Comment on "Two-phonon γ-vibrational strength in osmium nuclei"

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Claims in a recent paper by Wu *et al.* [Phys. Rev. C **64**, 014307 (2001)] for the $\gamma\gamma$ character of $K^{\pi}=4^{+}$ bands are based on a flawed argument. A paper they do not cite has explained this weakness in detail, and concluded a dominant *g* boson or hexadecapole structure is required to explain other data inconsistent with the $\gamma\gamma$ description.

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Wu *et al.* [1] report new lifetime measurements for levels in ^{188,190}Os which provide satisfying confirmations of earlier $B(E2)$ values from Coulomb excitation experiments [2]. They then conclude that the new experimental results also provide confirmation for their earlier $\gamma\gamma$ interpretation [3] of the $K^{\pi}=4^{+}$ bands. The purpose of the present Comment is to point out there is a weak link in the chain of logic leading to this conclusion, and also that this problem has already been discussed in detail in Ref. [4], which was not cited by Wu *et al.* [1].

Wu *et al.* consider the ratio

$$R=\frac{\langle K=2|E2|K=4\rangle}{\langle K=0|E2|K=2\rangle},$$

in which $\langle K=2|E2|K=4\rangle$ is the intrinsic $E2$ matrix element connecting the $K^{\pi}=4^{+}$ band with the γ band, and $\langle K=0|E2|K=2\rangle$ is the one connecting the γ and ground bands. This ratio was shown to be consistent with the value $\sqrt{2}$ expected if the $K^{\pi}=4^{+}$ band were a double-γ phonon. The weak link is in the claim that this consistency implies the $K^{\pi}=4^{+}$ bands have a dominant $\gamma\gamma$ character, a conclusion which cannot be safely made since other configurations in the $K^{\pi}=4^{+}$ bands are also expected to contribute to the $E2$ strengths, as will be explained below. In other words, an observed ratio R consistent with $\sqrt{2}$ would be a *necessary* condition for a pure double-phonon configuration, but is not a *sufficient* condition to claim a $\gamma\gamma$ interpretation for the band.

As acknowledged by Wu *et al.* [1], the $\gamma\gamma$ interpretation is not consistent with several other types of data, such as (p,p') results for ^{192}Os which showed the $K^{\pi}=4^{+}$ band was populated with an $E4$ strength several orders of magnitude too large for a $\gamma\gamma$ interpretation, and required a dominant *g* boson (or hexadecapole) structure for the $K^{\pi}=4^{+}$ band [5]. (α,α') results [6] showed similar large $E4$ strengths for $K^{\pi}=4^{+}$ bands in ^{188,190}Os. Also, the $(^{3}\mathrm{He},d)$, (t,α), and $(d,^{3}\mathrm{He})$ single-proton-transfer reactions show large admixtures of the $5/2^{+}[402]_{\pi}+3/2^{+}[402]_{\pi}$ two-quasiparticle (2QP) configuration in the $K^{\pi}=4^{+}$ bands of each isotope (amplitudes squared of $\sim$30%, $\sim$45%, and $\sim$54% in ^{188,190,192}Os, respectively) [4,8]. These 2QP components are inconsistent with a $\gamma\gamma$ interpretation [7], but are explained almost quantitatively if the $K^{\pi}=4^{+}$ bands are predominantly single-phonon hexadecapole excitations, since quasiparticle phonon nuclear model (QPNM) calculations predict the $5/2^{+}[402]_{\pi}+3/2^{+}[402]_{\pi}$ component should make up about half of the $K^{\pi}=4^{+}$ hexadecapole phonon and the other 2QP components are ones which would not be observed in the proton-transfer reactions.

A key point emphasized in Ref. [4], which weakens considerably the arguments based on $E2$ strengths, is that the $K^{\pi}=4^{+}$ bands can be expected to have other components than the $\gamma\gamma$ ones contributing to the $E2$ strength to the γ bands. As described in Ref. [4], several earlier works [7–11] point out that *sdg* interacting boson approximation (IBA) calculations predict the lowest $K^{\pi}=4^{+}$ band has primarily a Γ (*g* boson, or single-phonon hexadecapole) character. All the *sdg* IBA calculations predict large $E2$ strengths coupling the $K^{\pi}=4^{+}\Gamma$ and γ bands. Kuyucak warned [12] that $E2$ decays from a $K^{\pi}=4^{+}\Gamma$ band mimic those from a $\gamma\gamma$ band, so it is very difficult to distinguish between these configurations by examining the $E2$ decays. The $E2$ strengths from the Γ configurations are quite large. For ^{188,190,192}Os, *sdg* IBA calculations [11] yielded $B(E2;I,K^{\pi}=4,4^{+}\rightarrow I,K^{\pi}=2,2^{+}_{\gamma})$ values of $\sim$10 W.u., comparable to the experimental values. (Matrix elements for decay to some other members of the γ band were underestimated by factors up to $\sim$2, but further efforts to "fit" these were not made due to limited availability of computer time [13]. However, even if fine tuning these calculations did not improve the agreement, the factor of $\sim$2 for these cases could correspond to approximately equal $E2$ transition amplitudes from the configurations in Ref. [11] and $\gamma\gamma$ components added coherently, in contrast to the claim of Wu *et al.* [1] that the $\gamma\gamma$ components make up $\geqslant$75% of the $K^{\pi}=4^{+}$ bands.)

The *sdg* IBA results [11] were criticized [3] because some $E2$ matrix elements were underpredicted, as mentioned above, yielding some $E2$ intensities a factor of $\sim$4 too small. However, Baker *et al.* [5] report that the $E4$ matrix element is $\sim$60 times larger than predicted for the IBA 4^{+} state that is analogous to the $\gamma\gamma$ $K=4$ bandhead, so the $E4$ strength is $\sim$3600 times too large for a $\gamma\gamma$ state. This discrepancy for the $\gamma\gamma$ interpretation is much more serious than the factor of $\sim$4 for the Γ description.

Wu *et al.* [1] overestimate the $\gamma\gamma$ to γ $E2$ strength by assuming the total amount coupling the bands is due to the $\gamma\gamma$ component. Until the $E2$ contributions from the Γ and $\gamma\gamma$ components can be determined separately, conclusions

TABLE I. Successes of different $K^{\pi}=4^{+}$ band interpretations for various types of data.

Type of data	$\gamma\gamma$ interpretation	$K=4$ Γ, (or hexadecapole) interpretation
$E2$ strengths: $K^{\pi}=4^{+}\rightarrow K^{\pi}=2^{+}_{\gamma}$	(√)	(√)
$B(E4{:}0^{+}_{\text{g.s.}}\rightarrow 4^{+}_{K=4})$	×	√
$\frac{5}{2}^{+}[402]_{\pi}+\frac{3}{2}^{+}[402]_{\pi}$ 2QP component	×	√

drawn from the $E2$ data about the character of $K^{\pi}=4^{+}$ bands are ambiguous, and the $E4$ and 2QP results should be considered more meaningful.

The overall situation is summarized in Table I, where √ indicates that an interpretation explains the experimental results, and × indicates that it does not. Parentheses for the $E2$ data indicate the uncertainty which exists because for the Γ interpretation full quantitative agreement has not yet been achieved, and for the $\gamma\gamma$ one it is not yet clear how much of the observed strength should be attributed to decay of each of the Γ and the $\gamma\gamma$ components. More work (of a theoretical nature) is required to reduce these uncertainties. Since the Γ (hexadecapole) interpretation can reproduce much of the $E2$ strength, and is required as the dominant component to explain the $E4$ and 2QP results quantitatively, the best explanation of *all* the available data is obtained if the $K^{\pi}=4^{+}$ bands have predominantly a *g* boson (or hexadecapole) character, rather than a $\gamma\gamma$ one.

Intuitively, transitions between Γ and γ bands could be considered the destruction of one phonon and creation of another, so strong $E2$ decays might not be expected. However, an explanation in terms of the detailed microscopic structures of the individual phonons was proposed in Ref. [4]. It involved the coherent summation of favored $E2$ transitions connecting specific 2QP components predicted by random-phase-approximation calculations to dominate the hexadecapole and γ phonons. This suggested explanation was supported by preliminary QPNM predictions of $\sim$3 W.u. for $B(E2;I,K^{\pi}=4,4^{+}\rightarrow I,K^{\pi}=2,2^{+}_{\gamma})$. Although this is smaller than the experimental value by a factor of ~ 3, it is still very large for a microscopic calculation, and indicates such effects are too important to be ignored.

Thus the QPNM and IBA, two of the most successful and used models for heavy deformed nuclei, both predict the lowest $K^{\pi}=4^{+}$ band has a Γ character, consistent with the strongest evidence from experimental data as seen in Table I. (The sd IBA predicts a $\gamma\gamma$ character for the same band, and this difference in predictions indicates the truncation to only *s* and *d* bosons is not justified for these states.) Also, both the QPNM and IBA predict large Γ to γ $E2$ transitions, so it is a serious omission to ignore them. Smaller $\gamma\gamma$ components are undoubtedly present also. More precise estimates of their sizes could be obtained from a theoretical study sufficiently general to include all expected modes of excitation, and capable of giving predictions for all types of available data, including $E2$, $E4$, and single-nucleon transfer strengths. Since the experimental strengths are large for all these data types in ^{188,190,192}Os, these isotopes are an ideal testing ground for studying the interplay of these various modes of excitation. It is hoped this Comment will inspire such a study.

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