

Reply to “Comment on ‘Two-phonon γ -vibrational strength in osmium nuclei’ ”

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The claim that the two-phonon γ -vibrational configuration constitutes a major component for the $I_K^\pi=4_4^+$ states in osmium nuclei is based on solid experimental evidence, such as the systematics of the excitation energies, the absolute $E2$ strengths, the branching ratios, and the static quadrupole moments. Nevertheless, a non-negligible two-quasiparticle or hexadecapole component must exist in order to explain the observed $E4$ strength and the cross sections for the nucleon-transfer reactions.

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Burke argues in his Comment [1] that the $I_K^\pi=4_4^+$ states in Os isotopes near $A=190$ have large hexadecapole components in contrast to our conclusion that the two-phonon γ -vibrational components are dominant. Actually, this discussion started with previous Coulomb excitation studies, which suggested strongly enhanced $B(E2)$ values for the transitions between the $K=4$ and $K=2$, γ -vibrational bands, giving evidence for the two-phonon γ -vibrational strength. Since the determination of the electromagnetic matrix elements for multiple Coulomb excitation involves a complex analysis, one point of our recent paper [2] was to confirm these early results with a direct lifetime measurement. Indeed, the enhanced interband $B(E2)$ values, up to 47 W.u., were verified. By taking into account of all the existing data mentioned in both Refs. [1,2], one can conclude that *both* the hexadecapole and two-phonon γ -vibrational degrees of freedom are important in our understanding of the properties for the $I_K^\pi=4_4^+$ states in Os isotopes. To assess the different claims of Refs. [1,2], it is worthwhile to briefly summarize the experimental evidence and, most importantly, the relative uncertainties in the data.

The suggestion of the existence of two-phonon γ -vibrational states ($I^\pi=4^+$ and $K=4$) in osmium nuclei was made long ago [3,4]. The evidence includes their excitation energies, which lie at nearly twice those of the one-phonon states, and their decay branching ratios. However, the most convincing evidence is the enhanced $E2$ matrix elements between the suggested two- and one-phonon states, measured by Coulomb excitation [5].

The enhanced interband $E2$ strengths, which range up to 47 W.u., give only qualitative evidence for the existence of the two-phonon γ -vibrational configuration in the $I_K^\pi=4_4^+$ states. A quantitative discussion of the two-phonon γ -vibrational component must be made in the intrinsic frame because the interband matrix elements are modified by the coupling between the rotational and intrinsic motions. The analysis done in Ref. [6] paved a practical path to determine the intrinsic matrix elements for the phonon states by subtracting this coupling contribution. From the measured pho-

non strengths, it is concluded that the two-phonon γ -vibrational configuration constitutes a major component for the $I_K^\pi=4_4^+$ states in osmium nuclei. Note that these intrinsic matrix elements were determined by a fit to not only the absolute magnitudes of the interband matrix elements but also their relative ratios. This process is rigorous and unambiguous. The lifetime measurements [2] provide an independent experimental confirmation of the measured $E2$ strength.

Burke's argument for large hexadecapole strength in the $I_K^\pi=4_4^+$ states for osmium nuclei is based on large cross sections observed via light-ion induced reactions and the inferred $E4$ strength from both (α, α') [7,8] and (p, p') [9] reactions. Significant two-quasiproton admixtures, ranging from $\sim 30\%$ for ^{188}Os to $\sim 54\%$ for ^{192}Os , were derived from the (t, α) [10–12] reaction, which may be consistent with the suggestion of a large hexadecapole degree of freedom in those states. These admixtures are about 50% higher than those determined from the electromagnetic probes, which range from $\leq 25\%$ for $^{188,190}\text{Os}$ to $\approx 35\%$ for ^{192}Os .

Actually, these apparent discrepancies may not be as significant as might appear in view of the $\leq 30\%$ uncertainty [12] assigned to the hadronic-probe experiments and the $\leq 14\%$ assigned for the electromagnetic probes. The uncertainty for both probes originates mainly from systematic errors.

Thus, considering the uncertainties in the admixtures of hexadecapole or two-quasiparticle contributions determined by either electromagnetic or hadronic probes, we believe that there are no significant discrepancies between our interpretation of the data and that put forward by Burke. Evidently, there is a non-negligible two-quasiparticle component existing for the $I_K^\pi=4_4^+$ states in the Os isotopes pointing toward a hexadecapole component as well as a strong two-phonon γ -vibrational component. In light of this, we feel that Table I in Burke's Comment is an oversimplification, since it conveys the impression that the structure is either one mode or the other. While the data for some of the observables, such as the $B(E4)$ value, clearly point to hexadecapole components, it is hard to quantify the strength of that component without resorting to a model (e.g., for the expected collectivity of a

hexadecapole vibrator). Also, that observable does not argue against a two-phonon γ -vibrational structure—it is merely insensitive to it. We do agree with Burke's remark that, whatever the absolute magnitudes, the two-phonon γ -vibrational

component is larger in ^{188}Os and ^{190}Os than in ^{192}Os . We also support his call for more theoretical work to seek a more complete understanding of the wave functions of the $K=4$ states in the Os isotopes.

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