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Perfect randomness realized for the first time

Creating perfect randomness is surprisingly difficult. Even modern random number generators never generate completely ideal random numbers: small systematic errors can result in some numbers appearing slightly more frequently than others. For many applications, this does not matter. In cryptography, however, even the tiniest deviations can be problematic.

Now, researchers at ETH Zurich led by Renato Renner and Andreas Wallraff in the Department of Physics have demonstrated how perfect randomness can actually be created using quantum physics. Their results, which have just been published in *Nature*, represent a milestone in this area of research.

"It may seem strange, but it is almost impossible to create a perfect coin or a perfect die," says Renner. No matter how symmetric and smooth a die is made, after a roll one of its six faces will always point upwards slightly more often.

"Even modern random number generators, which are based on quantum mechanical effects like the reflection of photons from beam splitters, are not entirely immune to such a systematic error or 'bias,'" adds Wallraff. But now Wallraff's and Renner's teams have found a way to take imperfect randomness and still extract perfectly random numbers from it. They call their method randomness amplification.

"This was made possible by an improved so-called Bell-Test with simultaneously high quality and high data rate," says Wallraff.

https://phys.org/news/2026-05-randomness.html

The strange quantum property of tomorrow's insulator

A joint team of researchers led by scientists at King Abdullah University of Science and Technology (KAUST) and King Abdulaziz City for Science and Technology (KACST) has reported the fastest quantum random number generator (QRNG) to date based on international benchmarks. The QRNG, which passed the required randomness tests of the National Institute of Standards and Technology, could produce random numbers at a rate nearly a thousand times faster than other QRNG. Ultra-fast data transfer and superconductivity: Quantum materials offer significant technological prospects—if we can understand them at the atomic scale. A team from the University of Geneva (UNIGE), in collaboration with the University of Salerno, the Institute of Materials Science of Barcelona, and the National Research Council of Italy, has succeeded in observing the "quantum metric" in a topological insulator—a unique geometric property of these materials, which conduct electricity only on their surface.

Published in *Nature Materials*, this work represents a major step toward mastering the materials of the future.

Not all materials conduct electricity in the same way. These differences arise from the behavior of the electrons that make up the material. Among them, topological insulators—discovered in 2006—are of particular interest to scientists. Like conventional insulators, they block the flow of electric current through their interior, yet, remarkably, allow it to flow freely across their surface.

This phenomenon is explained by the unique properties of electrons on the surface of the material. These properties could prove invaluable for the electronics of the future, particularly in the field of quantum computing. One such property is known as the "quantum metric." Measuring it allows scientists to describe the geometric structure of the space in which the electrons move.

https://phys.org/news/2026-05-strange-quantum-property-tomorrow-insulator.html

Collective vibrations unlock fast ion flow in superionic crystals

In the race to develop safer, faster-charging solid-state batteries and more efficient thermoelectric conversion technologies, engineers and scientists have long faced a fundamental challenge: how to ensure ions move through hard, solid materials as quickly as they do in liquids?

A team led by Prof. Zhou Yanguang, Associate Professor in the Department of Mechanical and Aerospace Engineering (MAE) at The Hong Kong University of Science and Technology (HKUST), discovered a novel mechanism for rapid ion transport in solids, opening new avenues for materials design.

The study shows that the ionic transport is governed by collective dynamics. The results were published in the journal *Physical Review Letters*, titled "Fast Ionic Transport Governed by Collective Vibrational Dynamics."

Under the leadership of Prof. Zhou, the research team comprises Postdoctoral Fellows Dr. Xu Yixin and Dr. Xiang Xing, Prof. Li Zhigang, Professor, and Prof. Lu Yanglong, Assistant Professor, all from the MAE Department of HKUST.

https://phys.org/news/2026-05-vibrations-fast-ion-superionic-crystals.html

'Butterfly' molecule spotted at last, completing a 20-year quantum zoo hunt

For two decades, physicists have predicted the existence of a remarkable family of exotic molecules: giant atoms bound to ordinary atoms, with an electron so distant from its nucleus that it sculpts the pair into bizarre and diverse shapes. Reported in *Physical Review Letters*, the final member of this "quantum zoo" has been spotted. Led by Herwig Ott at RPTU University Kaiserslautern-Landau in Germany, a team of physicists has created and detected the "butterfly" molecule, completing a 20-year hunt for the elusive structure.

Searching for the butterfly

The molecules in this quantum zoo belong to a class known as ultralong-range Rydberg molecules. They form when an ordinary atom becomes bound to a Rydberg atom, whose outermost electron has been excited so far from the nucleus that the atom swells to thousands of times its normal size.

The orbital shapes traced out by these distant electrons give each molecule type its character, and its nickname. Some have elaborate lobed structures reminiscent of trilobites; others spread into the winged outline of a butterfly. These molecules are thousands of times more sensitive to electric fields than ordinary molecules, making them especially useful objects for probing the quantum world.

So far, however, the butterfly variety had proven especially difficult to produce experimentally. This is because the particular quantum spin configuration required, known as a "spin-singlet" state, leads to a much weaker molecular bond than the spin-triplet configurations seen in earlier experiments.

https://phys.org/news/2026-05-butterfly-molecule-year-quantum-zoo.html

Supercharging solar cells: Quantum dot-molecule hybrid states enable near-maximum efficiency

Solar panels have become more efficient over the years, but even the best designs still lose a large fraction of the energy they absorb. Scientists around the world have been searching for ways to capture more energy from every ray of sunlight and unlock the true potential of solar technology.

In a study published in *Nature Photonics*, researchers from the University of Osaka and collaborating institutions identified a new mechanism that could help us do exactly that. The study shows how specially designed combinations of molecules and quantum dots can be used to dramatically increase solar cell efficiency beyond currently known limits.

Singlet exciton fission is a photophysical phenomenon in which one particle of light creates two excited energy states instead of one. In theory, this allows solar cells to generate more electricity from the same amount of sunlight. However, the most effective photophysical processes require extra energy and are usually inefficient and difficult to control.

"We are interested in ways to increase the viability of singlet fission," says senior author Masanori Sakamoto. "Our idea is to leverage interactions between molecules and quantum dots to create an intermediate state that helps the process proceed smoothly."

https://phys.org/news/2026-05-supercharging-solar-cells-quantum-dot.html

Rethinking hysteresis—a thermodynamic framework for history-dependent solids

Many solid materials "remember" their past. A piece of metal may respond differently after being stretched, heated, or cooled, and memory materials rely precisely on this kind of history-dependent behavior. This phenomenon, known as hysteresis, is central to technologies such as memory devices, energy conversion materials, and durable structural materials.

However, hysteresis has long posed a problem for thermodynamics. In conventional thinking, the state of a material should be described by state variables, such as temperature and volume. But in solids, the same temperature and volume can correspond to different material properties depending on the material's past treatment.

For this reason, hysteresis has traditionally been treated as a nonequilibrium phenomenon, outside the standard framework of thermodynamics.

Prof. Koun Shirai, at the Graduate School of Engineering, The University of Osaka, has now shown that hysteresis in solids can be described thermodynamically by reconsidering what counts as an equilibrium state and what variables are needed to define the state of a solid.

The study, published in *International Journal of Thermophysics*, argues that the difficulty arises because temperature and volume alone are not enough to specify the state of a solid. Instead, the complete state of a solid must include its atomic configuration—the time-averaged equilibrium positions of all atoms making up the material.

https://phys.org/news/2026-05-rethinking-hysteresis-thermodynamic-framework-history.html

Physicists figure out how to reduce formation of 'viscous fingers'

When they reach the bottom of a soap dispenser, frugal handwashers might try adding water to the bottle to push out the last bit of soap. But usually, the water drills right through the soap and jets out an only slightly sudsy splash.

This happens because when you push a less viscous fluid like water into a more viscous fluid like soap in a confined space, the place where the two fluids meet can be unstable, and the runnier liquid might find a path of least resistance.

If you look very closely, you might see tiny protuberances form at the place where the fluids touch, in a phenomenon physicists call "viscous fingering." In certain types of confined spaces, the fingers form a branching pattern.

"The viscous fingering instability is one of the most-studied examples of pattern formation, consistently yielding new insights and variations into the formation of branched structures in the natural world, such as rivers splitting into smaller streams," said Sidney Nagel, Stein-Freiler Distinguished Service Professor of Physics.

In a new study published in *Science Advances*, Nagel's team discovered that changing the shape of the interface where the fluids touch can delay onset and slow the growth of the branches—promising improved efficiency for industrial and environmental processes.

https://phys.org/news/2026-05-physicists-figure-formation-viscous-fingers.html

Thank you

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