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Improved models of heavy ion collisions reveal new details of early universe nuclear matter

A researcher, Heikki Mäntysaari from the University of Jyväskylä (Finland), has been part of an international research group that has made significant advances in modeling heavy ion collisions. New computer models provide additional information about the matter in the early universe and improve our understanding of the extremely hot and dense nuclear matter. The work is published in the journal *Physical Review Letters*.

When atomic nuclei collide at near light speed, they form a new state of matter where quarks and gluons are liberated from protons and neutrons. To study this matter, called a quark–gluon plasma (QGP), scientists need to understand the initial conditions, including the shape and energy density of the created matter.

The University of Jyväskylä has participated in international research that has improved computer models that simulate these initial conditions along with the entire collision dynamics. Researchers solved equations that describe how the internal structure of the colliding protons and nuclei changes with collision energy. The updated models match patterns of particles produced by the collisions better than older ones, giving a clearer view of the QGP's birth.

"This research helps reveal how nuclear matter behaves under extreme conditions, like those that existed just after the Big Bang. By making models of these collisions more accurate, we can better measure the properties of the QGP," says Associate Professor Heikki Mäntysaari from the University of Jyväskylä, who participated in the research.

https://phys.org/news/2025-09-heavy-ion-collisions-reveal-early.html

Physicists demonstrate 3,000 quantum-bit system capable of continuous operation

One often-repeated example illustrates the mind-boggling potential of quantum computing: A machine with 300 quantum bits could simultaneously store more information than the number of particles in the known universe.

Now process this: Harvard scientists just unveiled a system that was 10 times bigger and the first quantum machine able to operate continuously without restarting.

In a paper published in the journal *Nature*, the team demonstrated a system of more than 3,000 quantum bits (or qubits) that could run for more than two hours, surmounting a series of technical challenges and representing a significant step toward building the super computers, which could revolutionize science, medicine, finance, and other fields.

"We demonstrated the continuous operation with a 3,000-qubit system," said Mikhail Lukin, Joshua and Beth Friedman University Professor and co-director of the Quantum Science and Engineering Initiative, and senior author of the new paper. "But it's also clear that this approach will work for much larger numbers as well."

The Harvard-led collaboration included researchers from MIT and was jointly headed by Lukin, Markus Greiner, George Vasmer Leverett Professor of Physics, and Vladan Vuletic, Lester Wolfe Professor of Physics at MIT. The team conducts research in collaboration with QuEra Computing, a startup company spun out from Harvard-MIT labs.

Conventional computers encode information—from a video on your phone to the words and images on this page—in bits with a binary code. Quantum computers use subatomic particles in individual atoms and take advantage of counterintuitive properties of quantum physics to achieve far more processing power.

Binary conventional bits store information as zeros or ones. Qubits can be zero, one, or both at the same time—and this linear combination of amplitudes is the key to the power of quantum computing.

https://phys.org/news/2025-09-physicists-quantum-bit-capable.html

New perspectives on light-matter interaction: How virtual charges influence material responses

Understanding what happens inside a material when it is hit by ultrashort light pulses is one of the great challenges of matter physics and modern photonics. A new study published in *Nature Photonics* and led by Politecnico di Milano reveals a hitherto neglected but essential aspect, precisely the contribution of virtual charges, charge carriers that exist only during interaction with light, but which profoundly influence the material's response.

The research, conducted in partnership with the University of Tsukuba, the Max Planck Institute for the Structure and Dynamics of Matter, and the Institute of Photonics and Nanotechnology (CNR-IFN) investigated the behavior of monocrystalline diamonds subjected to light pulses lasting a few attoseconds (billionths of a billionth of a second), using an advanced technique called attosecond-scale transient reflection spectroscopy.

By comparing experimental data with state-of-the-art numerical simulations, researchers were able to isolate the effect of so-called virtual vertical transitions between the electronic bands of the material. Such an outcome changes the perspective on how light interacts with solids, even in extreme conditions hitherto attributed only to the movement of actual charges.

"Our work shows that virtual carrier excitation, which develops in a few billionths of a billionth of a second, are indispensable to correctly predict the rapid optical response in solids," said Matteo Lucchini, professor at the Department of Physics, senior author of the study, and associate at CNR-IFN.

https://phys.org/news/2025-09-perspectives-interaction-virtual-material-responses.html

A new twist on Heisenberg's uncertainty principle can sharpen quantum sensors

For almost a century, Heisenberg's uncertainty principle has stood as one of the defining ideas of quantum physics: a particle's position and momentum cannot be known at the same time with absolute precision. The more you know about one, the less you know about the other.

In a new study published in *Science Advances*, our team demonstrates how to work around this restriction, not by breaking physics but by reshaping uncertainty itself.

The result is a breakthrough in the science of measurement that could power a new generation of ultra-precise quantum sensors operating at the scale of atoms.

Moving uncertainty around

The uncertainty principle makes clear there will always be a minimum amount of uncertainty in measurements. But you can think of it like air in a balloon: the air cannot escape, but you can freely move it around inside.

Similarly, when measuring position and momentum, the total amount of uncertainty is fixed. But we can redistribute it between the two.

Traditionally, this trade-off means making a choice. You can measure position precisely but lose information about momentum, or vice versa.

Our work takes a different approach. We push the uncertainty into a sensing range that is unimportant.

To understand this, let's try another analogy: imagine a clock with only one hand. If it's the hour hand, we know the hour exactly but only roughly know the minutes. If it's the minute hand, we can read minutes precisely but do not know the hour.

We apply this same idea to quantum measurements. We redistribute the uncertainty so that we can simultaneously track small changes in position and momentum around a chosen point, even if we do not know the absolute location of the point itself.

With this, we can detect very tiny changes in both position and momentum at once, beyond the limit of any classical sensor.

https://phys.org/news/2025-09-heisenberg-uncertainty-principle-sharpen-quantum.html

Spin may resolve century-old puzzle of light's momentum in matter

When you shine a flashlight into a glass of water, the beam bends. That simple observation, familiar since ancient times, hides one of the oldest puzzles in physics: what really happens to the momentum of light when it enters a medium?

In quantum physics, light is not just a wave—it also behaves like a particle, carrying energy and momentum. For more than a century, scientists have debated whether light's momentum inside matter is larger or smaller than in empty space. The two competing answers are known as the Minkowski momentum, which is larger and seems to explain how light bends, and the Abraham momentum, which is smaller and matches the actual push or pull that light exerts on the medium.

The controversy never went away because experiments seemed to confirm both sides. Some setups measured the larger Minkowski value, others supported Abraham, leaving physicists with a paradox.

Why does this matter?

At first glance, the Abraham–Minkowski debate may seem like a technical squabble. But it cuts to a deep question: How do we define momentum in systems where waves and particles intertwine? The answer shapes not only our understanding of fundamental physics, but also technologies like optical tweezers, laser cooling, and photonic devices that rely on precise control of light–matter interaction.

When I began this project, I set out to revisit this century-old controversy. What I found is that the resolution lies not in choosing between Abraham and Minkowski, but in recognizing that both are correct—once we include spin in the picture. My work is published in the journal *Physical Review A*.

https://phys.org/news/2025-09-century-puzzle-momentum.html

New tool steers AI models to create materials with exotic quantum properties

The artificial intelligence models that turn text into images are also useful for generating new materials. Over the last few years, generative materials models from companies like Google, Microsoft, and Meta have drawn on their training data to help researchers design tens of millions of new materials.

But when it comes to designing materials with exotic quantum properties like superconductivity or unique magnetic states, those models struggle. That's too bad, because humans could use the help. For example, after a decade of research into a class of materials that could revolutionize quantum computing, called quantum spin liquids, only a dozen material candidates have been identified. The bottleneck means there are fewer materials to serve as the basis for technological breakthroughs.

Now, MIT researchers have developed a technique that lets popular generative materials models create promising quantum materials by following specific design rules. The rules, or constraints, steer models to create materials with unique structures that give rise to quantum properties.

"The models from these large companies generate materials optimized for stability," says Mingda Li, MIT's Class of 1947 Career Development Professor. "Our perspective is that's not usually how materials science advances. We don't need 10 million new materials to change the world, we just need one really good material."

The approach is described in a paper published in *Nature Materials*. The researchers applied their technique to generate millions of candidate materials consisting of geometric lattice structures associated with quantum properties. From that pool, they synthesized two actual materials with exotic magnetic traits.

https://phys.org/news/2025-09-tool-ai-materials-exotic-quantum.html

Ultrathin films of ferromagnetic oxide reveal a hidden Hall effect mechanism

Researchers from Japan have discovered a unique Hall effect resulting from deflection of electrons due to "in-plane magnetization" of ferromagnetic oxide films ($SrRuO_3$). Arising from the spontaneous coupling of spin-orbit magnetization within $SrRuO_3$ films, the effect overturns the century-old assumption that only out-of-plane magnetization can trigger the Hall effect.

The study, now published in *Advanced Materials*, offers a new way to manipulate electron transport with potential applications in advanced sensors, quantum materials, and spintronic technologies.

When an electric current flows through a material in the presence of a magnetic field, its electrons experience a subtle sideways force which deflects their path. This effect of electron deflection is called the Hall effect—a phenomenon that lies at the heart of modern sensors and electronic devices. When this effect results from internal magnetization of the conducting material, it is called "anomalous Hall effect (AHE)."

Scientists have long believed that the Hall effect only emerges when magnetization is pointed out of the plane of electron flow, but the recent study from Japan challenges this assumption.

The study led by Associate Professor Masaki Uchida at the Department of Physics, Institute of Science Tokyo (Science Tokyo), Japan, in collaboration with Associate Professor Hiroaki Ishizuka from the same department and Professor Ryotaro Arita from the Graduate School of Science, The University of Tokyo, demonstrates that an AHE can occur even when the magnetization lies entirely within the plane of electron flow.

The effect was observed in an ultrathin film of strontium ruthenate ($SrRuO_3$), a ferromagnetic oxide, which can be magnetized and retain its magnetism.

https://phys.org/news/2025-09-ultrathin-ferromagnetic-oxide-reveal-hidden.html

Thank you!

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