Q-ESSENCE highlights

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The EU sponsored research initiative QESSENCE (Quantum Interfaces, Sensors, and Communication based on Entanglement) with a 3-year budget of €4.7 million to explore quantum entanglement, is in its final year. The research outcomes are expected to make significant impact on future disruptive technologies and provide enabling physics for larger scale quantum computers in the longer-term.

Just to name a few, the recent highlights of research within the consortium include:

Laser cooling of a nanomechanical oscillator into its quantum ground state
In a significant breakthrough, physicists have observed the quantum jittering of a large object. Normally, such jittering is obscured by other noise, coming from heat or external vibrations. In the collaboration between the group of M. Aspelmeyer at the Austrian Academy of Science in Vienna and O. Painter at Caltech, lasers were used to cool down a tiny silicon chip – tiny for us, but containing many millions of atoms – until they observed purely quantum motion. This quantum jittering is known as the “zero point” motion, and can be described as vibrations caused by empty space! The exquisite level of control demonstrated here points towards technologies exploiting the quantum motion of objects to process information in new ways, and the result opens the path to testing the strange predictions of quantum mechanics in larger and larger objects.

Diamond based single molecule magnetic resonance spectroscopy
Researchers from the University of Ulm have demonstrated the possibility of detecting single atomic nuclei by measuring the tiny magnetic fields they produce. MRI scanners are well-known for their ability to see inside the human body with magnetic fields. Now it seems a tiny magnetometer, made of a single nitrogen atom embedded in a crystal of pure diamond, could be millions of times more sensitive. The researchers foresee numerous applications in chemistry, biology and medicine.

Waveguide superconducting single-photon detectors for integrated quantum photonic circuits
Photons – particles of light – are capable of carrying quantum information, which allows more powerful computations than are possible with electronics. Photonics is a rapidly emerging field that promises to deliver radical new information processing technologies based on light. Now a pan-European collaboration led by A. Fiore at the COBRA research institute in Eindhoven has succeeded in producing tiny photon detectors, based on exotic superconducting “nanowires”, that can be incorporated onto photonic microchips, allowing more complex, cheaper and faster photonic circuits.

Compact Continuous-Variable Entanglement Distillation
Entanglement is a curious property of quantum objects that allows for powerful new quantum technologies. One of these is quantum communication, in which entangled light beams share correlations that cannot be “hacked”, allowing guaranteed security. However, sending light over long distances degrades the entanglement, and devices are required that can boost the quality of entanglement. Now the Ultrafast group at the University of Oxford has introduced the idea of an entanglement distillery, which uses four clouds of atoms – so-called quantum memories – to store and process light pulses rapidly and efficiently, increasing the amount of entanglement. The scheme could be implemented with current technology, and could usher in a new era of quantum communications.

A gravitational wave observatory operating beyond the quantum shot-noise limit
Einstein famously revolutionized astronomy with his theory of gravity, and equally famously rejected quantum physics with his dictum “God does not play dice”. Now an international collaboration of scientists calling themselves LIGO are using quantum mechanics to test gravity. When very large objects – like black holes – move, they should cause tiny ripples in space, called gravitational waves. Astronomers have built very precise sensors to detect these waves by carefully watching for changes in the distance between two mirrors by bouncing laser beams off them. But the light beams are

made of quantum particles – photons – which fluctuate and make the measurement too noisy. Now a new kind of light, known as squeezed light, which does not occur naturally in nature, has been used to reduce this noise. By passing the laser light through a special crystal (potassium titanyl phosphate), the photon fluctuations become quantum-correlated, which reduces the noise, making the measurement much more sensitive. The researchers hope that this new quantum-enhanced observatory will be the first to pick up the faint gravitational ripples from a distant black hole, confirming Einstein’s predictions with the help of the quantum theory he never believed.

Entangling Macroscopic Diamonds at Room Temperature
A diamond is a classical example of a hard, solid object. Although we may not all be able to afford one, our brains come equipped with the correct intuition to understand how a solid crystal like a diamond moves. Like a snooker ball or a cricket bat, Isaac Newton’s laws tell us what to expect. But recently a group of researchers at the Ultrafast Group at the University of Oxford showed that these “classical” expectations can be wrong. Quantum mechanics is a strange theory that describes atoms and molecules as waves, which spread out in space without having a definite position. These odd predictions usually disappear when dealing with large, familiar objects. But not so for diamond. To show this, the researchers hit a pair of diamonds with strong laser pulses. Sometimes the light would move one of the crystals, lose some energy and emerge red. Detecting a single red photon results in a single vibration, but this vibration is spread across both diamonds, with no definite position. The diamonds have become entangled, meaning that they cannot be described separately as two independent crystals. The shared vibration is a kind of quantum connection between them. This entanglement means that when a second laser pulse is sent through them, they give up their vibrational energy together, producing a blue photon that is also spread out in space. The spreading is very sensitive to tiny variations, and the researchers were able to use this so-called “phase sensitivity” to verify the quantum nature of the diamond vibration by moving a mirror through several millionths of a meter, and watching the effect on the detection of the blue photon. This is the first observation of quantum entanglement in the motion of two large (i.e. visible) solid objects at room temperature and pressure. In the future, perhaps larger objects, or even living organisms, will be entangled!

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