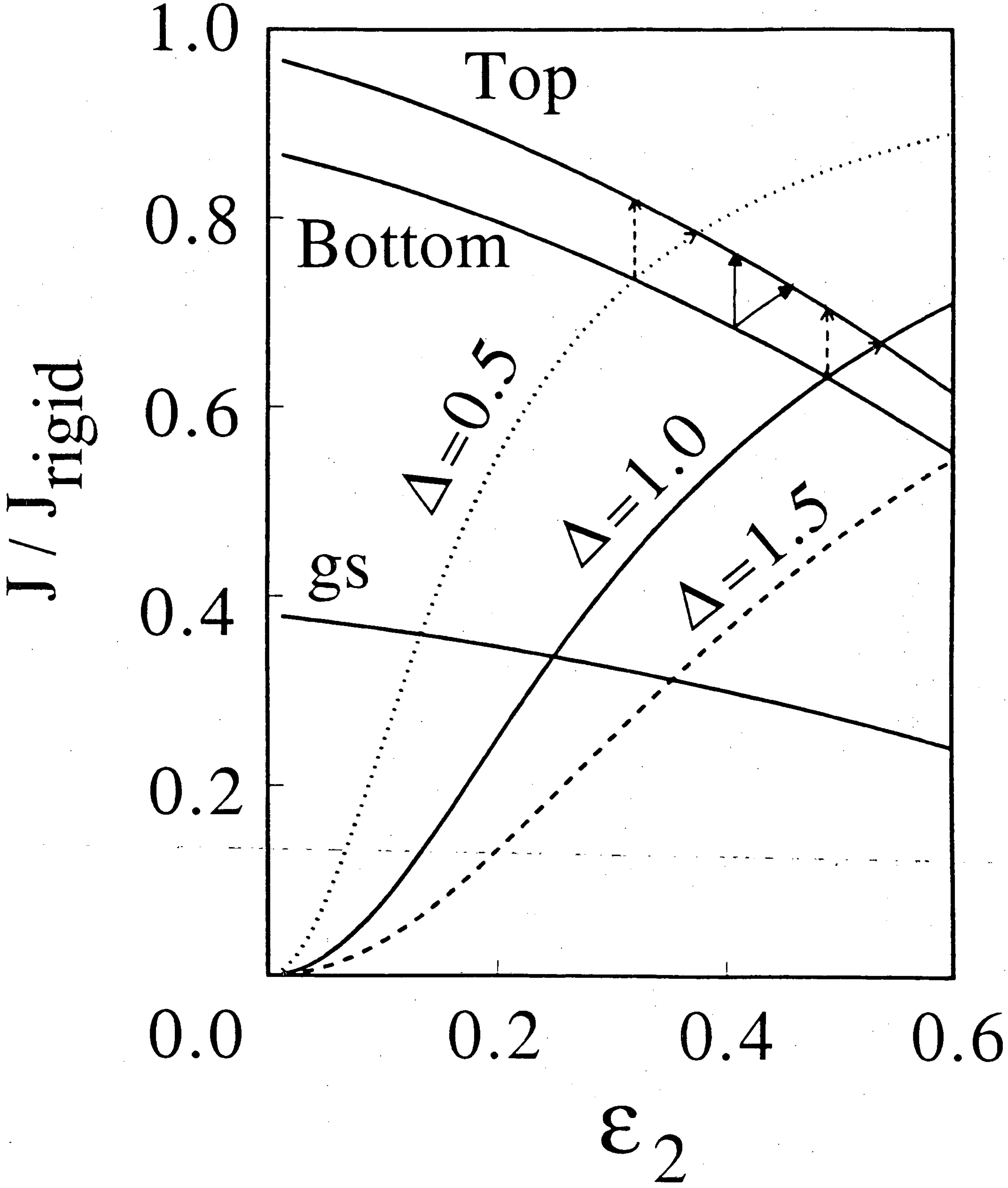

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Fig. 3