Ultrasonic investigation of off-center rattling in \( \text{Pt}_{0.55}\text{Nd}_{0.45}\text{Os}_4\text{Sb}_12 \)

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**Introduction**

Filled skutterudite PrOs\(_4\)Sb\(_{12}\) is of particular interest because this compound exhibits unconventional superconductivity and magnetic field-induced quadrupolar-order. NdOs\(_4\)Sb\(_{12}\) exhibits mean-field-type ferromagnetism. Both systems possess large Sommerfeld coefficient (shown on the right). These two compounds also show ultrasonic dispersion(s) singularity ~35 K for LaOs\(_4\)Sb\(_{12}\) and PrOs\(_4\)Sb\(_{12}\), double dispersions ~15 K and ~40 K for Nd, and also low temperature softening in C\(_{11}\) related elastic constants in PrOs\(_4\)Sb\(_{12}\) and LaOs\(_4\)Sb\(_{12}\) due to a thermally activated off-center motion of the rare-earth ion in an oversized atomic cage, known as ‘Rattling’ and ‘Tunneling’.

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**Motivation**

Present research is motivated to verify a systematic change of rattling parameter in Pr\(_{1-x}\)Nd\(_x\)Os\(_4\)Sb\(_{12}\) and successive transitions at low temperature, which is probably due to SC and FM coexisting at \( T = 0.76 \) K. The inset shows a comparison of low-temp physical properties. [5]

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**Experimental Details**

The six numbered open spheres illustrated in the cage represent the positions of off-center potential minima along [100]. The \( T_\Gamma \) off-center mode is described by two charge distributions (a) \( \rho_{\Gamma 23} \) and (b) \( \rho_{\Gamma 0} \). The inset is detailed behavior between 8 K to 20 K.

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**Results**

Fig. 2 (a) Frequency dependence of elastic constant \( C_{11} \) as a function of temperature. Upper and lower arrows display temperature that satisfy resonant condition \( \omega = T \). (b) Estimated rattling parameters possesses intermediate value between PrOs\(_4\)Sb\(_{12}\) (\( \omega = 115 \) K) and NdOs\(_4\)Sb\(_{12}\) (\( \omega = 337 \) K).

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**Summary**

1. Elastic constant \( C_{11} \) exhibits double ultrasonic dispersions at ~15 K and ~40 K, which are similar to the features found in NdOs\(_4\)Sb\(_{12}\).
2. Estimated rattling parameters possesses intermediate value between PrOs\(_4\)Sb\(_{12}\) and NdOs\(_4\)Sb\(_{12}\) (\( \omega = 337 \) K).
3. The levels off feature appears in \( C_{11} \) at around 200 K imply that the Nd\(^{3+}\) ion’s degenerate CEF ground state will split due to the FM order even in the Pr\(^{3+}\) ion contributes to superconducting below \( T_c = 0.76 \) K.

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**Reference**