Supercomputer Simulations of Superconductors

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Applications of Superconductors

- Maglev trains
  (343 Mi/hr)
- Magnetic resonance imaging (MRI)
- Energy storage
- Power transmission cables
- Electricity generators
- Particle accelerators
- Quantum computers?

The Yamanashi MLX01 MagLev train

MRI of a human skull
What is a Superconductor?

- Resistance is really zero, nothing, nada, all gone!
- Expels magnetic fields:
  See phenomenon at the end of this talk!
Type I Superconductors

- Two states: superconducting and normal.
- Require very low temperatures.
- They are well understood.

Examples:
- Lead $T_c = 7.2 \text{ K} = -446 \text{ F}$
- Mercury $T_c = 4.15 \text{ K} = -452 \text{ F}$

Meissner Effect
Type II Superconductors

- Three states: Superconductor, Normal, Mixed.
- Happen at higher temperatures.
- They are NOT all well understood.

Hg$_{0.8}$Tl$_{0.2}$Ba$_2$Ca$_2$Cu$_3$O$_{8-\delta}$, World record: 138 K (Still -211 F)

![Graph showing the phases of superconductivity](image)
How does it happen?

**Normal Metal:**
- Lattice vibrations are large.
- Electrons collide with lattice ions.
- Energy is lost.

**Superconductor:**
- Lattice vibrations favor forming of Cooper pairs.
- Those pairs form an ordered quantum state.
- Cooper pairs move without loss of energy.
Cooper pairs

- An electron distorts the lattice
- It generates an excess positive charge around itself
- A nearby electron is attracted
- A Cooper pair is formed
Ordered Quantum State

- Let an arrow \( \uparrow \) be a measure of the superconductivity at a certain point.
- The longer, the more superconductivity.
- The arrows need also be ordered to have superconductor.

**Superconducting**

**Non-superconducting**
At low $T$ arrows enjoy pointing in the same direction: Superconductor.

At high $T$, thermal fluctuations make them point randomly: Non-superconductor.

Computer simulations help to understand those states and the transition.

Results from a Computer Simulation
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Superconductors are interesting from both scientific and technological points of view.
Computers help to understand superconductors.
Superconductors have a wide range of applicability.