Nanoscale engines far colder than even deepest outer space

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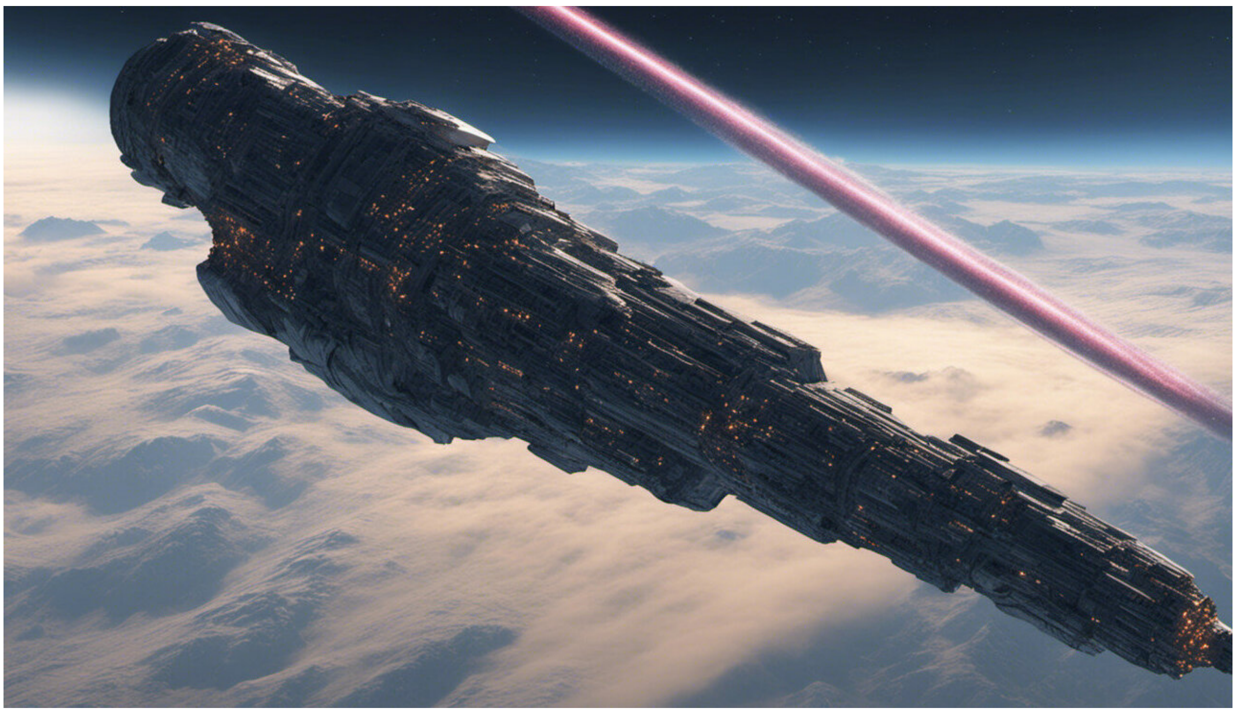

Credit: AI-generated image (disclaimer)

The theory of thermodynamics, commonly associated with the steam engines of the 19th century, is a universal set of laws that governs everything from black holes to the evolution of life. But with modern technologies miniaturizing circuits to the atomic scale, thermodynamics has to be put to the test in a completely new realm. In this realm, quantum rather than classical laws apply. In the same way that thermodynamics was key to building classical steam engines, the emergence of quantum circuits is forcing us to reimagine this theory in the quantum case.

Quantum thermodynamics is a rapidly advancing field of physics, but its theoretical development is far ahead of experimental implementations. Rapid breakthroughs in the fabrication and measurement of devices at the nanoscale are now presenting us with the opportunity to explore this new physics in the laboratory.

Whilst experiments are now within reach, they remain extremely challenging due to the sophistication of the devices needed to replicate the operation of a heat engine, and due to the high-level control and measurement sensitivity that are required. Dr. Ares' group will fabricate devices at nanometre scales, merely a dozen atoms across, and hold them at temperatures far colder than even deepest outer space.

These nanoscale engines will give access to previously inaccessible tests of quantum thermodynamics and they will be a platform to study the efficiency and power of quantum engines, paving the way for quantum nanomachines. Dr. Ares' will build engines in which the "steam" is one or two electrons, and the piston is a tiny semiconductor wire in the form of a carbon nanotube. She expects that exploring this new territory will have as great a fundamental impact on how we think of machines as previous studies in the classical regime have had.

The main question that Dr. Natalia Ares' recently awarded European Research Council (ERC project) seeks to answer is: what is the efficiency of an engine in which fluctuations are important and quantum effects might arise? The implications of answering this question are far ranging and could for example inform the study of biomotors or the design of efficient on-chip nanomachines. This research could also uncover unique behaviors that open the way for new technologies such as new on-chip refrigeration and sensing techniques or innovative means of harvesting and storing energy. By harnessing fluctuations, the requirements to preserve quantum behavior might become less demanding.

Dr. Ares' findings will have applications in both classical and quantum computing. In the same way that Joule's experiment demonstrated that motion and heat were mutually interchangeable, Dr. Ares aims to link the motion of a carbon nanotube with the heat and work produced by single electrons. She is excited to exploit devices with unique capabilities to discover the singularities of quantum thermodynamics.

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