Why might room temperature superconductivity be useful to discover?

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Since its discovery in 1911, the phenomenon of superconductivity has been a major breakthrough, suggesting a solution for near-perfect energy efficiency. While superconductivity could represent revolutionary development in electrical efficiency, its widespread adoption is hindered by the requirement for intense cooling systems to maintain a cryogenic state. Superconducting materials can conduct electricity with zero resistance and expel magnetic fields entirely, yet this state is fragile, existing only at temperatures near absolute zero. The discovery of Room-Temperature Superconductivity (RTSC) would let us speculate transitioning from a world of energy dissipation to one of quantum efficiency, offering potential solutions to our generation's defining challenge: global warming. This essay argues that the discovery of RTSC serving as a foundational pillar for a sustainable, carbon-neutral civilisation is largely where its value lies, given the increasing need for a response to the growing climate-crisis.

Superconductivity can be explained using BCS theory, standing for Bardeen, Cooper and Schrieffer, 3 theoretical physicists. While ordinary electricity relies on the flow of electrons, acting as individual fermions, colliding with the atomic lattice and dissipating energy as heat, superconductivity occurs when electrons form cooper pairs. These form through the interactions between the lattice vibrations (quantised as phonons) and electrons, allowing electrons to overcome their natural electrostatic repulsion and behave as bosons. Their bosonic behaviour allows them to condense into a single, coherent superfluid, flowing without interaction with the lattice, thus without any resistance.

A primary use of RTSC lies in its ability to transfer energy without producing heat and contributing to the current 'thermal tax' that affects modern electronics. In standard conductors, electrons follow the Pauli Exclusion Principle, which prevents them from occupying the same quantum state. As these solitary fermions travel through a metal wire, they collide with vibrating cations in the metal, experiencing resistance and dissipating energy as heat. RTSC allows these individual electrons to enter a collective state. Through one electron passing through the lattice, it creates a momentary deformation, or phonon, as the positive cations are attracted to it. This local path of positive charge then attracts a second electron, pairing the first and second into a cooper pair. These paired bosons condense into a macroscopic wave function, through a phase transition that occurs at temperatures near absolute zero, where their individual thermal de Broglie wavelengths overlap, forcing a large number of pairs into the lowest energy quantum state. Consequently, the paired bosons move in perfect unison (at room temperature, ignoring the typical delicacy of quantum coherence), allowing electricity to flow without producing heat.

Bringing this technology down to everyday temperatures is immensely useful, explicitly when looking at the existential threat of climate change. Our global infrastructure currently experiences losses of 5-10% to Joule heating ($P = I^2R$), as electrons experience resistance in copper conductors. In a world of RTSC, theoretically, this loss vanishes. A lossless grid would effectively 'recover' enough wasted energy to power more nations without the need of burning fossil fuels, thus reducing pollutants and harmful greenhouse gases emissions. In turn, this reduces the amount of heat trapped in the atmosphere. Furthermore, RTSC solves the geographical intermittency problem that prevents the wider use of renewable energy sources. The planet's most productive wind and solar sites are often too far from city centres, therefore inefficient to use as their percentage efficiencies drop due to transmission. However, superconducting cables would enable zero-loss transmission across continents, allowing for the transfer of energy harvested in the sunlit hemisphere to the other without penalty. A similar principle could apply to wind farms, typically located in plains and coastal areas, and so this method of lossless energy transfer encourages the wider usage of sustainable energy alternatives, transforming renewable energy from a localised supplement to a universal reality.

But the uses of RTSC extend beyond simple transmission through the Meissner Effect. This phenomenon involves the total expulsion of magnetic flux from the superconductor's interior, allowing for the generation of incredibly powerful magnetic fields without the large energy cost of cooling. In context of the climate crisis, this feature of RTSC could be used for the development of a commercial nuclear station, or nuclear fusion research projects like ITER, where the process of fusing hydrogen isotopes (at high temperatures and pressures) releases energy. Currently, ITER, the world's largest nuclear fusion experiment, is attempting to reach a net energy gain, where the energy produced by fusion exceeds the energy used to heat the hydrogen isotopes. To achieve this, the fuel must be heated to 150,000,000 °C, becoming a plasma so hot it would melt any physical container. The use of superconducting magnets creates a 'magnetic bottle' that contains the plasma, but these magnets themselves require massive amounts of energy for their cooling systems. RTSC would theoretically allow for far more powerful magnetic fields while also reducing energy consumption, potentially helping ITER reach a net energy gain. Therefore, RTSC has the potential to bring carbon-free, 'limitless' energy to the grid, replacing the use of fossil fuels as deuteruim is highly abundant on Earth, undoubtedly changing the nature of energy production world-wide.

However, the strength of the argument for RTSC's usefulness is undermined by the 'Critical Threshold' problem. For a superconducting material to be useful, it must maintain its state while remaining under its Critical Temperature, while testing the limits of the material itself, in reference to its Critical Current Density. As wires are subject to exceedingly high currents and magnetic fields, cooper pairs can be 'shaken' apart, so the material will no longer superconduct. Furthermore, the implementation of RTSC world-wide itself would be incredibly expensive; any RTSC material would be expensive to synthesise and would remain a scientific trophy rather than being integrated into society.

Ultimately, the discovery of RTSC could be immensely useful, changing the ways of energy production from wasteful to a new level of efficiency, necessary to decouple industrial needs from environmental degradation. RTSC could be the solution to a society with a vanishing carbon footprint, yet the delicacy needed to maintain superconductivity has to, first, be triumphed by modern science.

Words: 999

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