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Bismuth provides perfect dance partners for quantum computing qubits

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Hybridizing electronic and nuclear spin qubits makes quantum control much easier. This equation, spelt out in child's plastic letters on a fridge, describes the pure states of bismuth-doped silicon for which the nuclear and electronic qubits become maximally hybridized at specific magnetic fields. Credit: University of Warwick

New research has demonstrated a way to make bismuth electrons and nuclei work together as qubits in a quantum computer.

The discovery, published in Nature Materials, takes us a key step further to creating practical quantum computing which could tackle complex programs that would otherwise take the lifetime of the universe to finish.

The collaboration partners are based in the University of Warwick, UCL, ETH Zurich and the USA Sandia National Labs.

Information on our normal computers is stored as bits, which are either ones or zeros. Quantum bits work differently in that each quantum bit can try out being a one and a zero at the same time, which makes them much more powerful for solving certain problems.

Researchers have explored influencing the direction of spin in electrons to create those states but this approach has had its challenges.

Dr Gavin Morley from the University of Warwick's Department of Physics said: "Bismuth atoms in silicon crystals are great at working as quantum bits. Each bismuth atom has a spare electron, which has a "spin" that can be influenced by magnets.

"If we put the electron into a magnet, it lines up with the magnetic field, behaving like a compass needle.

"We can control the direction that the electron is pointing in, using microwaves. Microwaves let us flip the direction the electron is pointing in, and these "up and down" directions are what constitute the "one and zero" in our quantum bit.

"Unfortunately, our electron is constantly prone to interference from nearby atoms that are out of our control.

"And the more time we waste, the greater the chance that our poor electron will suffer from interference, making it unusable to us."

"Now, this electron is coupled to the bismuth nucleus, which has its own spin: a smaller compass needle. Using this as an extra quantum bit and flipping it at the same time as our electron, would really help out. We can control this smaller compass needle too, but as it's smaller, it takes longer to control, and we need to use radiowaves instead of microwaves to do this."

"The good news is that as it's slow to respond, our bismuth nucleus's smaller compass needle suffers less from interference by nearby rogue atoms than our electron's larger compass needle. Unfortunately in the time we spend controlling our bismuth nucleus, these rogue atoms interfere with our electron."

"However we found that if we reduce the magnetic field just enough, then the electron and the nucleus become hybridized. Our new experiments at ETH Zurich show that through hybridisation, we can flip both compass needles easily using microwaves."

Dr Morley compares it to the magnetic resonance imaging we find in hospitals.

He said: "MRI works by controlling the nuclear spins in your body.

"We have hybridized electron and nuclear spins and found that this makes it easier to control them.

"It's an easy new way to make slow and fast quantum bits work together. There are lots more challenges to face before anyone has a working computer with enough quantum bits to be useful, but with this hybridization as part of a computer's design, we are one step closer."

More information: The paper entitled "Quantum control of hybrid nuclear–electronic qubits" is published in *Nature Materials* and is by Gavin W Morley, Petra Lueders, M Hamed Mohammady, Setrak J Balian, Gabriel Aeppli, Christopher WM Kay, Wayne M Witzel, Gunnar Jeschke & Tania S Monteiro, doi: 10.1038/NMAT3499 (2012).

Provided by University of Warwick