SCIENCE FLASH NEWS

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Rethinking Carnot: Scientists overcome traditional power-efficiency trade-off

Challenging centuries-old assumptions about thermodynamics, a new study published in *Physical Review Letters* has shown that it is theoretically possible to design a heat engine that achieves maximum power output while approaching Carnot efficiency.

The Carnot heat engine is a thermodynamic device that converts heat into mechanical work by operating between two temperature reservoirs, a hot and cold one.

The engine works by taking heat from the hot reservoir, converting some of it into useful work, and rejecting the remaining heat to the cold reservoir. The thermodynamic cycle followed by the engine is known as the Carnot cycle.

In an ideal case, this process would be perfectly reversible and the Carnot engine would have maximum efficiency. In reality, real heat engines are not reversible and lose energy in the form of heat.

Thus, the efficiency of a real heat engine is always less than that of a Carnot heat engine operating between the same reservoirs. This is the second law of thermodynamics.

The challenge with building a heat engine that has an efficiency close to the Carnot heat engine is it takes infinite time to do the work with minimal power output.

The researchers addressed this problem with a biochemical heat engine.

https://phys.org/news/2025-01-rethinking-carnot-scientists-traditional-power.html

An overlooked nuclear force helps keep matter stable, study reveals

Researchers from Kyushu University, Japan have revealed how a special type of force within an atom's nucleus, known as the three-nucleon force, impacts nuclear stability. The study, published in *Physics Letters B*, provides insight into why certain nuclei are more stable than others and may help explain astrophysical processes, such as the formation of heavy elements within stars.

All matter is made of atoms, the building blocks of the universe. Most of an atom's mass is packed into its tiny nucleus, which contains protons and neutrons (known collectively as nucleons). Understanding how these nucleons interact to keep the nucleus stable and in a low energy state has been a central question in nuclear physics for over a century.

The most powerful nuclear force is the two-nucleon force, which attracts two nucleons at long range to pull them together and repels at short range to stop the nucleons from getting too close.

"Scientists have formed a good understanding of the two-nucleon force and how it impacts nuclear stability," says first author Tokuro Fukui, Assistant Professor of Kyushu University's Faculty of Arts and Science. "On the other hand, three-nucleon force, which is when three nucleons interact with each other simultaneously, is much more complicated and poorly understood."

https://phys.org/news/2025-01-overlooked-nuclear-stable-reveals.html

Hear ye! Hear ye! Previously unknown set of cochlear hearing modes supports complexities in human hearing

Yale physicists have discovered a sophisticated, previously unknown set of "modes" within the human ear that put important constraints on how the ear amplifies faint sounds, tolerates noisy blasts, and discerns a stunning range of sound frequencies in between.

By applying existing mathematical models to a generic mock-up of a cochlea—a spiral-shaped organ in the inner ear—the researchers have revealed a new layer of cochlear complexity. The findings, which appear in *PRX Life*, offer fresh insight into the remarkable capacity and accuracy of human hearing.

"We set out to understand how the ear can tune itself to detect faint sounds without becoming unstable and responding even in the absence of external sounds," said Benjamin Machta, an assistant professor of physics in Yale's Faculty of Arts and Science and co-senior author of the new study. "But in getting to the bottom of this we stumbled onto a new set of low frequency mechanical modes that the cochlea likely supports."

In humans, sound is converted into electrical signals in the cochlea. People are able to detect sounds with frequencies across three orders of magnitude and more than a trillion-fold range in power, down to tiny vibrations of air.

https://phys.org/news/2025-01-ye-previously-unknown-cochlear-modes.html

Nonlinear optical crystal for ultraviolet lasers remains remarkably stable under extreme pressure

Researchers from Oakland University have made a significant breakthrough in the field of optical materials, unveiling the exceptional capabilities of $Ba_3(ZnB_5O_{10})PO_4$ (BZBP). Although this transparent crystal closely resembles ordinary window glass, it exhibits extraordinary properties that set it apart from others.

Already renowned for its exceptional qualities, such as excellent heat dissipation, minimal uneven expansion when exposed to temperature changes, and the ability to transmit ultraviolet light (a type of light that comes from the sun and other sources like special lamps, but it's invisible to the human eye), BZBP has emerged as an ideal choice for laser systems operating in deep ultraviolet ranges. These systems are crucial in fields such as medical diagnostics, semiconductor production, and cutting-edge scientific research.

In a study recently published in *Advanced Functional Materials*, researchers explored how BZBP performs under extreme pressure.

Utilizing cutting-edge techniques like synchrotron X-ray diffraction and Raman spectroscopy, the team discovered that BZBP remains remarkably stable up to 43 Gigapascals (GPa)—a pressure almost 400,000 times greater than Earth's atmospheric pressure at sea level.

https://phys.org/news/2025-01-nonlinear-optical-crystal-ultraviolet-lasers.html

Fox and rabbit in the quantum world: Atomic particles with antagonistic interactions

Researchers at the University of Basel have shown that quantum systems can have antagonistic interactions, too—one agent attracts the other, but the other way around, there is a repulsion. Such interactions could be realized using cold atoms that are coupled to each other.

In physics lessons we learned that like charges repel each other, but unlike charges attract each other. Note the "each other" here: charge A attracts charge B, and charge B attracts charge A. This sounds intuitive and obvious.

However, nature is often not that mutual; for instance, when predators and prey are involved, the fox is attracted to the rabbit and chases it, but the rabbit runs away from the fox. As long as the fox does not catch the rabbit, this results in a kind of dynamic that can also be seen in other systems of so-called active agents such as nanoparticles or colloids, in which particles are finely distributed inside a medium.

Physicists Tobias Nadolny, Prof. Christoph Bruder, and Dr. Matteo Brunelli at the University of Basel have shown that such antagonistic or opposing interactions (A attracts B, B repels A) could theoretically exist in the quantum world.

Their work, published in the journal *Physical Review X*, also provides a recipe for realizing antagonistic quantum interactions in practice.

https://phys.org/news/2025-01-fox-rabbit-quantum-world-atomic.html

Electron spin resonance sheds light on tin-based perovskite solar cell efficiency

Perovskite solar cells are attracting attention as next-generation solar cells. These cells have high efficiency, are flexible, and can be printed, among other features. However, lead was initially used in their manufacture, and its toxicity has become an environmental issue.

Therefore, a method for replacing lead with tin, which has a low environmental impact, has been proposed. Nevertheless, tin is easily oxidized; consequently, the efficiency and durability of tin perovskite solar cells are lower than those of lead perovskite solar cells.

To improve the durability of tin perovskite by suppressing tin oxidation, a method that introduces large organic cations into tin perovskite crystals to form a two-dimensional layered structure called Ruddlesden-Popper (RP) tin-based perovskites has been proposed. However, the internal state of this structure and the mechanism by which it improves performance have not been fully elucidated.

In this study, researchers at University of Tsukuba used electron spin resonance to investigate an RP perovskite solar cell's internal state during operation from a microscopic perspective. The research is published in the journal *npj Flexible Electronics*.

https://phys.org/news/2025-01-electron-resonance-tin-based-perovskite.html

Nano rainbows: Expanding the light spectrum at the smallest scale

Since the invention of the laser in 1960, nonlinear optics has aimed to broaden light's spectral range and create new frequency components. Among the various techniques, supercontinuum (SC) generation stands out for its ability to produce light across a wide portion of the visible and infrared spectrum.

However, traditional SC sources rely on weak third-order optical nonlinearity, requiring long interaction lengths for broad spectral output. In contrast, second-order optical nonlinearity offers far greater efficiency and lower power requirements, though phase mismatching in bulk crystals has historically limited its spectral coverage and overall efficiency.

In a study published in *Light: Science & Applications*, a collaborative research team from Aalto University, Tampere University, and Peking University, led by Professor Zhipei Sun, has demonstrated a revolutionary method for generating octave-spanning coherent light at the deep-subwavelength scale (<100 nm). Their innovative approach employs phase-matching-free second-order nonlinear optical frequency down-conversion in ultrathin gallium selenide (GaSe) and niobium oxide diiodide ($NbOI_2$) crystals.

The researchers successfully generated coherent light with a -40 dB spectral width spanning from 565 to 1906 nm via difference-frequency generation. This produced a light source that is five orders of magnitude thinner and requires two to three orders of magnitude less excitation power than conventional coherent broadband light sources based on bulk materials. Furthermore, the conversion efficiency per unit length from the nanometer-thick $NbOI_2$ crystal exceeded 0.66% per micrometer—about three orders of magnitude higher than typical bulk methods.

https://phys.org/news/2025-01-nano-rainbows-spectrum-smallest-scale.html

Thank you

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