Quantum Entanglement of 15 Trillion Atoms at 450 Kelvin With "Surprising Results"

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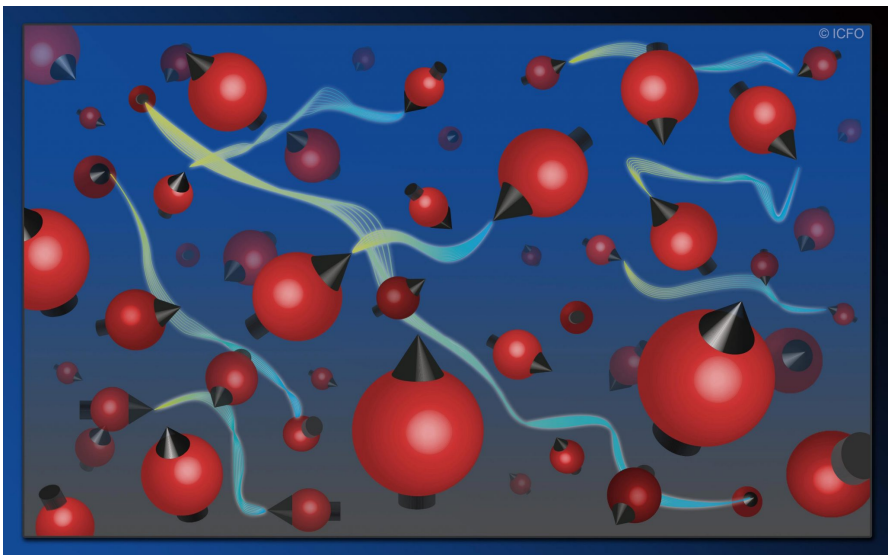
By ICFO MAY 15, 2020



Artistic illustration of a cloud of atoms with pairs of particles entangled between each other, represented by the yellow-blue lines. Credit: © ICFO

Quantum entanglement is a process by which microscopic objects like electrons or atoms lose their individuality to become better coordinated with each other. Entanglement is at the heart of quantum technologies that promise large advances in computing, communications and sensing, for example detecting gravitational waves.

Entangled states are famously fragile: in most cases even a tiny disturbance will undo the entanglement. For this reason, current quantum technologies take great pains to isolate the microscopic systems they work with, and typically operate at temperatures close to absolute zero. The ICFO team, in contrast, heated a collection of atoms to 450 Kelvin, millions of times hotter than most atoms used for quantum technology. Moreover, the individual atoms were anything but isolated; they collided with each other every few microseconds, and each collision set their electrons spinning in random directions.

The researchers used a laser to monitor the magnetization of this hot, chaotic gas. The magnetization is caused by the spinning electrons in the atoms, and provides a way to study the effect of the collisions and to detect entanglement. What the researchers observed was an enormous number of entangled atoms — about 100 times more than ever

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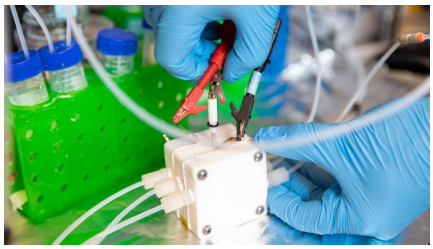

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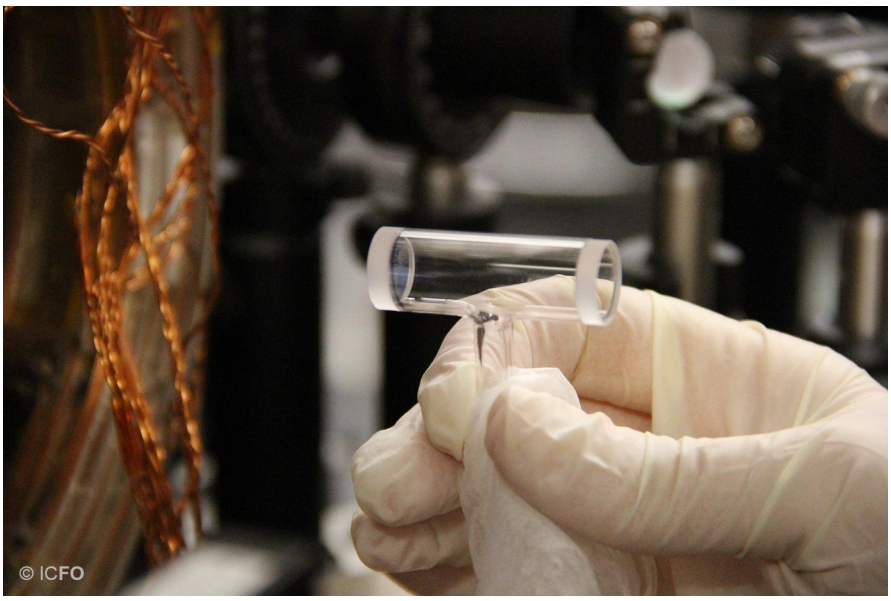
Researchers at University of Toronto Engineering and

before observed. They also saw that the entanglement is non-local — it involves atoms that are not close to each other. Between any two entangled atoms there are thousands of other atoms, many of which are entangled with still other atoms, in a giant, hot and messy entangled state.



Picture of the glass cell that where the rubidium metal is mixed with nitrogen gas and heated up to 450 degrees Kelvin. At that high temperature, the metal vaporizes, creating free rubidium atoms that diffuse around inside the cell. Credit: © ICFO

What they also saw, as Jia Kong, first author of the study, recalls, "is that if we stop the measurement, the entanglement remains for about 1 millisecond, which means that 1000 times per second a new batch of 15 trillion atoms is being entangled. And you must think that 1 ms is a very long time for the atoms, long enough for about fifty random collisions to occur. This clearly shows that the entanglement is not destroyed by these random events. This is maybe the most surprising result of the work."

The observation of this hot and messy entangled state paves the way for ultra-sensitive magnetic field detection. For example, in magnetoencephalography (magnetic brain imaging), a new generation of sensors uses these same hot, high-density atomic gases to detect the magnetic fields produced by brain activity. The new results show that entanglement can improve the sensitivity of this technique, which has

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applications in fundamental brain science and neurosurgery.

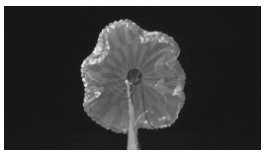
As ICREA Prof. at ICFO Morgan Mitchell states, “this result is surprising, a real departure from what everyone expects of entanglement.” He adds “we hope that this kind of giant entangled state will lead to better sensor performance in applications ranging from brain imaging to self-driving cars to searches for dark matter.”

A Spin Singlet and QND

A spin singlet is one form of entanglement where the multiple particles’ spins–their intrinsic angular momentum–add up to 0, meaning the system has zero total angular momentum. In this study, the researchers applied quantum non-demolition (QND) measurement to extract the information of the spin of trillions of atoms. The technique passes laser photons with a specific energy through the gas of atoms. These photons with this precise energy do not excite the atoms but they themselves are affected by the encounter. The atoms’ spins act as magnets to rotate the polarization of the light. By measuring how much the photons’ polarization has changed after passing through the cloud, the researchers are able to determine the total spin of the gas of atoms.

The SERF regime

Current magnetometers operate in a regime that is called SERF, far away from the near absolute zero temperatures that researchers typically employ to study entangled atoms. In this regime, any atom experiences many random collisions with other neighboring atoms, making collisions the most important effect on the state of the atom. In addition, because they are in a hot medium rather than an ultracold one, the collisions rapidly randomize the spin of the electrons in any given atom. The experiment shows, surprisingly, that this kind of



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disturbance does not break the entangled states, it merely passes the entanglement from one atom to another.

Reference:"Measurement-induced, spatially-extended entanglement in a hot, strongly-interacting atomic system" by Jia Kong, Ricardo Jiménez-Martínez, Charikleia Troullinou, Vito Giovanni Lucivero, Géza Tóth and Morgan W. Mitchell, 15 May 2020, *Nature Communications*.
DOI: 10.1038/s41467-020-15899-1

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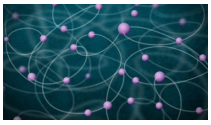

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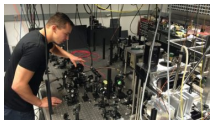

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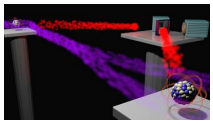

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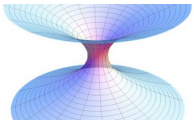

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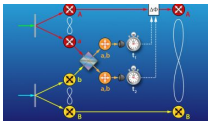

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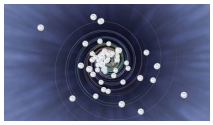

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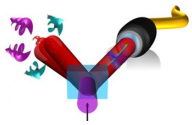

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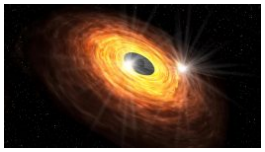

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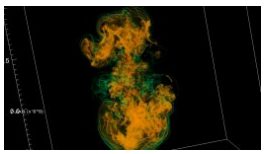

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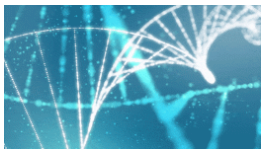

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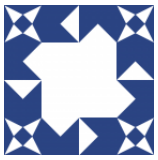
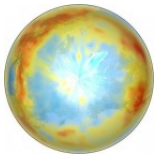


C. Peter O'Connor | May 15, 2020 at 2:06 am | Reply

THIS HAS TO BE THE WORST GRAPHIC OF ATOMS I’VE EVER SEEN



Timothy Chase | May 15, 2020 at 4:55 am | Reply

Peter, it helps to ask, what are they trying to represent? In chemistry, when representing molecular structure, individual atoms are represented by spheres. That is what this artist is doing. The rod with a cone going through the center of a sphere? That indicates the orientation of spin. The wavy line? Entanglement between two atoms. The wavy-ness itself? The nonlocal nature of entanglement. The image is abstract, but actually I think they captured some of what

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the article is about.

Sten Hakanson | May 15, 2020 at 5:30 am | Reply

How is it determined which two atoms are entangled? How is it known there are atoms between ones that are entangled? Is it possible that what we refer to as “entanglement” is something else? Has the Copenhagen interpretation taken us down the proverbial rabbit hole?

Alan | May 15, 2020 at 5:38 am | Reply

Pete is right, spin doesn’t even mean literal spinning. Also nobody on Earth would think “atom” when looking at the picture, it’s interesting don’t get me wrong but I think it missed the user testing phase…

Glenn | May 15, 2020 at 6:29 am | Reply

Art critics reporting on physicists…. Exactly why human race. Is doomed. Maybe ellen degenerous should also give us her opinion on the subject? Lol

Paul Jordan-Smith | May 15, 2020 at 6:59 am | Reply

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How to represent what you can't see? As someone relatively unsophisticated but not totally ignorant of the principles of the quantum realm, I found the individual representations immediately understandable and the overal picture rather clever. In other words "I got it" before reading, and found it an adroit representation that prepared me for the article. I'm not so naive as to take "spin" literally, as words themselves stand to verbal explanation as the balls and arrows to visualization. Both are approximations to facilitate coming to grips with general principles without the maths necessary for a deeper understanding.

Aubrey | May 15, 2020 at 8:07 am | Reply

What does "collision" really mean though? As I understand it, atoms don't really "collide" the way we think of it on a macroscopic scale. They just have electrons that repel each other more or less depending on how close they are. So it seems to me that every charged particle in the universe is constantly "colliding" with something in that sense. Does it really mean anything then, to say that "50 random collisions happen in a millisecond"? It might be more meaningful to ask how close an electron needs to be to

another to break its entanglement.

Jim Gagnon | May 15, 2020 at 10:11 am | Reply

This comes from a paper that's over two years old: https://arxiv.org/pdf/1804.07818.pdf. Wonder why it's being reported now.

edwardo deleon | May 15, 2020 at 1:51 pm | Reply

The first thing I did not understand is how you can have rubidium vapor at 450 degrees kelvin when rubidium's boiling point is 961K. The second thing I did not understand was the rest of the paper.

Oded Arbel | May 15, 2020 at 3:02 pm | Reply

@edwardo:
> The first thing I did not understand is how you can have rubidium vapor at 450 degrees kelvin when rubidium's boiling point is 961K.

It isn't written in this summary, and I must have missed the link to the source, but these kinds of rubidium setups are often in a vacuum chamber, where you can have rubidium gas with a temperature of as low as a few Kelvins or as "high" as 450K.

I'm with you in the rest of the stuff.

HimarAli | May 15, 2020 at 7:07 pm | Reply

@Glenn “Art critics reporting on physicists…. Exactly why human race. Is doomed. Maybe ellen degenerous should also give us her opinion on the subject? Lol”

Well, if Greta Thunberg can provide expert opinion on Covid-19 to Anderson Cooper of CNN, why can’t a graphic artist such as the minister of health of Canada under Trudeau be able to critique physicists on quantum mechanics?

HimarAli | May 15, 2020 at 7:23 pm | Reply

I think what this article is saying, and the author obviously has no idea what he is writing about, is that if you have pairs of entangled atoms in a high temperature soup, where the pairs are colliding with other entangled pairs (or non-entangled atoms), it is NOT the case that the whole soup will become entangled together after a while due to collisions (collisions can create new entanglements). What happens is that when two non-entangled pairs collide, the

entanglement transfers over from one pair to another pair (or to an atom), so they are switching entangled partners instead of becoming one entangled system of 4 or 3 atoms. If this is the case, then it is actually very surprising, but makes a lot of sense.

Entanglement and its inverse, superposition, is not as mysterious as some people (Einstein) have thought. It has its own logic which is very unintuitive. But still logical.

Genetic Avatar | May 16, 2020 at 1:31 am | Reply

Great article! This is what I suspected. I said there needs to be a new law called the conservation of entanglement. We see this in entanglement swapping experiments. Alice and Bob each have an entangeled particle pair. They send one to be measured a short distance away and the other one further away to Victor. If Victor chooses to entangle the particles Alice and Bob sent to him then Alice and Bob's particles at the detectors become correlated even though they were never in contact with each other and the particles are measured before Victor makes a choice to entangle or not and the initial entanglement of Alice and Bob's particle pairs is conserved. It also supports what some scientist believe and that is space-time is a quantum error correcting code. Quantum error correction is supported by entanglement. This would mean most of space is physical qubits and doing error correction to protect information encoded on logical qubits, so it makes sense that

entanglement is preserved. M.I.T. Professor Seth Lloyd is right. The universe is a Quantum Computer.

Spyroe theory | May 16, 2020 at 1:34 am | Reply

Instead of using the idea of particles spinning and interacting with one another I imagine a network of vortexes unwinding and winding within each other. This may be a better way of describing entangled energy.

Laws Of Nature | May 16, 2020 at 5:41 am | Reply

Most informative article.

Robert T Deloyd | May 16, 2020 at 1:11 pm | Reply

What “atoms” did the experiment use?
450 Kelvin is what I’d bake a cake in the oven 350F… I’m not arguing with the article… being a novice and interested in science I just had to do the math to figure it out; I thought it was a lot higher and wanted to see at which point in Kelvin electrons would be stripped off the atoms= about 7000 Kelvin.

HimarAli | May 17, 2020 at 12:23 am | Reply

@genetic avatar — When two particles collide, they generally become entangled. So entanglement does not conserve, but is ceated. Entanglement is simply the inverse of superposition, i.e. the lack of superposition. The fact that coherent particles lose their coherence over time and get entangled with the environment is common knowledge.

I think what this article may be saying is that under certain circumstances, entanglements get erased in a collision, when they get transferred from one particle to another. It is pretty easy to erase entanglements.

Will | May 18, 2020 at 6:31 am | Reply

So changing the polar field in a binary measured experiment would give the author a new found power source. The energy storage is difficult so the transmission would need multiple cells to provide a usable amount. But to just measure it to prove feasibility would cause discussion, right?

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