SCIENCE FLASH NEWS

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Strong magnetic field helps answer a question about the 'new duality' in materials physics

As someone who studies materials, Lu Li knows people want to hear about the exciting new applications and technologies his discoveries could enable. Sometimes, though, what he finds is just too weird or extreme to have any immediate use.

Working with an international team of researchers, Li has made one of those latter types of discoveries, detailed in *Physical Review Letters*.

"I would love to claim that there's a great application, but my work keeps pushing that dream further away," said Li, professor of physics at the University of Michigan. "But what we've found is still really bizarre and exciting."

The discovery pertains to what are called quantum oscillations. These oscillations are found in metals and can be thought of as a phenomenon in which the metal's electrons act like springs, Li said. By applying a magnetic field, researchers can change the speed with which those electron springs wiggle.

But, over the past several years, researchers have discovered the same quantum oscillations in insulators—nonmetals that don't typically conduct heat or electricity. This led to a question that has stymied the field: Are those oscillations originating at only the surface of the material or is the behavior something that comes from within the material's bulk?

From the standpoint of applications, the surface would be the more enthralling answer. Scientists are already exploring materials called topological insulators, which demonstrate metal-like behaviors at their surfaces while maintaining an insulator identity in their bulk, to enable new electronic, optical and quantum technologies.

https://phys.org/news/2025-10-strong-magnetic-field-duality-materials.html

How a chorus of synchronized frequencies helps you digest your food

Synchronization abounds in nature: from the flashing lights of fireflies to the movement of fish wriggling through the ocean, biological systems are often in rhythmic movement with each other. The mechanics of how this synchronization happens are complex.

For instance, in the vasculature of the brain, blood vessels oscillate, expanding and contracting as needed. When there is neural activity, the arterioles expand to increase blood flow, oxygen and nutrients. These oscillations are self-sustained, but the arterioles also work in concert with each other. How this happens is not well understood.

To uncover the answer, researchers at the University of California San Diego looked to another part of the body: the gut. Here they found that oscillators operating at similar frequencies lock onto each other in succession, creating a staircase effect. Their work appears in *Physical Review Letters*.

Biology in sync

It is known in the scientific community that if you have a self-sustained oscillation, such as an arteriole, and you add an external stimulus at a similar but not identical frequency, you can lock the two, meaning you can shift the frequency of the oscillator to that of the external stimulus. In fact, it has been shown that if you connect two clocks, they will eventually synchronize their ticking.

Distinguished Professor of Physics and Neurobiology David Kleinfeld found that if he applied an external stimulus to a neuron, the entire vasculature would lock at the same frequency. However, if he stimulated two sets of neurons at two different frequencies, something unexpected happened: some arterioles would lock at one frequency and others would lock at another frequency, forming a staircase effect.

https://phys.org/news/2025-10-chorus-synchronized-frequencies-digest-food.html

Mirrorless laser: Physicists propose a new light source

A team of physicists from the University of Innsbruck and Harvard University has proposed a fundamentally new way to generate laser light: a laser without mirrors. Their study, published in *Physical Review Letters*, shows that quantum emitters spaced at subwavelength distances can constructively synchronize their photon emission to produce a bright, very narrow-band light beam, even in the absence of any optical cavity.

In conventional lasers, mirrors are essential to bounce light back and forth, stimulating coherent emission from excited atoms or molecules, and thus light amplification. But in the new "mirrorless" concept, the atoms interact directly through their own electromagnetic dipole fields, given that interatomic spacing is smaller than the emitted light's wavelength. When the system is pumped with enough energy, these interactions cause the emitters to lock together and radiate collectively—a phenomenon called superradiant emission.

The team led by Helmut Ritsch found that this collective emission generates light that is both highly directional and spectrally pure, with a single narrow spectral line, in cases where only a fraction of emitters are excited by a laser and the rest of atoms remain unpumped. Since this passive emitter fraction is not broadened by the driving laser or power broadening, it effectively acts as an optical resonator for the active emitters, in analogy with a conventional laser where the optical resonator and the gain medium are separate physical entities.

"The atoms synchronize their emission and, above a certain threshold, start to shine light collectively or in unison with each other," explains Anna Bychek, postdoc from the Department of Theoretical Physics at the University of Innsbruck. "There are still many questions to be studied in future work, but it is clear that atoms build their own feedback mechanism and frequency selection via dipole-dipole interaction in free space."

https://phys.org/news/2025-10-mirrorless-laser-physicists-source.html

Nonlocality-enabled photonic analogies unlock wormholes and multiple realities in optical systems

Researchers have harnessed nonlocal artificial materials to create optical systems that emulate parallel spaces, wormholes, and multiple realities. A single material acts as two distinct optical media or devices simultaneously, allowing light to experience different properties based on entry boundaries. Demonstrations include invisible optical tunnels and coexisting optical devices, opening new avenues for compact, multifunctional optical devices by introducing nonlocality as a new degree of freedom for light manipulation.

What if a single space could occupy two different objects at once, depending on how photons access this space? Scientists have brought this sci-fi concept to life, creating optical systems that mimic the exotic phenomena of parallel universes and wormholes.

In a study published in *Nature Communications*, researchers in China used nonlocal artificial materials to develop "photonic parallel spaces."

By manipulating shifted dispersion relations in the momentum space, they managed to create a single material that behaves as two distinct optical media or devices simultaneously.

Light entering from one boundary experiences one set of optical properties, while light entering the space from another boundary encounters a completely different set, with no interference between them. This emulates the magical wardrobe from The Lion, the Witch, and the Wardrobe, where different doors lead to separate worlds located at the same place (behind the door).

"This approach lets us emulate higher-dimensional phenomena in a photonic lab," said Yun Lai, professor from the school of physics at Nanjing University.

"It's like hosting two optical realities in one material, opening the door to compact, multifunctional devices that were previously unimaginable."

The team demonstrated two remarkable phenomena. First, in microwave experiments, the researchers designed an elongated nonlocal artificial material acting as a photonic "wormhole," i.e. invisible optical tunnels.

When a Gaussian beam enters the short side, it is confined in the material and transmits as if traveling through a zero-refractive-index waveguide. When a beam is incident upon the long side, the material exhibits near-zero reflection due to the omnidirectional impedance matching in a parallel photonic space, rendering it effectively invisible to external light.

Secondly, they achieved "photonic multiple realities," where the same material mimics arbitrary optical objects or devices based on the entry boundary.

https://phys.org/news/2025-10-nonlocality-enabled-photonic-analogies-wormholes.html

Exotic roto-crystals can break into individual fragments then reassemble themselves

It sounds bizarre, but they exist: crystals made of rotating objects. Physicists from Aachen, Düsseldorf, Mainz and Wayne State (Detroit, U.S.) have jointly studied these exotic objects and their properties. They easily break into individual fragments, have odd grain boundaries and evidence defects that can be controlled in a targeted fashion.

In an article published in the *Proceedings of the National Academy of Sciences*, the researchers outline how several new properties of such transverse interaction systems can be predicted by applying a comprehensive theory.

Transverse forces can occur in synthetic systems, such as in certain magnetic solids. They exist in systems of living organisms too, however. In an experiment observing a host of starfish embryos conducted at American university MIT, it was found that, through their swimming movements, the embryos influence each other in a manner leading them to rotate around one another.

What biological function this may have is not yet understood. The common thread in these systems is that they involve rotating objects.

Professor Dr. Hartmut Löwen of the Institute of Theoretical Physics II at Heinrich Heine University Düsseldorf (HHU) explains, "A system of many rotating constituent elements exhibits a qualitatively new behavior that is non-intuitive: At high concentrations, these objects form a solid body of rotors, which possess 'odd' material properties."

The property of odd elasticity, for example, is affected. When a conventional material is pulled, it deforms in the pull direction, but an odd elastic material will not deform, but rather twist.

https://phys.org/news/2025-10-exotic-roto-crystals-individual-fragments.html

The quantum door mystery: Electrons that can't find the exit

What happens when electrons leave a solid material? This seemingly simple phenomenon has, until now, eluded accurate theoretical description. In a new study, researchers have found the missing piece of the puzzle.

Imagine a frog sitting inside a box. The box has a large opening at a certain height. Can the frog escape? That depends on how much energy it has: if it can jump high enough, it could in principle make it out. But whether it actually succeeds is another question. The height of the jump alone isn't enough—the frog also needs to jump through the opening.

A similar situation arises with electrons inside a solid. When given a bit of extra energy—for example, by bombarding the material with additional electrons—they may be able to escape from the material.

This effect has been known for many years and is widely used in technology. But surprisingly, it has never been possible to calculate this process accurately.

A collaboration between several research groups at TU Wien has now solved this mystery: just like the frog, it's not only the energy that matters—the electron also needs to find the right "exit," a so-called "doorway state."

A simple situation, puzzling results

"Solids from which relatively slow electrons emerge play a key role in physics. From the energies of these electrons, we can extract valuable information about the material," says Anna Niggas from the Institute of Applied Physics at TU Wien, first author of the new study published in the journal *Physical Review Letters*.

https://phys.org/news/2025-10-quantum-door-mystery-electrons-exit.html

Quantum mechanics trumps the second law of thermodynamics at the atomic scale

Two physicists at the University of Stuttgart have proven that the Carnot principle, a central law of thermodynamics, does not apply to objects on the atomic scale whose physical properties are linked (so-called correlated objects). This discovery could, for example, advance the development of tiny, energy-efficient quantum motors. The derivation has been published in the journal *Science Advances*.

Internal combustion engines and steam turbines are thermal engines: They convert thermal energy into mechanical motion—or, in other words, heat into motion. In recent years, quantum mechanical experiments have succeeded in reducing the size of heat engines to the microscopic range.

"Tiny motors, no larger than a single atom, could become a reality in the future," says Professor Eric Lutz from the Institute for Theoretical Physics I at the University of Stuttgart. "It is now also evident that these engines can achieve a higher maximum efficiency than larger heat engines."

Professor Lutz and Dr. Milton Aguilar, a postdoctoral researcher at the Institute for Theoretical Physics I, explain the reasons behind this in their paper. In this interview, the two scientists summarize their discovery.

What exactly did you discover?

Almost exactly 200 years ago, French physicist Sadi Carnot determined the maximum efficiency of heat engines. The Carnot principle, the second law of thermodynamics, was developed for large, macroscopic objects. This applies to steam turbines, for example. However, we have now been able to prove that the Carnot principle must be extended to describe objects on the atomic scale—for example, strongly correlated molecular motors.

Why is that?

Carnot demonstrated that the temperature difference has a decisive influence: the greater the difference between hot and cold, the higher the maximum possible efficiency of a heat engine. However, the Carnot principle neglects the influence of so-called quantum correlations. These are special bonds that form between particles on a very small scale.

For the first time, we have derived generalized laws of thermodynamics that fully account for these correlations. Our results show that thermal machines operating at the atomic scale can convert not only heat but also correlations into work. As a result, they can produce more work—and the efficiency of a quantum engine can surpass the traditional Carnot limit.

https://phys.org/news/2025-10-quantum-mechanics-trumps-law-thermodynamics.html

Thank you!

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