Unusual Particle-to-Wave Phonon Heat Transport in Solids

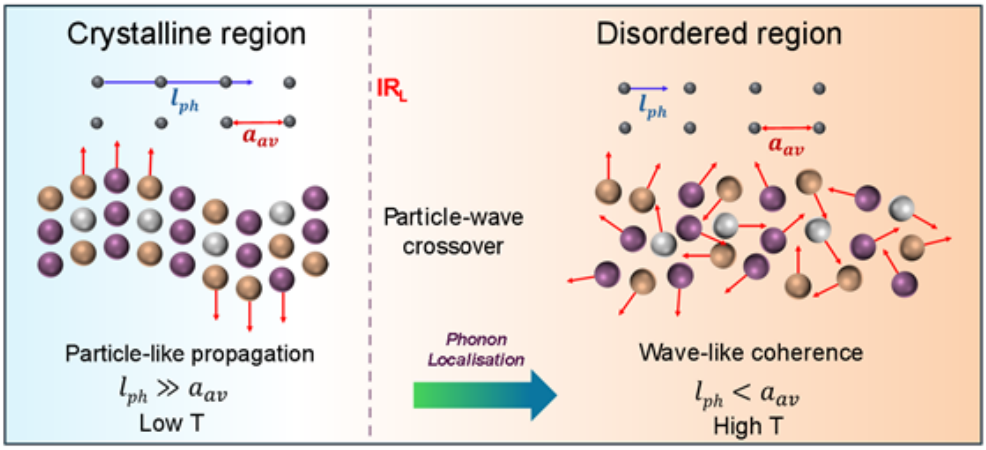
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Why in News?

Recently, Indian researchers discovered a rare particle-to-wave-like phonon heat transport mechanism in Tl_2AgI_3.

- **Tl_2AgI_3 –** It is a ***zero-dimensional inorganic metal halide crystalline material*** with discrete cluster-like building blocks.
  - i.e., A crystal made of tiny isolated groups of atoms.
- **Developed by –** Researchers at ***Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR)***, Bengaluru.
- **Nodal Authority –** Department of Science and Technology (DST).
- **Components –** Tl_2AgI_3 is composed of Thallium (Tl), Silver (Ag), and Iodine (I) atoms.
- Discrete cluster of subunits include $(Tl_6I)^{5+}$ and $(Ag_3I_8)^{5-}$ in the crystal structure.
- **Working Principle – Atomic Repulsion and Distortion –** *Pauling's third rule–driven cation–cation repulsion* causes local structural distortions and anharmonicity.
  - i.e., Positive atoms pushed too close move out of place, creating a shaky structure that blocks heat flow.
- **Phonon Trapping –** This leads to ***phonon localization*** and breakdown of the phonon-gas model.
  - i.e., Heat vibrations get trapped instead of flowing normally through the material.
- **Wave-like Heat Tunnelling –** With rising temperature, heat transport shifts from particle-like scattering to wave-like coherent tunnelling, analysed using the linearized Wigner transport equation (LWTE).
  - i.e., At higher temperatures, heat moves like waves tunnelling through obstacles rather than flowing smoothly.
- **Key Features – Ultralow heat flow** – The material blocks heat so effectively that it performs ultralow thermal conductivity.
- **Heat-proof stability** – Once the material reaches a certain warmth, its ability to block heat stays constant regardless of how much hotter it gets, unlike most materials that change.
- **Applications –**
  - Thermal insulators.
  - Thermoelectric materials.
  - Advanced thermal management technologies.

- **Benefits –** Provides a new design strategy to suppress heat transport using structural confinement and local disorder.
- Enhances understanding of phonon physics in low-dimensional solids.
- **Significance –** Challenges the classical phonon-gas model of heat conduction in crystals.
- Establishes a mixed phononic regime (particle + wave) in crystalline solids.
- Positions India as a leader in fundamental materials research with technological relevance.



Quick Fact

• **Phonons** – They are *quantised sound waves* that represent the collective vibrations of atoms in a solid crystalline structure.
  - Relevant to the behaviour of heat and sound in crystals.
• Phonons play a critical role in heat conduction, particularly in insulating materials where they *facilitate thermal energy transfer, and they also influence electrical resistance in metals*.

Reference

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