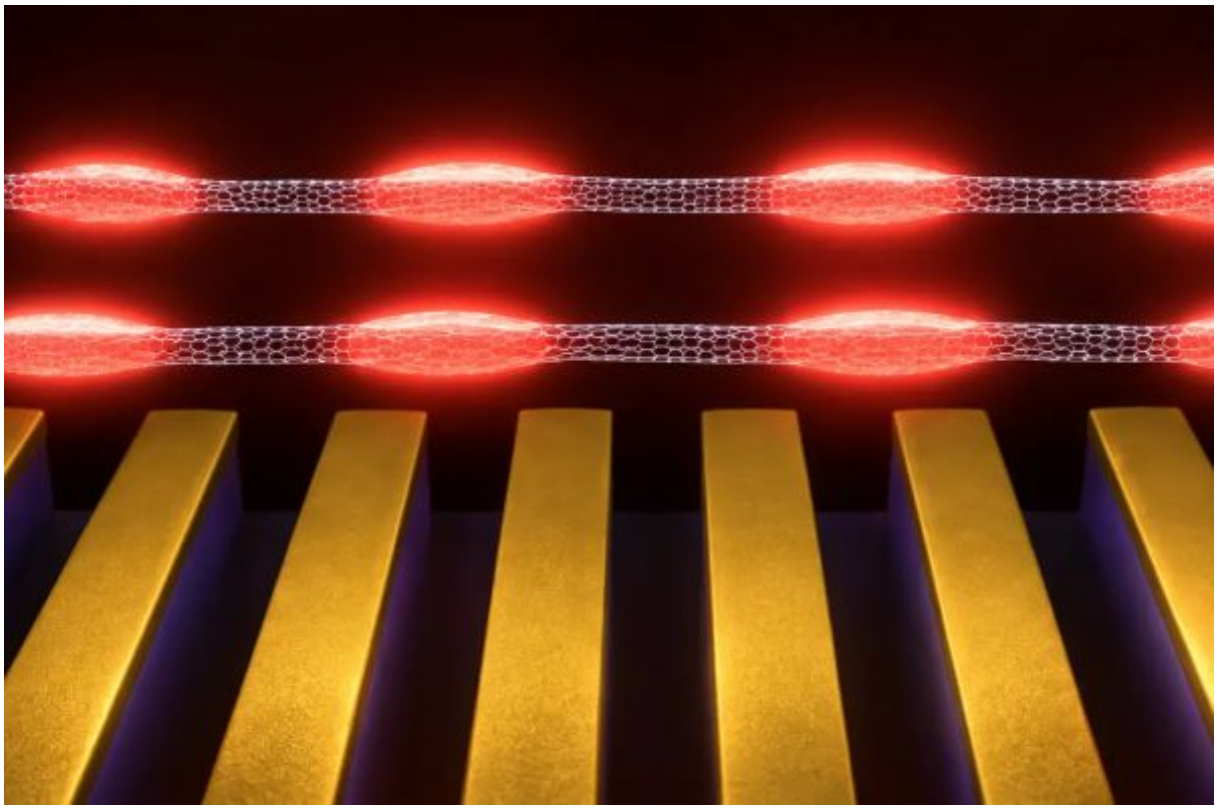


Two nanotubes, one entangled state: a new platform to simulate electron-phonon physics

Researchers from the Universitat Autonoma de Barcelona (UAB) and the Institute of Photonic Sciences (ICFO) have proposed a strategy to entangle the electronic configuration of two carbon nanotubes. The envisioned platform, recently investigated in a study published in SciPost Physics, could be used to simulate strongly correlated electron-phonon interactions, like those underlying unconventional superconductivity.

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What makes exotic quantum phases emerge in unconventional superconductors? Or exotic electron behavior in twisted bilayer graphene? Scientists believe that interactions between electrons and phonons (quantized vibrations in the atomic lattice of the material) play an important role.

But how do these electron-phonon interactions unfold in a strongly correlated electron

system? What makes them appear? And how do they precisely affect the material's phononic and electronic properties? Answering these questions would require taking into account an enormous number of particles, each having many possible quantum states and interacting in a complex way with the others. The number of possible states grows exponentially with the number of particles, so simulating this on a classical computer is out of reach.

There is a possible alternative, though: to replace classical software with quantum hardware. Indeed, one can employ a well-known quantum system -one that hosts this kind of electron-phonon interactions, but in an experimentally controllable way- to mimic the physics occurring in unconventional superconductors or twisted bilayer graphene. This is called a quantum simulator and the challenge is to find the appropriate quantum platform.

PhD student David Ullrich and **ICREA Prof. Anna Sanpera**, researchers at UAB, together with **Dr. Marta Cagetti**, **Dr. Stefan Forstner**, and **Prof. Adrian Bachtold**, researchers at ICFO, have now theoretically proposed **a quantum simulation platform for electron-phonon physics**. In a SciPost Physics study, the team predicts that this system hosts **an entangled phase, the so-called Bell phase**, which does not appear when only one nanotube is present.

More specifically, the proposed platform consists of suspending **two carbon nanotubes** and using gate electrodes to control their electronic states. By applying voltages to these electrodes, one can create a series of potential wells along the nanotubes, which contain quantum states of electrons; these are the so-called **quantum dots**. In each nanotube, there are four such dots and four electrons to fill them. As the nanotubes are suspended, they can also vibrate. Due to the extremely low temperature at which such experiments are conducted, these vibrations can reveal their quantum nature; these are the so-called **phonons**.?

There are several ways the electrons can arrange between the dots, pairing up, spreadin among them. The key finding of the study is that, due to the interplay of the electronic state with the phononic states, the electronic configurations in the nanotubes become entangled This is a genuinely quantum, maximally-entangled Bell state, which here naturally emerges a the ground state of the system, that is, the state with the lowest possible energy

The researchers admit that bringing this platform into reality will be challenging. In particular the two tubes have to be placed closer than neighbouring quantum dots in the same tube. i¿½Placing two carbon nanotubes so close together has never been done before,i¿½ say Dr. Marta Cagetti, researcher at ICFO and co-author of the paper. i¿½But we are opti istic, because a new machine will arrive at ICFO, and it will allow us to move the nanotub s with the required precision of tens of nanomet rs.i¿½ In the future, the team would like to explore what happens when additional quantum dots are added to the set-up, when the system is coupled to the environment, and if t e phonon states of the two tubes could also be entangled. Once realized, the platform could become a valuable tool for quantum simulation, especially due to its high tunability, whi h allows adjustments to be made either at the fabrication stage or during the experiment.

Reference:
David Ullrich, Marta Cagetti, Stefan Forstner, Adrian Bachtold, Anna Sanpera, Emergent Bell phase in an electro-nanomechanical quantum simulator, SciPost Phys. **21**, 043 (2026).
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